WIMPS AND THEIR RELATIONS

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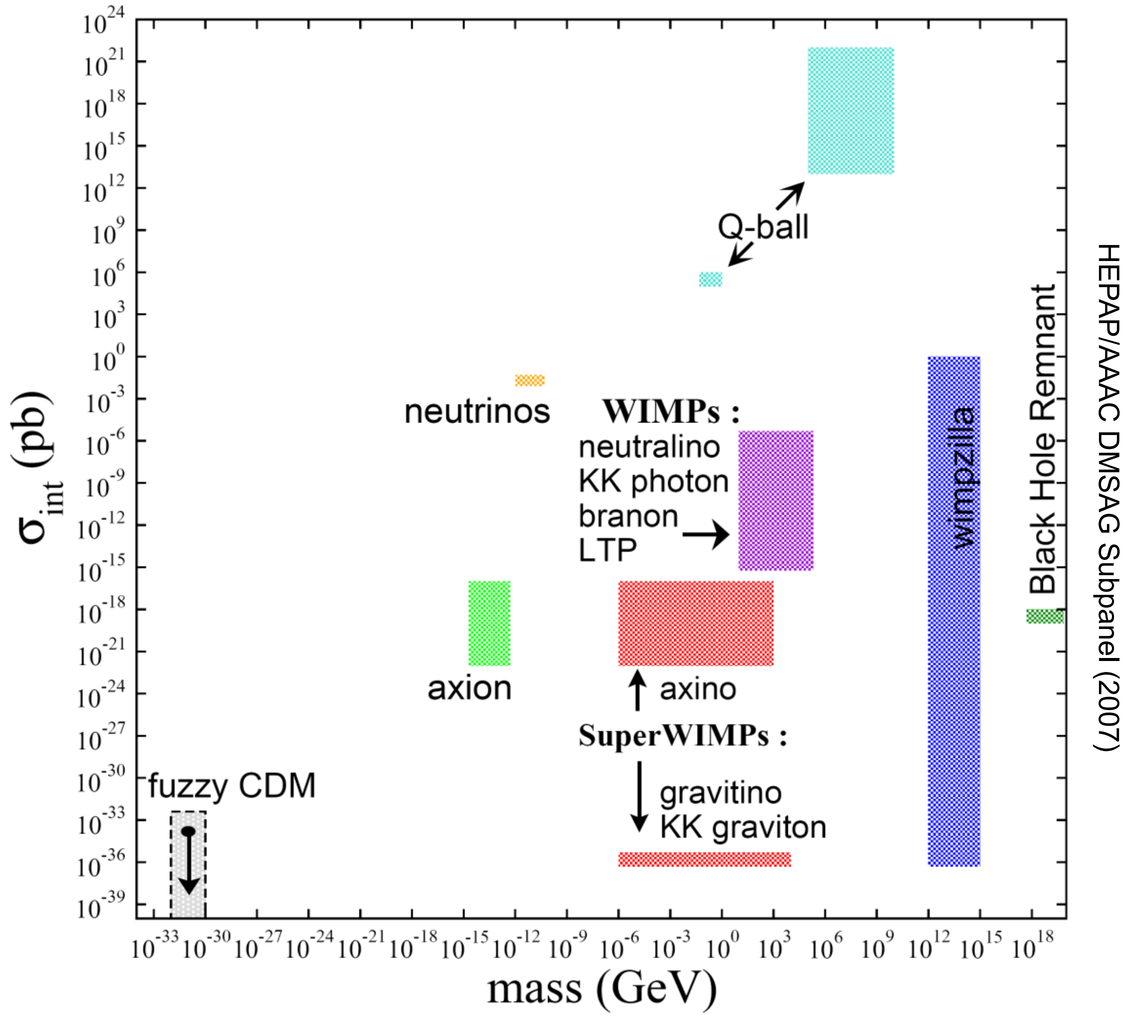
DARK MATTER

- We know how much there is, but what is it?
- Possible masses and interaction strengths span many, many orders of magnitude



