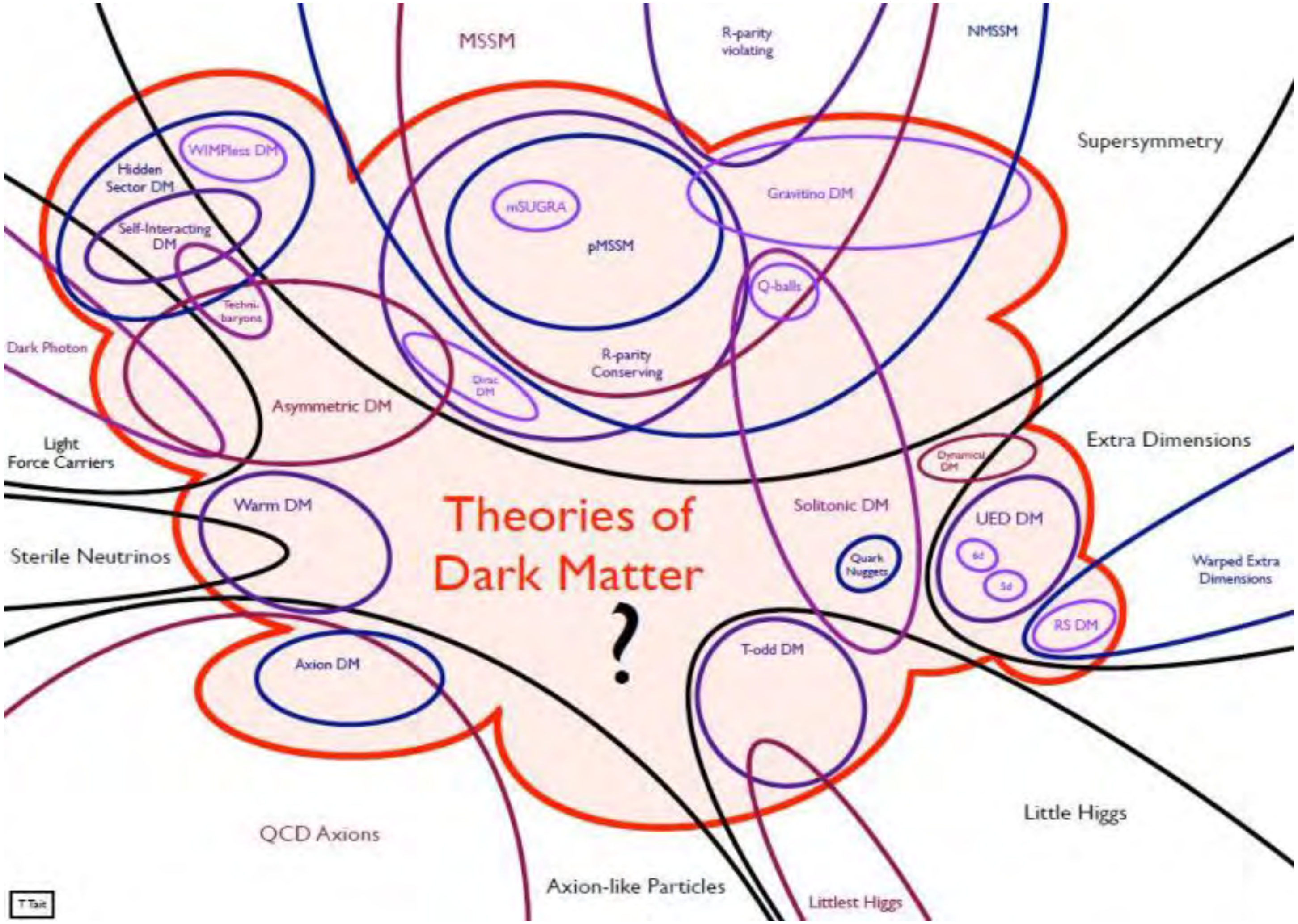
IV. WIMP VARIATIONS

WIMP VARIATIONS

- The WIMP paradigm has spawned many spin-offs that preserve the WIMP miracle to various extents, but have vastly different implications for particle physics and astrophysics.



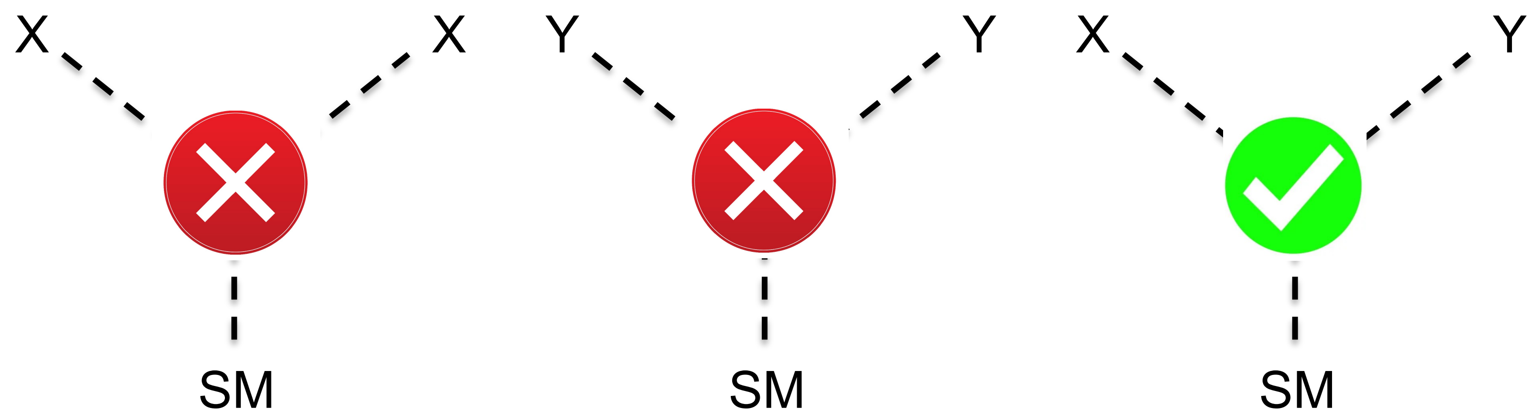
INELASTIC DARK MATTER

- The DAMA signal, whatever its ultimate fate, has been a fantastic driver for new ideas in dark matter.

