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

\[ n \rightarrow p \, e^- \bar{\nu} \]

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

\[ m_{\text{weak}} \sim 100 \text{ GeV} \]

• 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

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

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

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

- $g_X \sim g_{\text{weak}} \sim 0.6$

  \[ \{ \Rightarrow \Omega_X \sim 0.1 \]
WIMP MIRACLE IMPLICATIONS

- Astrophysics: DM is cold, collisionless
- Particle Physics: DM has weak interactions
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WRONG!
Consider supersymmetry: graviton $G \rightarrow$ gravitino $\tilde{G}$

- Assume $m_{\tilde{G}} \sim 100$ GeV, but $\tilde{G}$ is the lightest new particle:
  - WIMPs freeze out as usual
  - But then all WIMPs decay to gravitinos after $M_{Pl}^2/M_W^3 \sim$ 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 $\lambda_{FS}, Q$
- Warm DM with cold DM pedigree, as motivated as neutralinos
THE SKELETON IN THE CLOSET

• Leading WIMP candidate: neutralino $\chi$

• Background check: Neutralino DM $\rightarrow$ flavor problems
  – Neutralino DM $\rightarrow$ $m_{\tilde{G}} > m_\chi$
  – $m_{\tilde{G}}$ characterizes the size of gravitational effects, which generically violate flavor symmetries
  – Current bounds require $m_{\tilde{G}} < 0.01 m_\chi$ (e.g., $\mu \rightarrow e \gamma$)

• There are ways to reconcile $\chi$ 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
  - $m_{G} \ll m_{\chi}$
  - Several sectors of particles
  - Superpartner masses
    - $m \sim (\text{gauge couplings})^2$
WIMPLESS DARK MATTER

• Suppose there are additional “hidden” sectors linked to the same SUSY breaking sector

• These sectors may have different
  – masses $m_X$
  – gauge couplings $g_X$

• But $m_X/g_X^2 \sim \Omega_X \sim \text{constant}$
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

\[
\begin{align*}
X & \xrightarrow{\lambda} f \\
Y & \\
X & \xrightarrow{\lambda} f
\end{align*}
\]

- Many new, related ideas

Pospelov, Ritz (2008)

\[\ldots\]
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
  – WIMPIless dark matter
  – superWIMP dark matter

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