THE WEAK SCALE

- Fermi's constant G_F introduced in 1930s to describe beta decay

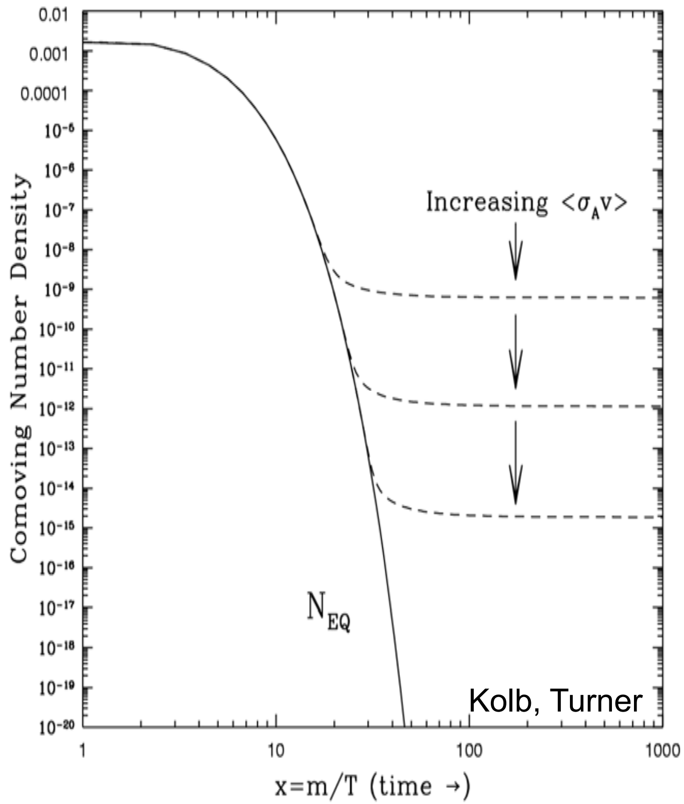
$$n \to p\, e^- \bar{\nu}$$

- $G_F \approx 1.1\ 10^5\ \text{GeV}^{-2}$ → a new mass scale in nature

$$m_{weak} \sim 100\ \text{GeV}$$

- We still don't understand the origin of this mass scale, but every attempt so far introduces new particles at the weak scale

THE WIMP MIRACLE



- Assume a new (heavy) particle X is initially in thermal equilibrium
- Its relic density is

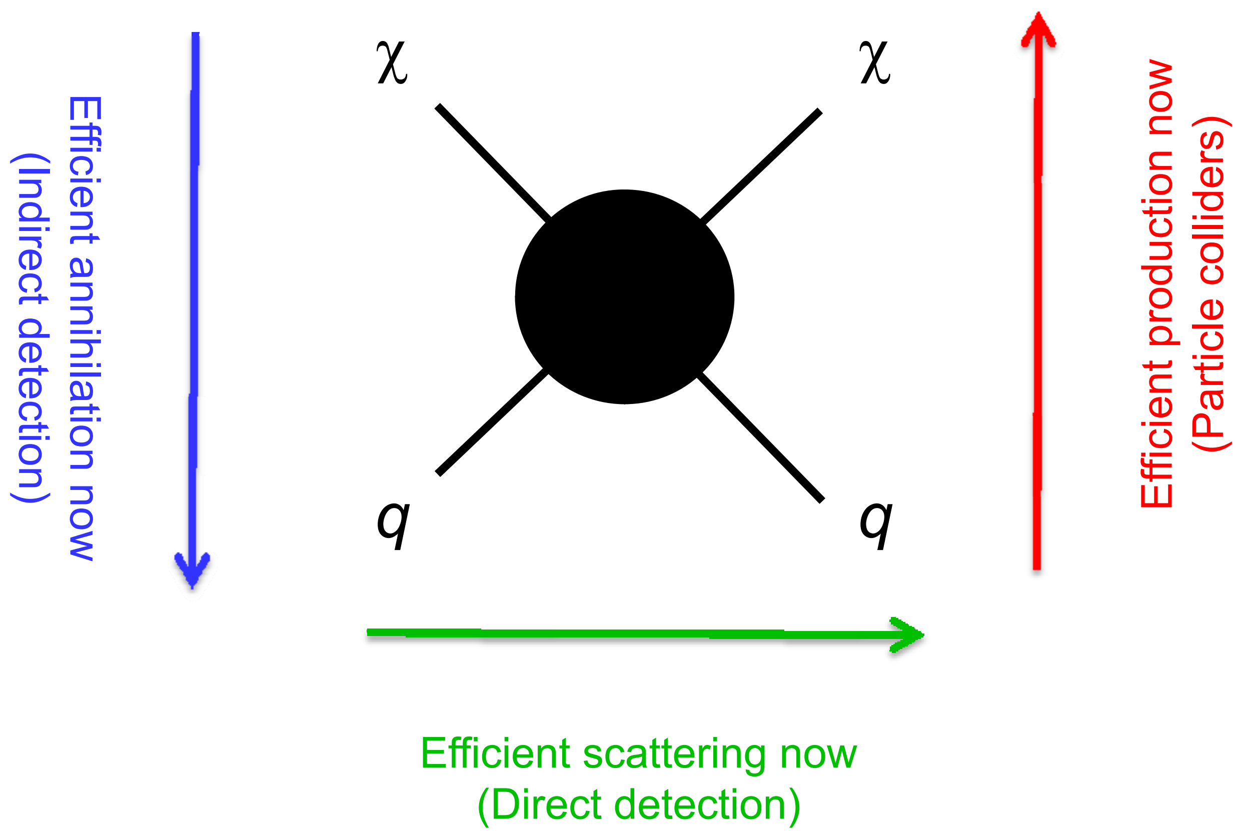
$$\Omega_X \propto \frac{1}{\langle \sigma v \rangle} \sim \frac{m_X^2}{g_X^4}$$