- A prominent example: inelastic dark matter. Grew out of considerations of another SUSY WIMP candidate, the (messenger) sneutrino, a complex scalar, which could be split into two real scalars.

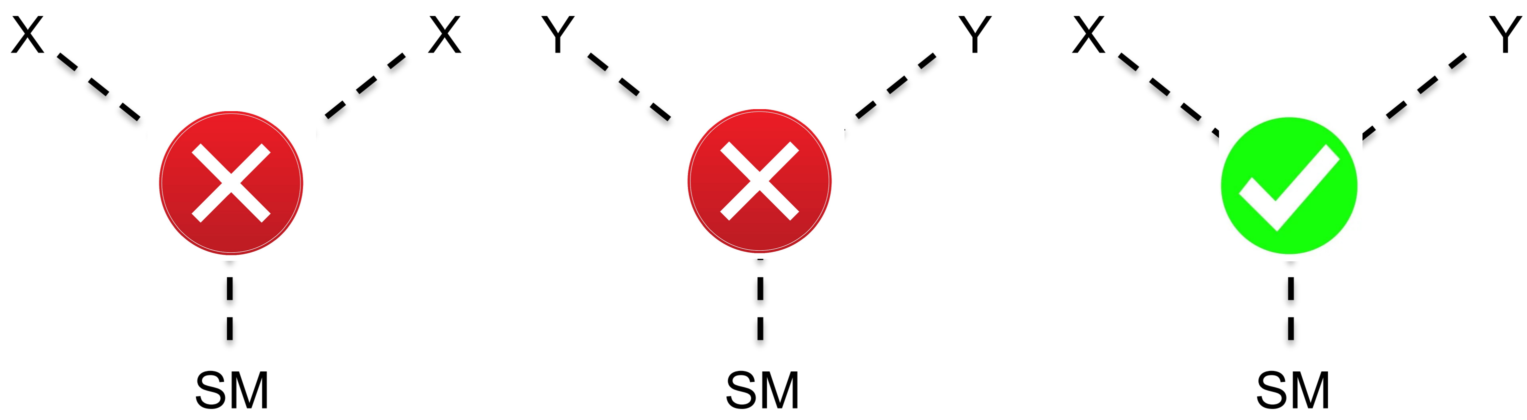
Han, Hempfling (1997); Hall, Moroi, Murayama (1998); Tucker-Smith, Weiner (2001)

- Consider two highly-degenerate WIMPy particles X and Y, and assume there are only off-diagonal couplings:



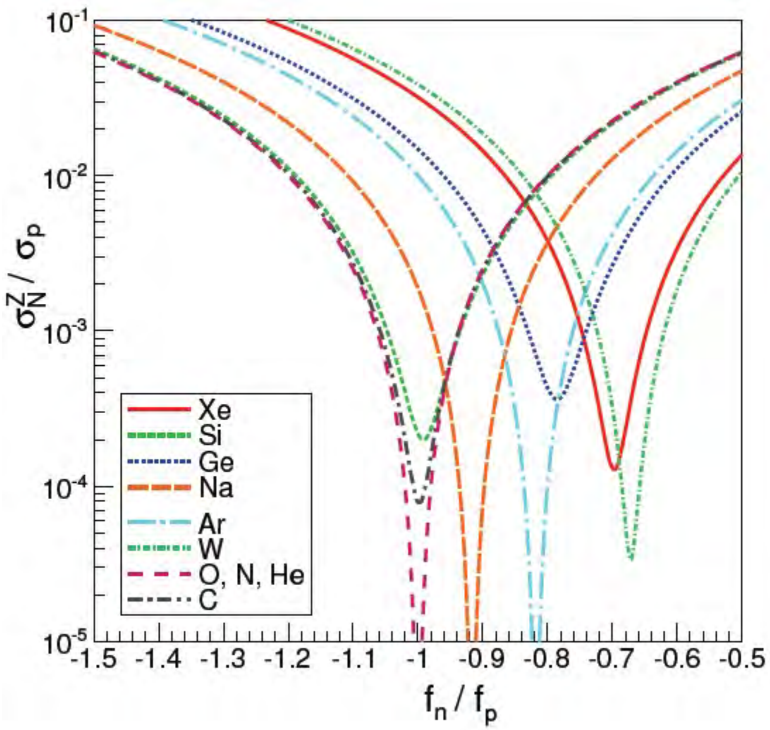
INELASTIC DARK MATTER

- Suppose m_X, m_Y ~ 100 GeV, but $\Delta = m_Y - m_X$ ~ MeV.
- In the early universe, and particularly at freeze out, $\Delta \ll T$, so X and Y freeze out as usual. Eventually all Y's decay to X's, X is the DM.
- But now, since $v \sim 10^{-3}$, K.E. ~ 100 keV, there is not enough energy for X's to up-scatter to Y's, and so X dark matter escapes all direct and indirect searches, opening up new parameter for other searches.
- For Δ ~ 100 keV, can suppress scattering off of Ge (CDMS), preserve scattering off of I (DAMA), reconcile DAMA with other null results.



