THE WIMPLESS MIRACLE

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Based on Feng and Kumar, arXiv:0803.4196, and work in progress with

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LHC EXPECTATIONS

2 reasons to anticipate something rather than nothing (beyond the Higgs):

• Gauge hierarchy problem

• Dark matter
  – Qualitative: Ockham’s razor
  – Quantitative: WIMPs give the right thermal relic density
  – Less robust: Other production mechanisms, candidates possible
  – More robust: Independent of notions of naturalness

WIMPs motivate many experimental searches
  – Colliders: missing energy
  – Dark matter searches: focused on masses around $m_W \sim 100$ GeV

Xerxes Tata’s talk
START OVER

• What do we really know about dark matter?
  – All solid evidence is gravitational
  – Also solid evidence against strong and EM interactions

• A reasonable 1st guess: dark matter has no SM gauge interactions, i.e., it is hidden

• Hidden sectors: distinguished history and recent interest
  
  Lee, Yang (1956); Gross, Harvey, Martinec, Rohm (1985)
  Schabinger, Wells (2005); Patt, Wilczek (2006); Strassler, Zurek (2006); Georgi (2007); Kang, Luty (2008)
  March-Russell, West, Cumberbatch, Hooper (2008); McDonald, Sahu (2008); Kim, Lee, Shin (2008);
  Krolikowski (2008); Foot (2008); many others

• What one (seemingly) loses
  – The WIMP miracle
  – Predictivity
  – Non-gravitational signals
THE WIMP MIRACLE

- WIMPs naturally freeze out with the desired relic density

- More explicitly:

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

\[(g_X, m_X) \sim (g_W, m_W) \rightarrow \Omega_X \sim \Omega_{DM}\]

- Note: \( \Omega_X \), not \( n_X \), appears above; \( m_X \) enters through \( \sigma \) and dimensional analysis
HIDDEN SECTORS

• Can we obtain something like the WIMP miracle, but with hidden DM? Need some structure.

• Consider standard GMSB with one or more hidden sectors

• Each hidden sector has its own gauge groups and couplings
The Wimpless Miracle

Feng, Kumar (2008)

- Particle Physics

Superpartner masses, interaction strengths depend on gauge couplings

\[
W = \lambda \Phi S \Phi + \lambda_X \Phi_X S \Phi_X
\]

\[
\langle S \rangle = M + \theta^2 F
\]

\[
m \sim \frac{g^2}{16\pi^2} \frac{F}{M}
\]

- Cosmology

\[
\frac{m_X}{g_X^2} \sim \frac{m}{g^2} \sim \frac{F}{16\pi^2 M}
\]

\(\Omega\) depends only on the SUSY Breaking sector:

\[
\Omega_X \sim \Omega_{\text{WIMP}} \sim \Omega_{\text{DM}}
\]

Any hidden particle with mass \(m_X\) will have the right thermal relic density (for any \(m_X\))
WIMPLESS DARK MATTER

- 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, gives a new class of candidates with WIMP pedigree, but with a range of masses/couplings, e.g.:

$$10^{-3} \lesssim g_X \lesssim 3$$

$$10 \text{ MeV} \lesssim m_X \lesssim 10 \text{ TeV}$$
STABILITY

• This requires that an $m_X$ particle be stable. Can one be?

<table>
<thead>
<tr>
<th>MSSM</th>
<th>Flavor-free MSSM O(1) Yukawas</th>
</tr>
</thead>
<tbody>
<tr>
<td>$m_X$ sparticles, $W$, $Z$, $t$</td>
<td>$m_X$ sparticles, $W$, $Z$, $q$, $l$, $\tilde{\tau}$ (or $\tau$)</td>
</tr>
<tr>
<td>$q$, $l$</td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>$p$, $e$, $\gamma$, $\nu$, $\tilde{G}$</td>
<td>$g$, $\gamma$, $\nu$, $\tilde{G}$</td>
</tr>
</tbody>
</table>

• If the hidden sector is a flavor-free MSSM, a natural NLSP candidate, the stau (or tau), would be stabilized by charge conservation. No bounds from hidden sea water, etc.
AN ASIDE: SUSY FLAVOR AND DARK MATTER

• Generically in SUSY there is tension between flavor and dark matter solutions
  – Flavor: small gravity effects → light gravitino
  – DM: neutralino LSP → heavy gravitino

• The standard thermal gravitino is no longer viable
  – $\Omega_{\tilde{G}}\, h^2 \approx 1.2 \,(m_{\tilde{G}} / \text{keV})$  
    Pagels, Primack (1982)
  – $m_{\tilde{G}} > 2 \, \text{keV}$; DM can’t be too hot
    Viel et al.; Seljak et al. (2006)

• WIMPless DM provides one resolution (there are others)
  Han, Hempfling (1997); Baltz, Murayama (2003); Ibe, Kitano (2006); Feng, Smith, Takayama (2007)
CONCRETE MODELS

• Does all of this hold up under closer scrutiny?

