WIMPless Dark Matter

Jason Kumar
University of Hawaii
w/ Jonathan Feng, John Learned and Louis Strigari
(0803.4196,0806.3746,0808.4151, in progress)
Relic Density

- dark matter in early universe in thermal equilibrium
- matter decouples because of the expansion of the universe
  - when particles can’t find each other to interact, they decouple from equilibrium
- matter is non-relativistic at decoupling
- Boltzmann equation

\[
\frac{d\eta}{dt} + 3H\eta = -\langle \sigma_{\text{ann}} v \rangle (\eta^2 - \eta_{\text{eq}}^2)
\]

- \( x \sim 20 \), \( \rho \propto T^3 (M_p \langle \sigma v \rangle)^{-1} \)

Y. Zeldovich (1965)
E. Kolb, M. Turner (1990)
WIMP miracle

• knowing $\sigma$, we can figure out relic density

• to get observed DM density need $\sigma \sim 1$ pb

• stable matter with coupling and mass of the electroweak theory would have about right relic density for dark matter
  – WIMP miracle

• one of the best theoretical ideas for dark matter

• guide for most theory models and experimental searches

• but is this miracle really so miraculous?
A New Dark Matter Scenario

• common feature of beyond-the-Standard-Model physics
  – hidden gauge symmetries, particles

• arise in most theory frameworks
  – supersymmetry, string theory, GUTs, etc.

• possible dark matter candidates?
  – can get left over symmetries which stabilize particles
    • discrete, global, gauged?
  – if stable, they contribute to dark matter
    • could be either good, or bad

• what are the dark matter implications for this scenario?
Setup

• the standard “low-energy SUSY” setup
  – one sector breaks supersymmetry
  – an energy scale is generated in Standard Model sector by
gauge-mediation from the SUSY-breaking sector
  – this sets the mass of the W, Z, Higgs, etc.
• the standard “low-energy SUSY” setup
  – one sector breaks supersymmetry
  – an energy scale is generated in Standard Model sector by gauge-mediation from the SUSY-breaking sector
  – this sets the mass of the W, Z, Higgs, etc.

• we add to this extra gauge sectors, which behave in a qualitatively similar way
  – symmetry stabilizes particle at SUSY-breaking scale
The Energy Scale

- gauge interactions determine energy scale in a known way
- \( F, M_{\text{mess}} \) set by dynamics of supersymmetry-breaking
  - same for all sectors
- in each sector, ratio of coupling to mass is approximately fixed
  - determines relic density
    (Scherrer, Turner; Kolb, Turner)
  - if WIMP miracle gets it right, so does every other sector

\[
m^2_{\text{scalar}} = \frac{g^4 N_{\text{mess.}}}{(4\pi)^4} \left( \frac{F}{m_{\text{mess.}}} \right)^2
\]

see G. Giudice, R. Rattazzi (1998)

\[
\frac{g_h^4}{m_h^2} \propto \left( \frac{m_{\text{mess.}}}{F} \right)^2 = \text{const.}
\]

\[
\Omega \propto \frac{1}{\langle \sigma v \rangle} \propto \left( \frac{g_h^4}{m_h^2} \right)^{-1} \propto \left( \frac{F}{m_{\text{mess.}}} \right)^2
\]
we find in this scenario, a generic stable particle at soft-mass scale should have the right density (order of magnitude) to be dark matter

maybe this is really a \textit{WIMPIless miracle} ... any gauge sector with any coupling would have worked

in fact, it should have worked for the MSSM in gauge-mediation
  – two stable particles $\rightarrow$ the LSP and the electron
  – first accident $\rightarrow$ electron Yukawa coupling is extremely (perhaps unnaturally) small
    • mass much lighter than “natural” scale ($m_{\text{top}}$)
    • set by flavor physics which we don’t understand
  – second accident $\rightarrow$ in gauge mediation, the LSP is not gauge charged

but in any other sector, a discrete symmetry can stabilize a hidden sector particle at soft-mass scale
  – in the right ball-park for dark matter
Upshot

• a new well-motivated scenario for dark matter

• natural dark matter candidates with approximately correct mass density

• unlike “WIMP miracle” scenario, here dark matter candidate can have a range of masses and couplings

• opens up the window for observational tests, beyond standard WIMP range

• implications for LHC, direct and indirect detection
Detection Scenarios

- if no connection between SM and hidden sector…
  - no direct, indirect or collider signature
  - only gravitational
Detection Scenarios

• if no connection between SM and hidden sector…
  – no direct, indirect or collider signature
  – only gravitational

• but could have connectors between those sectors
  – exotics charged under both SM and hidden sector
Yukawa coupling

- $W = \lambda X Y_L f_L + \lambda X Y_R f_R + m Y_L Y_R$

- $f$ is a SM multiplet

- $Y_{L,R}$ are 4th generation-like connector particles

- allows both annihilation to and scattering from SM particle $f$, and LHC production
Scattering from **b-quarks**

- **assume WIMPless DM couples to 3rd generation quarks**
  - assume coupling to other generations **suppressed**
  - reasonable FCNC solution

- **this gives a coupling to gluons in nucleus via loop of b-quarks**
  - coupling via t-quarks suppressed by $m_{\text{top}}$

- **can compute coupling via conformal anomaly** (Shifman, Vainshtein, Zakharov)
Detection Prospects

- **direct detection**
  - DAMA
  - could use low-mass WIMPless DM
- **indirect detection**
  - Super-K can probe $XX \rightarrow bb \rightarrow \nu \nu$ at low mass
    - model-independent check to direct detection
  - may also get signals at Fermi
- **LHC**
  - can produce YY pairs through QCD processes
  - $m_\gamma$ constrained by precision EW data
  - will definitely find them at LHC
  - signal remains at small $\lambda$, where direct and indirect go bad
- **multi-component** dark matter natural
  - each with $O(1)$ fraction of relic density
  - mass scales can be very different
Conclusion

• new theoretical window for dark matter
  – large range of masses and couplings
  – can be multi-component

• possible explanation for results of DAMA/LIBRA

• interesting corroborative checks at LHC

• possible to corroborate at Super-Kamiokande

Mahalo!