ISOSPIN-VIOLATING DARK MATTER

- Recall that DM scattering off nuclei is
  $$\sigma_A \sim [\, f_p Z + f_n (A-Z)\,]^2$$
- Typically assume $f_n = f_p$, $\sigma_A \sim A^2$.
- But there is no model-independent reason that f_n and f_p are equal, or even that they have the same sign.
- IVDM relaxes this assumption, introduces 1 new parameter: f_n / f_p .



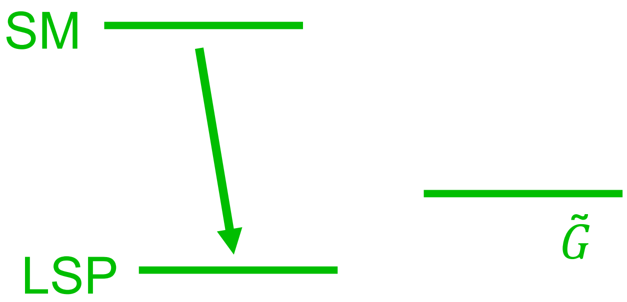
Feng, Kumar, Marfatia, Sanford (2013)

- Can decouple any given isotope by a suitable choice of f_n / f_p , and isotope distributions in each target become important. At one time could reconcile DAMA with all null results with IVDM, but not now.
- Lasting lesson: one should take all comparisons across different target materials and different techniques with a grain of salt.

GRAVITINO DM AND LONG-LIVED PARTICLES

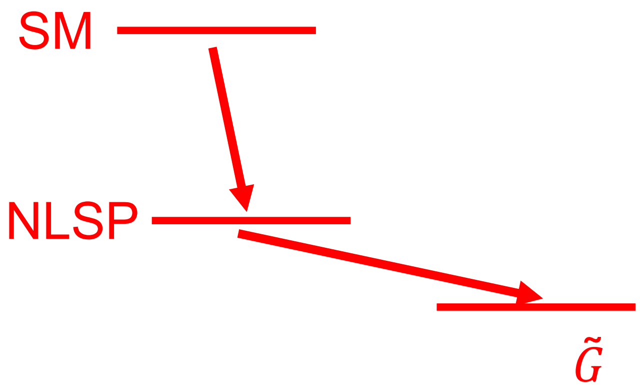
- In all supersymmetric models, there is yet another new neutral particle: the gravitino $\tilde{G}$. Its mass can be anything from eV to PeV, but its couplings are typically superweak (weaker than weak), as expected for the graviton's partner.

- $\tilde{G}$ not LSP



- Assumption of most of literature

- $\tilde{G}$ LSP



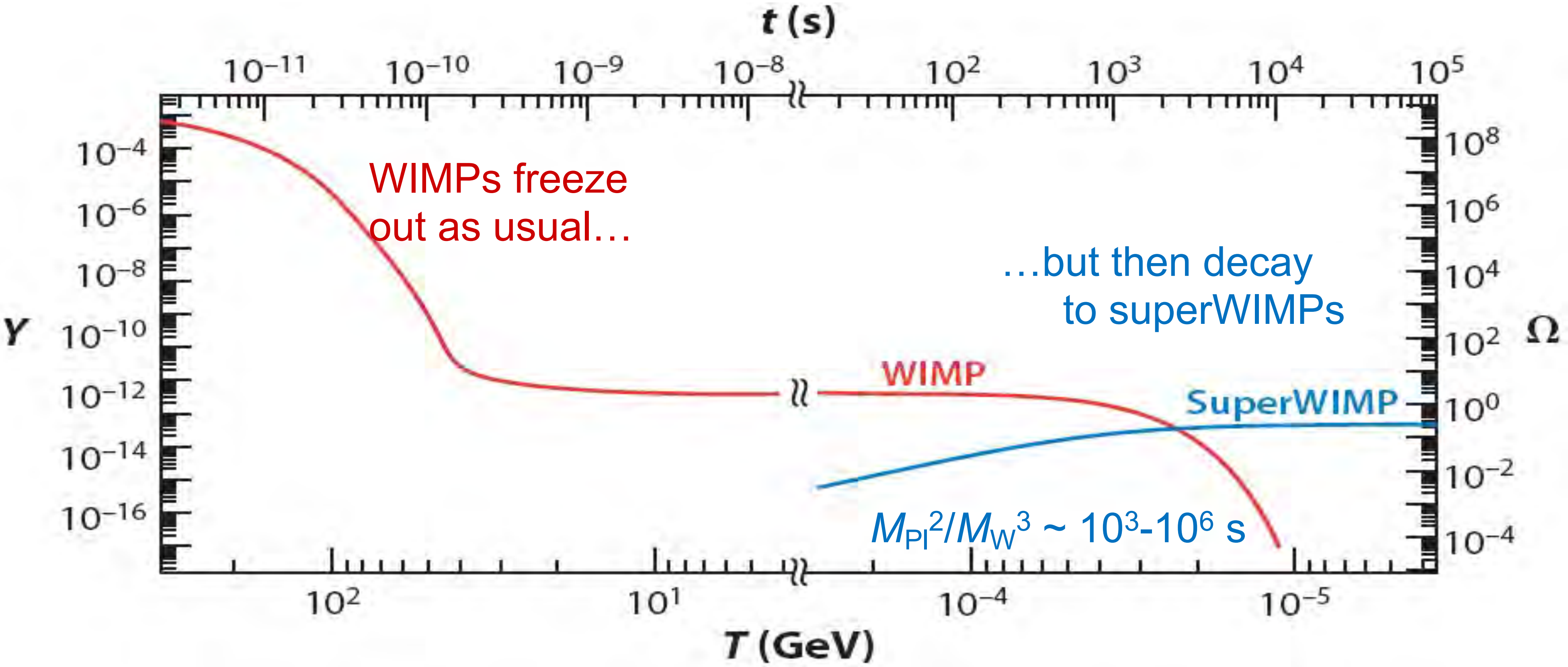
- Completely different cosmology and particle physics

