CoGeNT, DAMA, and Light Neutralino Dark Matter.

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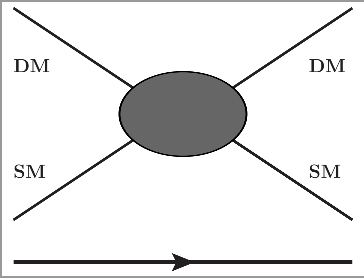
A.Belikov, J.F.Gunion, D.Hooper, T.Tait, arXiv:1009.0549

Direct detection of Dark Matter



- DAMA - NaI - 1.17 ton-years
- CoGeNT - Ge - I. 0.33 kg x 56 days or II. 145 kg-days
- XENON100 - Xe - 100.9 day x 48 kg
- CDMS-Si - Ge - 83.3 kg-days
- CDMS II - Ge - 612 kg-days
- CRESST - $CaWO_4$ - 0.3 kg

MSSM

Generically, the spin-independent elastic scattering cross section of dark matter with a nucleus is written:

$$\sigma \approx \frac{4m_{\rm DM}^2 m_N^2}{\pi(m_{\rm DM}+m_N)^2}[Zf_p + (A-Z)f_n]^2$$

$$f_{p,n} = \sum_{q=u,d,s} f_{T_q}^{(p,n)} a_q \frac{m_{p,n}}{m_q} + \frac{2}{27} f_{TG}^{(p,n)} \sum_{q=c,b,t} a_q \frac{m_{p,n}}{m_q},$$

a_q are the dark matter's couplings to quarks and $f_{T_q}^{(p,n)}$, $f_{TG}^{(p,n)}$ are hadronic matrix elements.

MSSM

Neutralino down-type quark coupling:

$$\frac{a_d}{m_d} = \frac{g_2}{4m_W \cos\beta}[-g_1 N_{11} + g_2 N_{12}] \times \left[\left(\frac{N_{13}c_\alpha^2 - N_{14}c_\alpha s_\alpha)}{m_H^2}\right) + \left(\frac{N_{13}s_\alpha^2 + N_{14}c_\alpha s_\alpha)}{m_h^2}\right)\right]$$

$$(\chi_1^0 = N_{11}\tilde{B} + N_{12}\tilde{W}^3 + N_{13}\tilde{H}_d + N_{14}\tilde{H}_u)$$

s_α and c_α relate the scalar mass and gauge eigenstates
In large $\tan\beta$, $\sin(\beta - \alpha) \sim 1$, significant N_{13}, and light m_H

$$\frac{a_d}{m_d} \approx \frac{-g_2 g_1 N_{13} N_{11} \tan\beta\, c_\alpha^2}{4m_W m_H^2}$$

$$\sigma_{\chi^0 p,n} \approx 1.7 \times 10^{-41}\mathrm{cm}^2 \left(\frac{N_{13}^2}{0.103}\right)\left(\frac{\tan\beta}{50}\right)^2\left(\frac{100\,\mathrm{GeV}}{m_H}\right)^4\left(\frac{c_\alpha}{1}\right)^4$$

Singlet extended MSSM

Superpotential:

$$W = \frac{1}{2}\mu_S \hat{S}^2 + \mu \hat{H}_u \hat{H}_d + \lambda \hat{S}\hat{H}_u\hat{H}_d + \frac{1}{3}\kappa \hat{S}^3$$

Soft Lagrangian:

$$\mathcal{L}_{soft} = v_S^3 S + B_\mu H_u H_d + \frac{1}{2}m_S^2|S|^2 + \frac{1}{2}B_S S^2 + \lambda A_\lambda S H_u H_d + \frac{1}{3}\kappa A_\kappa S^3 + H.c.$$

$$\mathcal{M}_{\widetilde{\chi}^0} = \begin{pmatrix} M_1 & 0 & \frac{g_1 v_u}{\sqrt{2}} & -\frac{g_1 v_d}{\sqrt{2}} & 0 \\ 0 & M_2 & -\frac{g_2 v_u}{\sqrt{2}} & \frac{g_2 v_d}{\sqrt{2}} & 0 \\ \frac{g_1 v_u}{\sqrt{2}} & -\frac{g_2 v_u}{\sqrt{2}} & 0 & -\mu - \lambda s & -\lambda v_d \\ -\frac{g_1 v_d}{\sqrt{2}} & \frac{g_2 v_d}{\sqrt{2}} & -\mu - \lambda s & 0 & -\lambda v_u \\ 0 & 0 & -\lambda v_d & -\lambda v_u & 2\kappa s + \mu_S \end{pmatrix}$$