- $m_X \sim m_{weak} \sim 100$ GeV, $g_X \sim g_{weak} \sim 0.6$ } $\Omega_X \sim 0.1$

- Remarkable coincidence: particle physics independently predicts particles with the right density to be dark matter

WIMP MIRACLE IMPLICATIONS

- Astrophysics: DM is cold, collisionless
- Particle Physics: DM has weak interactions



WIMP MIRACLE IMPLICATIONS

- Astrophysics: DM is cold, collisionless
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EXCITING!

WIMP MIRACLE IMPLICATIONS

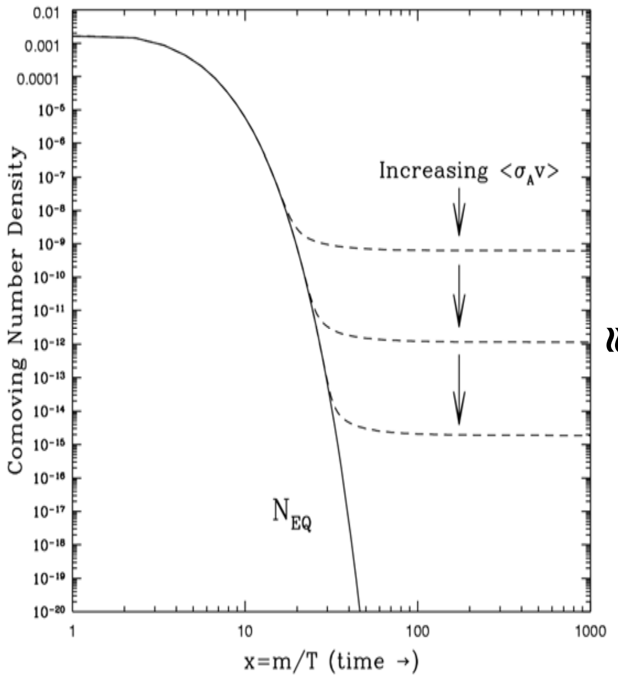
- Astrophysics: DM is cold, collisionless
- Particle Physics: DM has weak interactions

WRONG!