Dine, Nelson, Nir, Shirman (1994, 1995); Dimopoulos, Dine, Raby, Thomas (1996)

FREEZE OUT WITH SUPERWIMPS

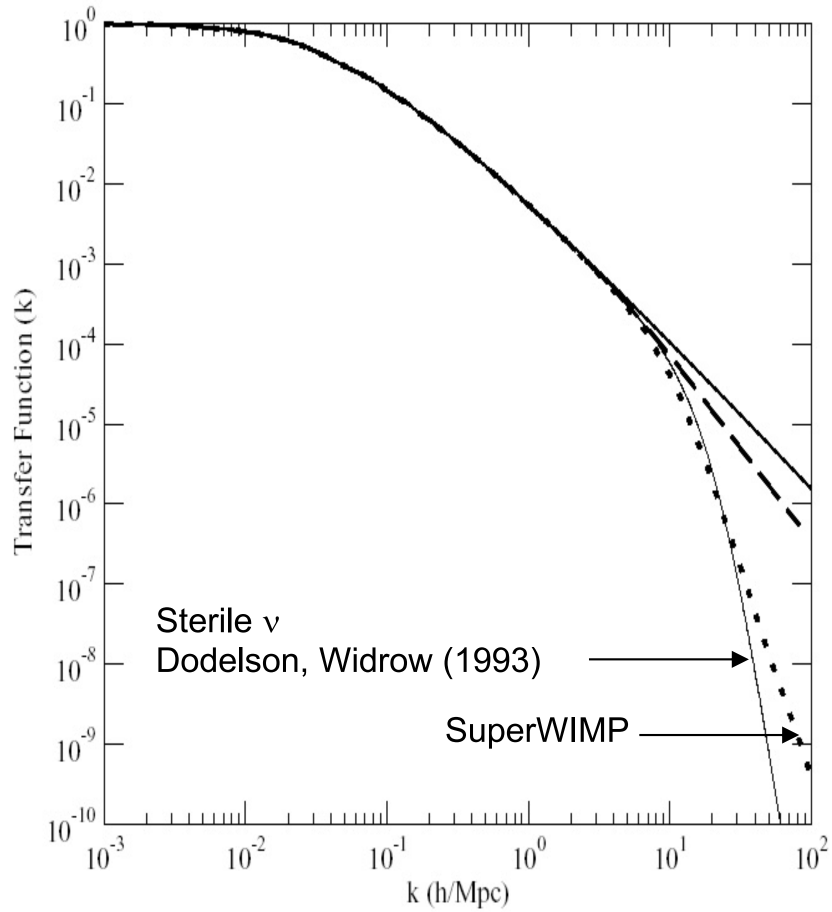
Feng, Rajaraman, Takayama (2003)

If the WIMP and superWIMP masses are similar, the superWIMPs naturally inherit the right density through the WIMP miracle, share all the motivations of WIMPs, but DM becomes superweakly interacting.



WARM DARK MATTER

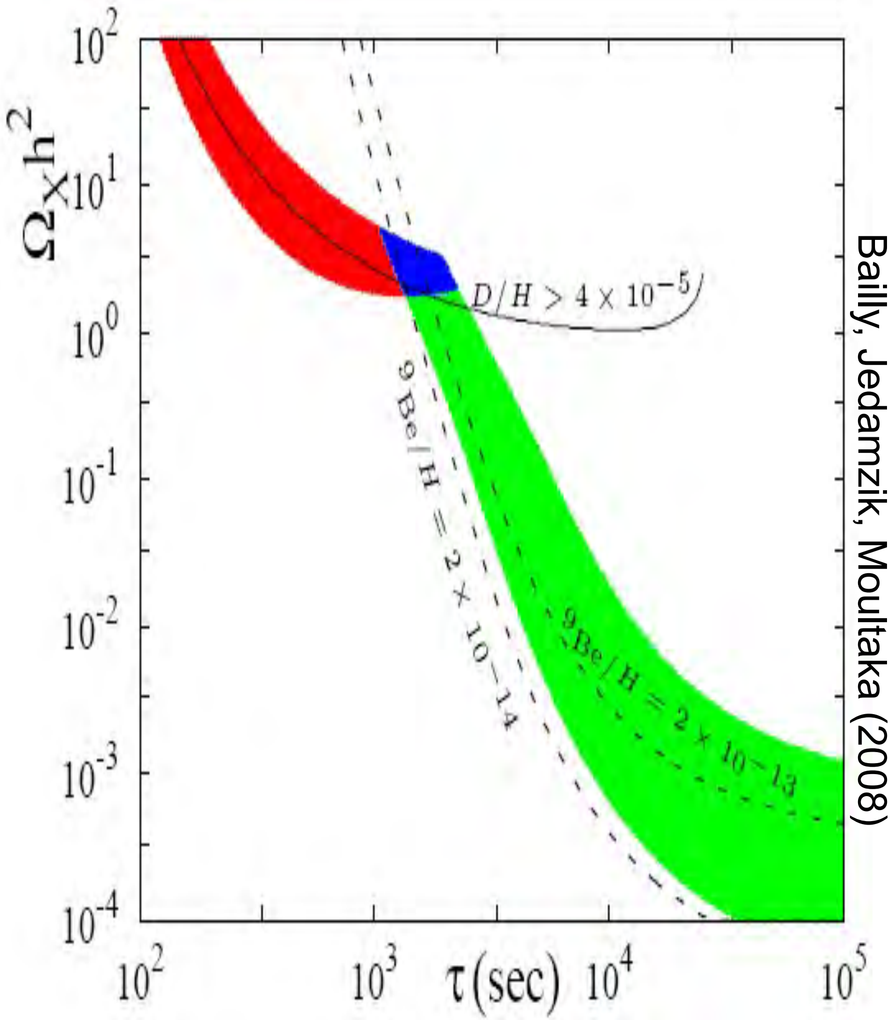
- SuperWIMPs are produced in late decays with large velocity (0.1c – c).
- This motion prevents them from forming potential wells, suppresses small scale structure.
- Hot DM, like active neutrinos, is excluded, but superWIMPs could be warm DM with cold DM pedigree.
- Also implications for BBN, CMB.



