Supersymmetric dark matter after LUX

Marcin Badziak

UC/LBNL Berkeley & University of Warsaw

Based on:
MB, Marek Olechowski, Pawel Szczerbiak
arXiv:1705.00227
Neutralino as a thermal relic

• Dark matter particle should be stable (at least at cosmological time scales)
• The simplest SUSY models predict that the lightest sparticle (LSP) is stable
• SUSY WIMP miracle: the lightest neutralino has (roughly) the right relic abundance to account for DM
• But the devil is in details... and experimental constraints
Relic abundance of neutralinos

• In MSSM there are 4 neutralinos:

\[
\begin{pmatrix}
    M_1 & 0 & -M_Z \sin \theta_W \cos \beta & M_Z \sin \theta_W \sin \beta \\
    0 & M_2 & M_Z \cos \theta_W \cos \beta & -M_Z \cos \theta_W \sin \beta \\
    -M_Z \sin \theta_W \cos \beta & M_Z \cos \theta_W \cos \beta & 0 & -\mu \\
    M_Z \sin \theta_W \sin \beta & -M_Z \cos \theta_W \sin \beta & -\mu & 0
\end{pmatrix}
\]

- **Pure Bino**: generically $\Omega h^2 \gg 1$ (due to lower limits on sfermion masses)
- **Pure Higgsino**: $\Omega h^2 \approx 0.12 \Rightarrow m_{\text{LSP}} \approx 1$ TeV
- **Pure Wino**: $\Omega h^2 \approx 0.12 \Rightarrow m_{\text{LSP}} \approx 3$ TeV (but strong tension with indirect detection exp.)
- **The most viable option**: mixed (well-tempered) Bino-Higgsino DM with mass from 100 GeV to 1 TeV

Arkani-Hamed, Delgado, Giudice ‘06
Direct detection of neutralinos

• Neutralinos interact with nucleons via exchange of Higgs boson(s) and Z boson

\[ h_i \]

Spin-independent (SI) interaction

\[ Z^0 \]

Spin-dependent (SD) interaction
Limits on WIMP scattering off nuclei

- The strongest constraints from LUX (Xenon1T only slightly better in SI so far)
LUX Limits on Bino-Higgsino

- Most parameter space excluded but small $\tan \beta$ still allowed
Blind spots for SI direct detection: vanishing Higgs-LSP coupling

- In parts of parameter space (blind spots) the SI LSP-nucleon effective coupling vanishes.

- If only Higgs mediates this interaction SI blind spot occurs at

\[ \frac{M_1}{\mu} = -\sin(2\beta) \]

- \( \Omega h^2 \approx 0.12 \) requires large bino-higgsino mixing:

\[ M_1 \sim \mu \Rightarrow \tan \beta \lesssim 2 \]

- 125 GeV Higgs mass requires very heavy stops (big fine-tuning of the EW scale) in MSSM.

Cheung, Hall, Pinner, Ruderman ‘13
Blind spots for SI direct detection: interference with heavy Higgs $H$

• If $H$ is light SI blind spot is modified

\[ \frac{M_1}{\mu} \approx -\sin(2\beta) - \frac{m_h^2 \tan \beta}{m_H^2} \frac{\tan \beta}{2} \]

• $\Omega h^2 \approx 0.12$ may be obtained also for large $\tan \beta$

• But the LHC lower mass limits on $m_H$ are strong, especially for large $\tan \beta$
Blind spots for SI direct detection: interference with heavy Higgs H

- Well-tempered LSP still requires quite small $\tan \beta$
- Strong resonant annihilation ($m_{\text{LSP}} \approx m_A / 2$) may be out of reach of future SI direct detection experiments
Testing SI blind spots with SD direct detection

- Neutralino SI blind spots can be efficiently probed using SD interaction with nucleons
- LUX provides lower mass limit for LSP of 250 GeV
- The limit is model-independent when LSP dominantly annihilates to ttbar via Z boson exchange
- The limits may be strongly improved by Xenon1T/LZ
- If no signal observed by LZ then direct detection exp. would be accommodated by:
  - Pure 1 TeV Higgsino
  - Pure Bino with fine-tuned spectrum of scalar masses (co-annihilations, resonant annihilation)
NMSSM: Beyond minimal SUSY

\[ W = W_{\text{MSSM}} + \lambda S H_u H_d + \xi_F S + \frac{1}{2} \mu' S^2 + \frac{\kappa}{3} S^3 \]

- New DM candidate: (Higgsino-)Singlino
- Singlino similar to Bino except that it can strongly annihilate to singlet scalars
- SD constraints relaxed (due to smaller LSP-Z coupling required to get \( \Omega h^2 \approx 0.12 \))
NMSSM: Higgsino-Singlino DM

- SD constraints relaxed (due to smaller LSP-Z coupling required to get $\Omega h^2 \approx 0.12$)
- Future Xenon1T lower mass limit on Singlino-Higgsino LSP may be relaxed by 200-300 GeV as compared to the MSSM case
Conclusions

• Supersymmetric DM under pressure (as any other WIMP)
• Still, there are parts of parameter space consistent with the lack of observation
• Future results for SD scattering x-sec may close most of SI blind spots
• If there is no direct detection in next 5 years (LZ) the most viable scenario would be 1 TeV Higgsino or strong LSP annihilation to new light singlet scalars – cases for indirect DM detection
Acknowledgments

This work has been supported by Polish Ministry of Science Education through its programme Mobility Plus and the Department of Energy.