SUPERWIMPS

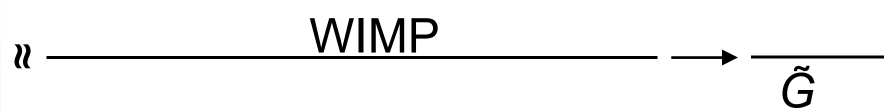
Feng, Rajaraman, Takayama (2003)

Consider supersymmetry: graviton G → gravitino $\tilde{G}$



- Assume $m_{\tilde{G}}$ ~ 100 GeV, but $\tilde{G}$ is the lightest new particle:

  WIMPs freeze out as usual



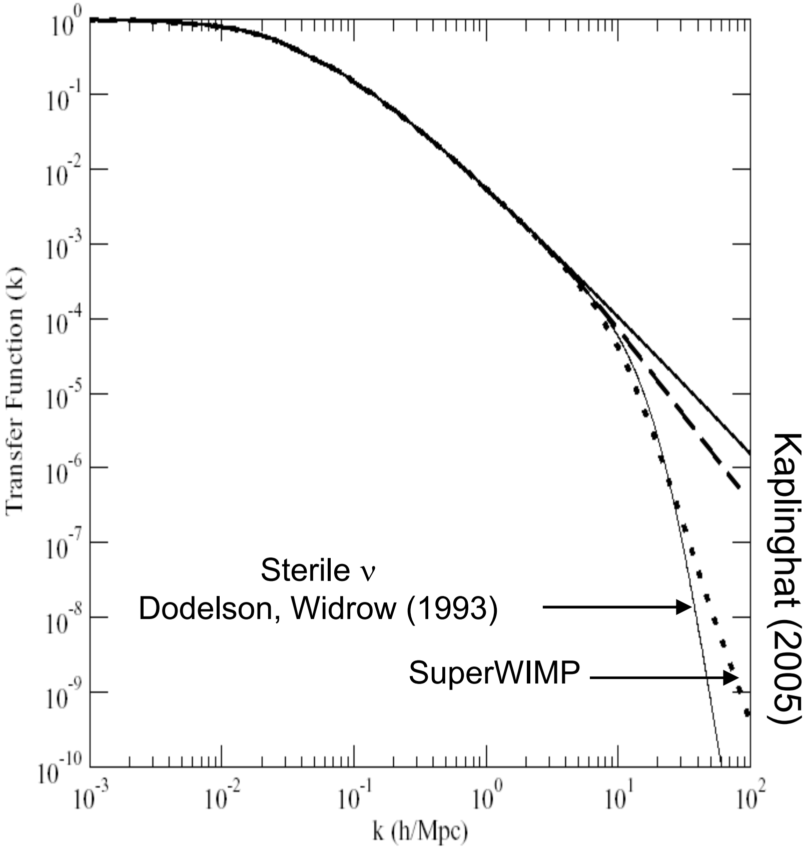
But then all WIMPs decay to gravitinos after

M_{Pl}^2/M_W^3 ~ seconds to months

Gravitinos naturally inherit the right density, but interact only gravitationally – they are superWIMPs

WARM SUPERWIMPS

- SuperWIMPs → no signals for direct and indirect searches
- But superWIMPs are produced in late decays with large velocity (0.1c – c)
- Suppresses small scale structure, as determined by λ_{FS}, Q
- Warm DM with cold DM pedigree, as motivated as neutralinos



THE SKELETON IN THE CLOSET

- Leading WIMP candidate: neutralino χ
- Background check: Neutralino DM → flavor problems
  - Neutralino DM → $m_{\tilde{G}} > m_\chi$
  - $m_{\tilde{G}}$ characterizes the size of gravitational effects, which generically violate flavor symmetries
  - Current bounds require $m_{\tilde{G}} < 0.01\, m_\chi$ (e.g., $\mu \to e\,\gamma$)
- There are ways to reconcile χ DM with flavor constraints, but none is pretty

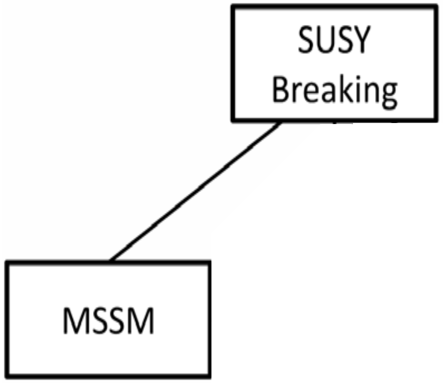
FLAVOR-CONSERVING MODELS

- There are well-known SUSY models that naturally conserve flavor: gauge-mediated SUSY-breaking models

- Can we find DM candidates in these models?