Kaplinghat (2005)

LATE DECAYS AND BBN

- Late decays deposit energy into the Universe, potentially destroy light elements
- Simple way around this is to make decays before T ~ MeV, t ~ 1s
- More ambitious: ^{7}Li does not agree with standard BBN prediction
  - Too low by factor of 3, ~5σ at face value
  - May be solved by convection in stars, but then why so uniform?
- Also the standard BBN prediction for ^{6}Li may be too low
- Decays after 1 s can possibly fix both



Bailly, Jedamzik, Moultaka (2008)

LATE DECAYS AND CMB

- Late decays may also distort the black body CMB spectrum

- For 10^5 s < τ < 10^7 s, get "μ distortions":

$$\frac{1}{e^{E/(kT)+\mu} - 1}$$

μ=0: Planckian spectrum

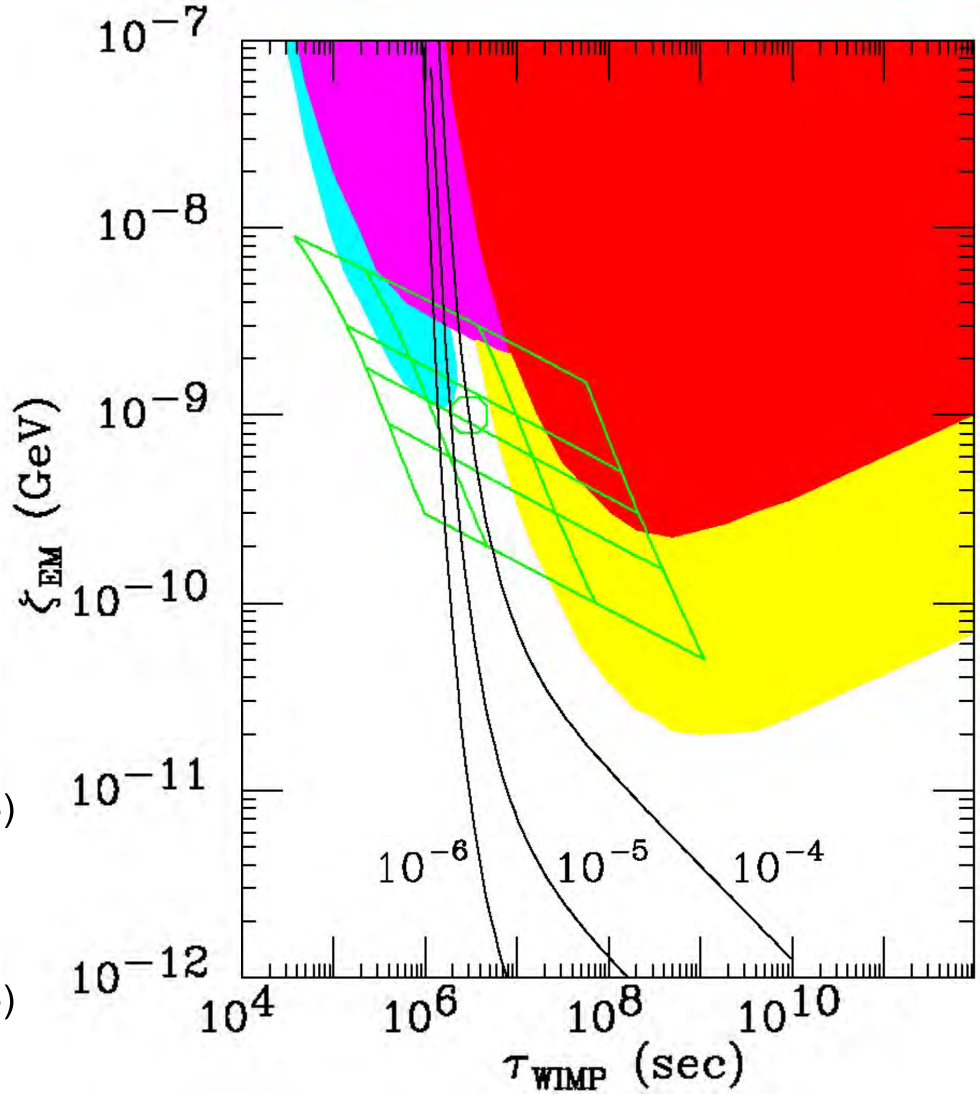
$\mu \neq$0: Bose-Einstein spectrum

Hu, Silk (1993)