• What hidden sectors are viable?
  
  BBN: \( N_v = 3.24 \pm 1.2 \)
  Cyburt et al. (2004)

• Possible resolutions
  – Model building: \( g^*_H < g^*_\text{MSSM} \)
  – Cosmology: Hidden = MSSM or similar, but hidden sector reheats to lower temperature

\[ T_H = \zeta T_{\text{MSSM}} \]

Feng, Tu, Yu (2008)
The hidden Boltzmann equation:
\[
\frac{dn}{dt} = -3Hn - \langle \sigma v \rangle \left[ n^2 - n_{\text{eq}}^2 \right]
\]
- All sectors contribute to H
- \(\langle \sigma v \rangle\) thermally-averaged over \(T_H\)

Consider a hidden sector with
- flavor-free MSSM
- 1 generation
- \(\tilde{\tau}\) WIMPless candidate
- \(\tilde{\tau} \tilde{\tau} \rightarrow \gamma\gamma, \gamma Z\) (all are hidden particles)

Minimal impact: \(\langle \sigma v \rangle = \sigma_0 + \sigma_1 v^2 + \ldots\), low T only suppresses sub-dominant P-wave contributions
RELIC DENSITIES IN COLDER HIDDEN SECTORS

• Numerically solve hidden Boltzmann equation for various \( (g_X, m_X) \)

• The parameters that give the correct relic density are also those that give weak-scale MSSM masses.

• The dimensional analysis is confirmed in this concrete example

Feng, Tu, Yu (2008)
DETECTION

- So far, WIMPless DM has no observable consequences (other than gravitational)

- But we can add connectors with both MSSM and hidden charges; e.g., bifundamentals motivated by intersecting brane models

- $Y$ particles mediate both annihilation to and scattering with MSSM particles

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Feng, Kumar, Strigari (2008)
EXAMPLE

• Suppose the connectors are chiral Y multiplets, interacting through

\[ \mathcal{L} = \lambda_f X \bar{Y}_{f_L} f_L + \lambda_f X \bar{Y}_{f_R} f_R + m_{Y_f} \bar{Y}_{f_L} Y_{f_R} \]

• Y particles get mass from both MSSM and hidden gauge-mediation, so

\[ m_Y \sim \text{max} (m_W, m_X) \]

• Does annihilation through Y’s destroy the relic density properties?
  No, annihilation to MSSM is subdominant, as long as \( \lambda_f < g_W \).

• Y’s are subject to 4th generation constraints from collider direct
  searches, precision electroweak, Yukawa perturbativity. For 4th
  generation quarks,

\[ 250 \text{ GeV} < m_Y < 500 \text{ GeV} \]

Kribs, Plehn, Spannowsky, Tait (2007); Fok, Kribs (2008)
SIGNATURES

- DM is under investigation in ~100 experiments around the world. Many hints of DM have been reported
  - DAMA
  - HEAT
  - HESS
  - INTEGRAL
  - WMAP haze
  - ...

- Most are not naturally explained by WIMPs. What about WIMPless DM?
DIRECT DETECTION

- WIMPless DM can have very large cross sections, and masses from MeV to 10 TeV, explain DAMA

Gelmini, Gondolo (2005); TEXONO (2007)
INDIRECT DETECTION

- WIMPless DM predicts constant $\Omega$ for all $m$

- But $n \sim 1/m$, and so indirect rates $\sim n^2$ are greatly enhanced for light DM (annihilation cross sections are determined by $\lambda$, not $g$)

- GLAST will be sensitive to $\sim$GeV to 10 GeV WIMPless DM, even for smooth halos with $\bar{J} \sim 1$ (not so for WIMPs)
LHC SIGNALS

• The WIMPless DM scenario motivates unusual LHC phenomenology of GMSB + 4th generation. Many effects:
  – Conventional GMSB spectrum with GMSB signals (prompt photon, multi-leptons, etc.)
  – But also pair production $YY \rightarrow XX f f$, “gravity-mediated” missing energy signal
  – Higgs mass as high as 300 GeV
  – $gg \rightarrow h$ enhanced by $\sim 10$ from 4th generation in loop
  – Higgs portal
  – Enhanced, viable electroweak baryogenesis

Kribs, Plehn, Spannowsky, Tait (2007); Fok, Kribs (2008)
SUMMARY

• Early days

• WIMPless dark matter
  – Relic density: $\Omega \sim 0.1$
  – Mass: MeV to 10 TeV
  – Hidden gauge couplings: $10^{-3}$ to 1

• WIMP pedigree with potential for new signals
  – Direct detection
  – Indirect detection
  – LHC
  – Cosmology