- 3 key features
  - $m_{\tilde{G}} << m_{\chi}$
  - Several sectors of particles
  - Superpartner masses

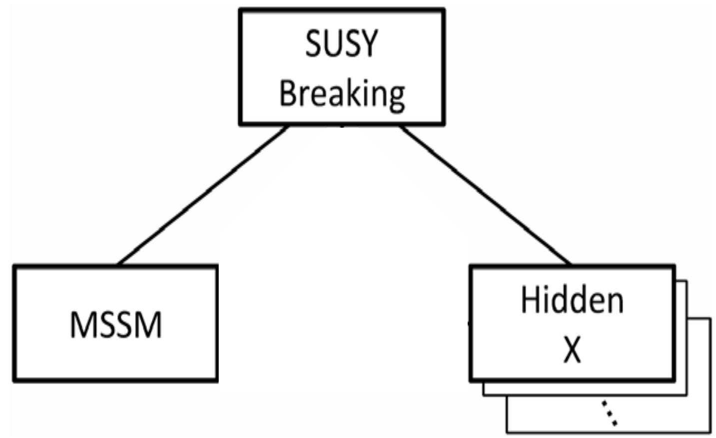
    $m \sim (\text{gauge couplings})^2$



WIMPLESS DARK MATTER

Feng, Kumar (2008)

- Suppose there are additional "hidden" sectors linked to the same SUSY breaking sector



- These sectors may have different
  - masses m_X
  - gauge couplings g_X

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

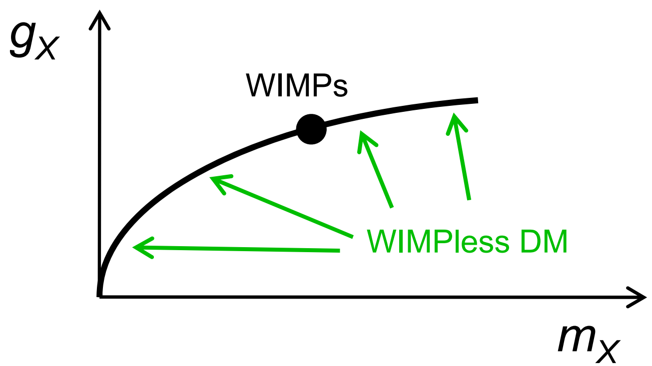
- But $m_X/g_X^2 \sim \Omega_X \sim$ constant

THE WIMPLESS MIRACLE

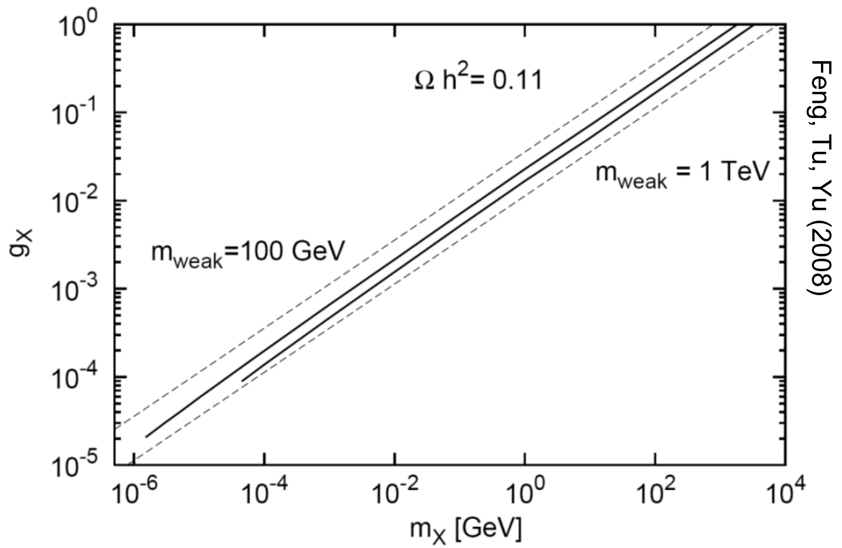
- The thermal relic density constrains only one combination of g_X and m_X