- Current bound: $|\mu| < 9 \times 10^{-5}$

COBE-FIRAS (1996)

Future: possibly $|\mu| \sim 10^{-8}$



Feng, Rajaraman, Takayama (2003)

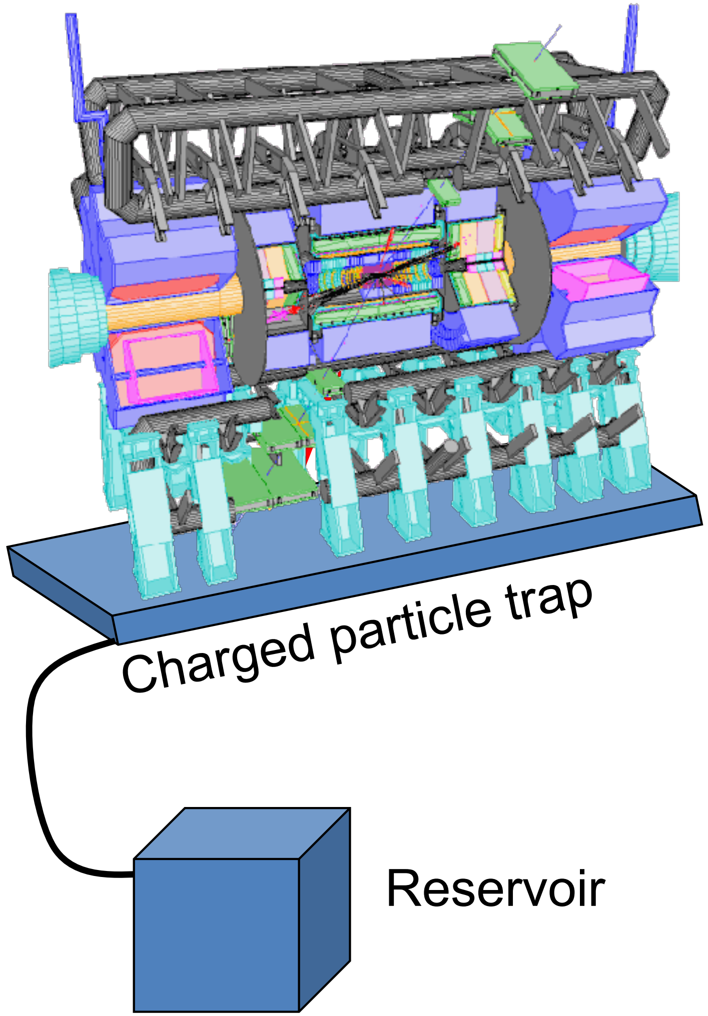
IMPLICATIONS FOR THE LHC

- If DM is a superWIMP, the parent particle is metastable, and can also be charged.
- Signature of new physics is "stable," charged, massive particles, not missing E_T .
- If stable on timescales of seconds to months, can collect these particles and study their decays. Several ideas:
  - Catch sleptons in a 1m thick water tank

    Feng, Smith (2004)
  - Catch sleptons in LHC detectors

    Hamaguchi, Kuno, Nakawa, Nojiri (2004)
  - Dig sleptons out of detector hall walls

    De Roeck, Ellis, Gianotti, Moortgat, Olive, Pape (2005)

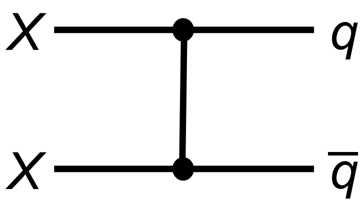


WIMPLESS DARK MATTER

Feng, Kumar (2008)

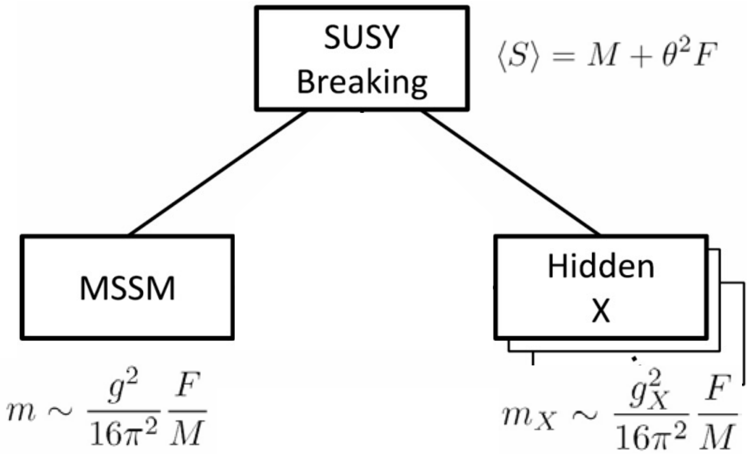
- Recall the WIMP miracle: the relation between Ω_X and annihilation strength is wonderfully simple:

$$\Omega_X \propto \frac{1}{\langle \sigma v \rangle} \sim \frac{m_X^2}{g_X^4}$$



$m_X \sim 100$ GeV, $g_X \sim 0.6 \rightarrow \Omega_X \sim 0.1$

- Consider SUSY with a hidden sector. In models that suppress flavor violation (GMSB, AMSB…), $m_X \sim g_X^2$