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

- These models map out the remaining degree of freedom

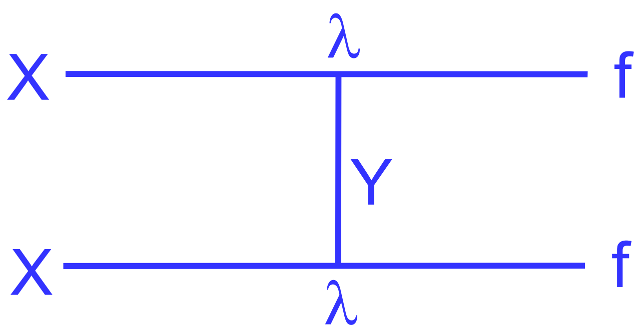


- This framework decouples the WIMP miracle from WIMPs, candidates have a range of masses/couplings, but always the right relic density



WIMPLESS SIGNALS

- WIMPless DM may have hidden sector charge, so *not* collisionless
- But WIMPless matter may also interact with normal matter through non-gauge interactions



- Many new, related ideas

Arkani-Hamed, Finkbeiner, Slatyer, Weiner (2008)

Pospelov, Ritz (2008)

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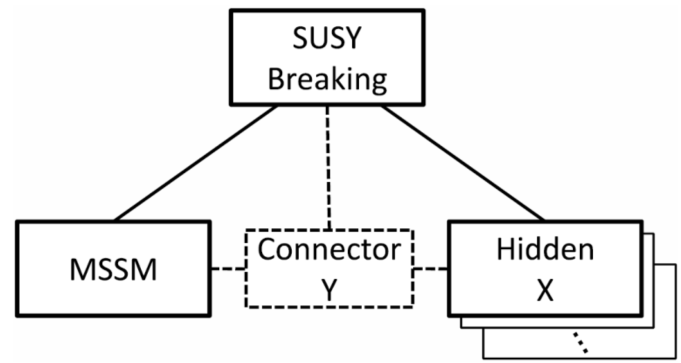

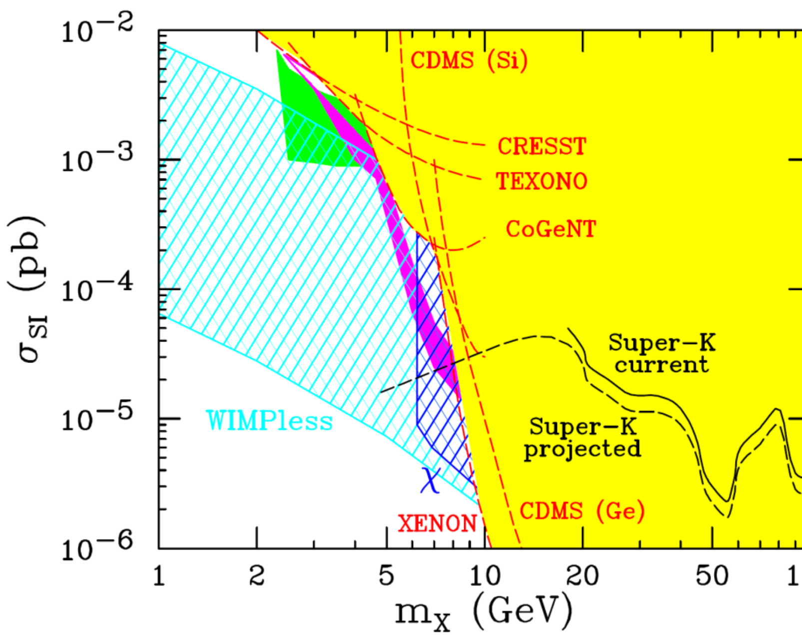

Feng, Kumar, Learned, Strigari (2008)

CONCLUSIONS

- The WIMP miracle is a striking coincidence, but it does not necessarily mean that DM is WIMPs

- Proliferation of new classes of DM candidates
  - WIMP dark matter
  - WIMPless dark matter
  - superWIMP dark matter

- These have qualitatively different implications for particle physics, astrophysics, cosmology