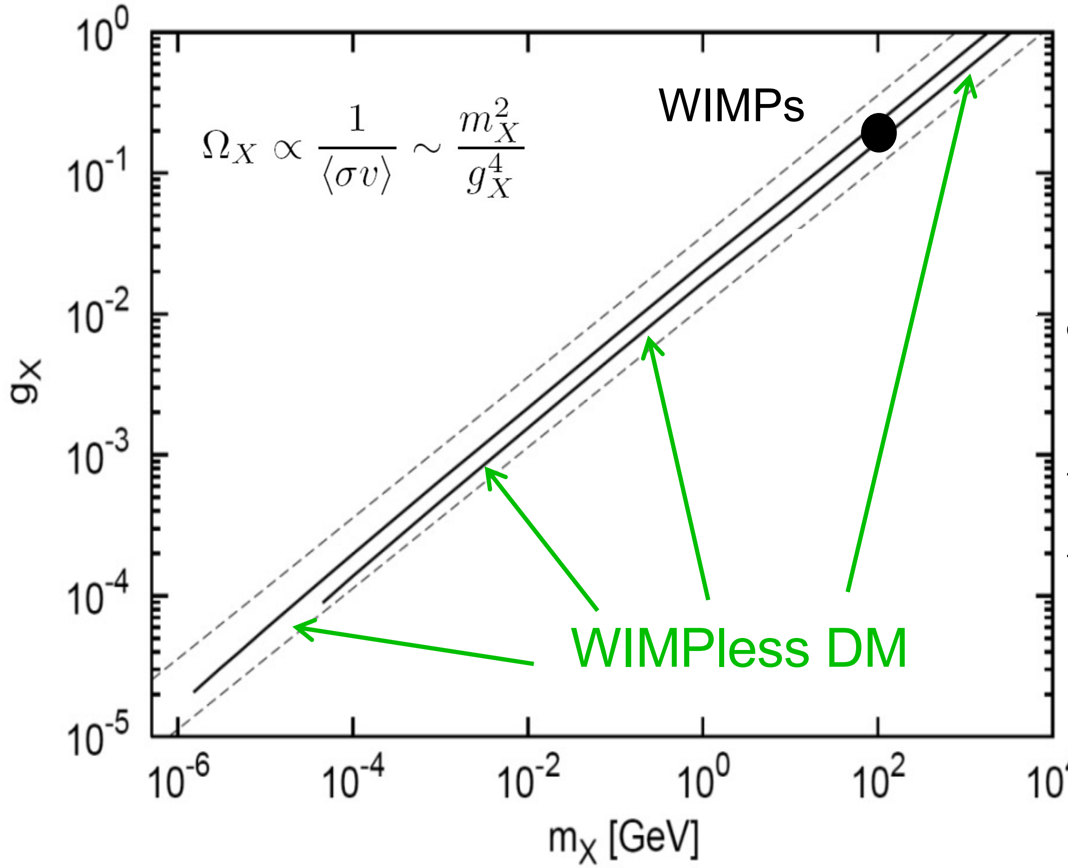


- The hidden sector superpartner masses and gauge couplings can be vastly different from the MSSM, but the thermal relic density is the same.

WIMPLESS DARK MATTER

Feng, Kumar (2008)

- WIMPless miracle: with a hidden sectors, the gauge coupling may not be ~ 1. But light, weakly-coupled DM can also have the correct thermal relic density, opening up a whole new set of dark sector signals in particle physics and cosmology, all with the same WIMP miracle pedigree.



Feng, Tu, Yu (2008)

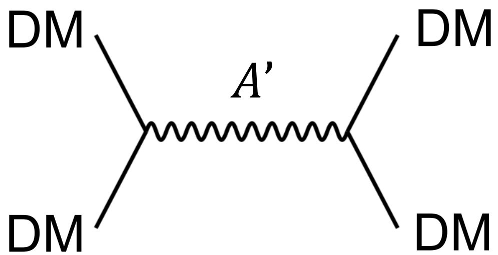
SELF-INTERACTING DARK MATTER

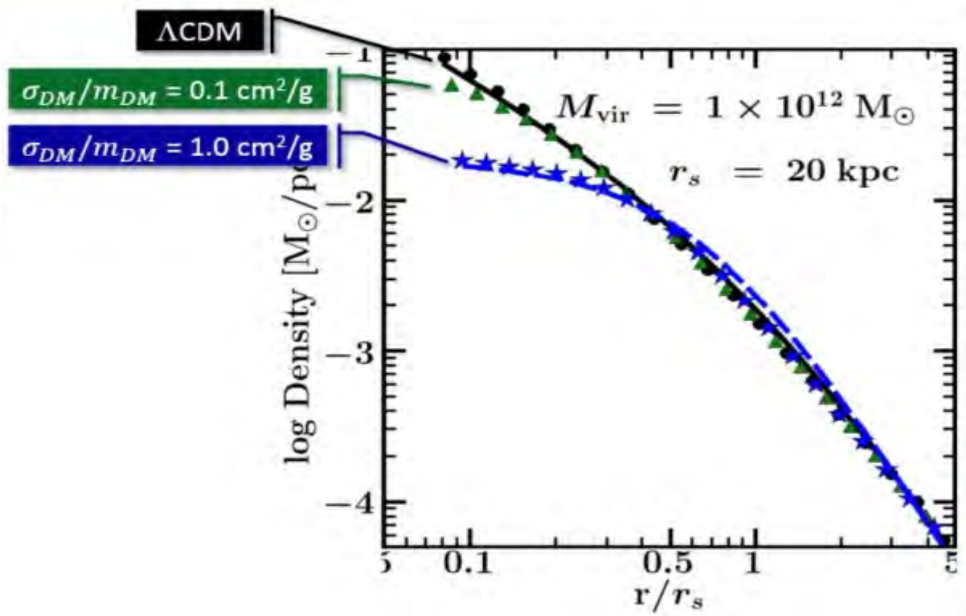
- WIMPless DM (and related scenarios) open up sub-GeV DM, self-interacting DM, strongly-interacting DM with a host of new implications.

- For example: there are indications from small-scale structure that dark matter may be strongly self-interacting (cuspy halo profiles, etc.)

- To make a difference, the required self-interaction cross section is

$$\frac{\sigma}{m} \sim \frac{\text{cm}^2}{\text{g}} \sim \frac{\text{barn}}{\text{GeV}} \sim (100\ \text{MeV})^{-3}$$

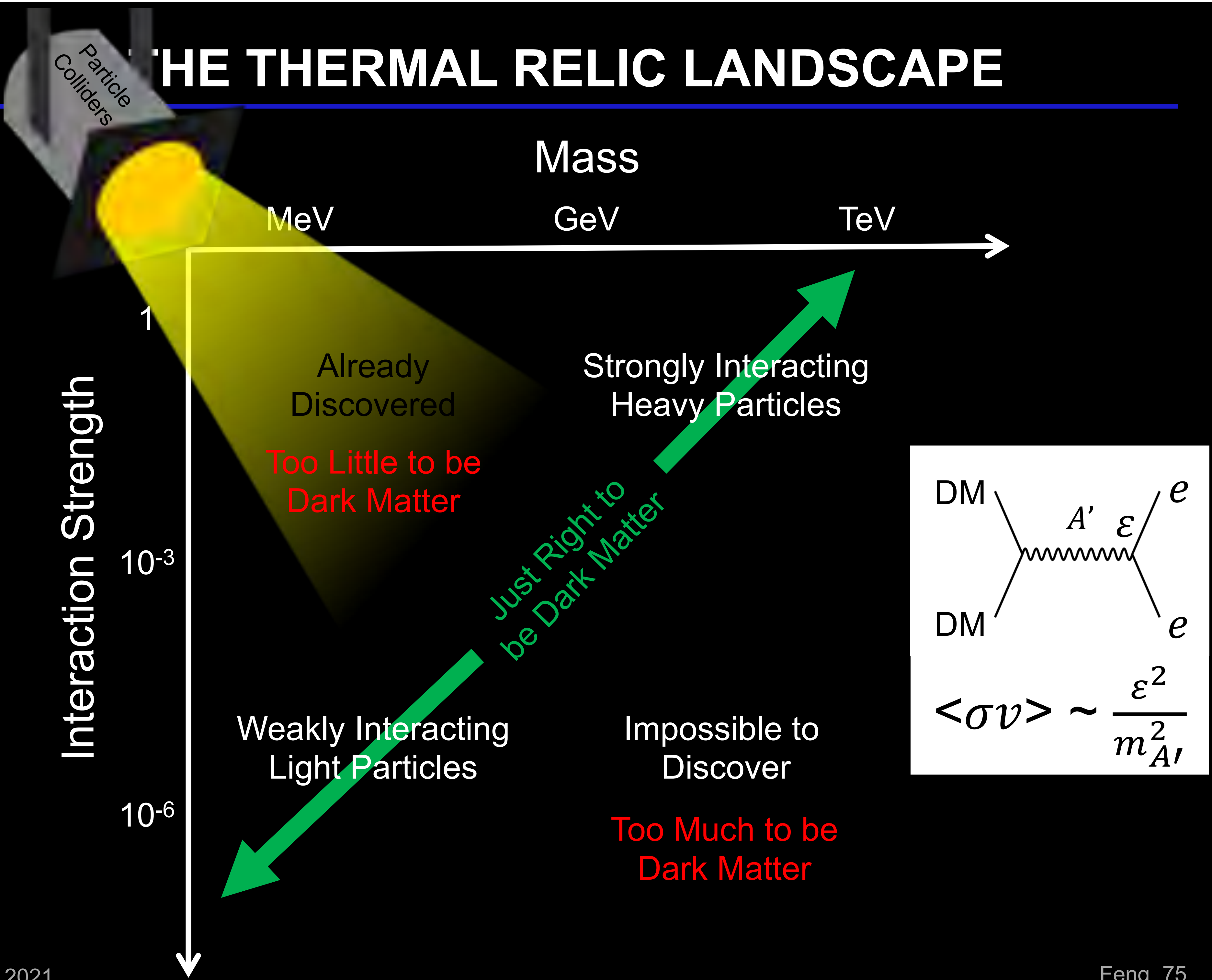




Tulin, Yu (2017)
Rocha et al. (2012), Peter et al. (2012);
Vogelsberger et al. (2012); Zavala et al. (2012)

- This can be explained by a characteristic dark sector mass scale of ~ 10-100 MeV.

THE THERMAL RELIC LANDSCAPE



SUMMARY

I. Why WIMPs?

The WIMP miracle, and discrete WIMP miracle imply that WIMPs emerge naturally as stable, cold, collisionless DM candidates with the correct thermal relic density from connections to central problems in particle physics.

II. WIMPs in Supersymmetry

The neutralino is the leading supersymmetric WIMP candidate, with the WIMP miracle realized in a variety of regions of parameter space.

III. WIMP Detection

The WIMP miracle suggests promising signal rates in many direct, indirect, and collider search experiments.

IV. WIMP Variations

Variations on the WIMP theme have new and extremely interesting implications:

- Inelastic DM (motivates collider searches)
- Isospin-violating DM (motivates diversity of direct detection targets)
- SuperWIMPs (warm DM, BBN, CMB)
- WIMPless DM (light DM, self-interacting DM, strongly-interacting DM)