The lightest neutralino is mostly $\tilde{S}$ provided that $|2\kappa s + \mu_S|$ is much smaller than $|\mu + \lambda s|$, M_1 and M_2.

Singlet extended MSSM

For $\kappa = 0.6$, $s = 6$ GeV, $\mu_S \approx 0$, $\lambda = 0.1$, large $\tan\beta$, large M_1, large M_2, and $\mu =$150 GeV the lightest neutralino is singlino-like ($N_{15}^2 = 0.974$) with $m_{\chi^0} \approx 7.2$ GeV.

h_1 is singlet-like: in the limit $\lambda \to 0$ the singlet decouples from the MSSM and m_{h_1} is determined by B_S, m_S^2, μ_S, κ, s and A_κ

$$\frac{a_d}{m_d} = \frac{g_2 \kappa N_{15}^2 \tan\beta F_s F_d}{8 m_W m_{h_1}^2},$$

where F_s and F_d are the singlet and the down fractions of the h_1.

$$\sigma_{\chi^0 p,n} \approx 2.2 \times 10^{-40}\,\mathrm{cm}^2 \times \left(\frac{\kappa}{0.6}\right)^2 \left(\frac{\tan\beta}{50}\right)^2 \left(\frac{45\,\mathrm{GeV}}{m_{h_1}}\right)^4 \left(\frac{F_s^2}{0.85}\right) \left(\frac{F_d^2}{0.15}\right)$$

$F_s^2 = 0.85$ of h_1 easily allows it to evade the constraints from LEP II and the Tevatron.

Singlet extended MSSM. Thermal relic density.

$\chi\bar{\chi} \to b\bar{b}$ (or, to a lesser extent, to $\tau^+\tau^-$) through the s-channel exchange of a higgs boson. s-channel exchange of the *same* scalar higgs, h_1, as employed for elastic scattering:

$$\sigma v = \frac{N_c g_2^2 \kappa^2 m_b^2 F_s^2 F_d^2}{64\pi m_W^2 \cos^2\beta} \frac{m_{\chi^0}^2 (1 - m_b^2/m_{\chi^0}^2)^{3/2} v^2}{(4m_{\chi^0}^2 - m_{h_1}^2)^2 + m_{h_1}^2 \Gamma_{h_1}^2}$$

$$\Omega_{\chi^0} h^2 \approx \frac{10^9}{M_{\rm Pl}} \frac{m_{\chi^0}}{T_{\rm FO}\sqrt{g_\star}} \frac{1}{\langle \sigma_{\chi^0\chi^0} v \rangle}$$

where $g_\star$ is the number of relativistic d.o.f. available at freeze-out, $\langle \sigma_{\chi^0\chi^0} v \rangle$ is the thermally averaged annihilation cross section at freeze-out, and $T_{\rm FO}$ is the temperature at which freeze-out occurs.

Singlet extended MSSM. Thermal relic density.

$$\Omega_{\chi^0} h^2 \approx 0.11 \left(\frac{0.6}{\kappa}\right)^2 \left(\frac{50}{\tan\beta}\right)^2 \left(\frac{m_{h_1}}{45\,\mathrm{GeV}}\right)^4 \times \left(\frac{7\,\mathrm{GeV}}{m_{\chi^0}}\right)^2 \left(\frac{0.85}{F_s^2}\right) \left(\frac{0.15}{F_d^2}\right)$$

All that is difficult to realize within NMSSM but possible within a more generic singlet extension

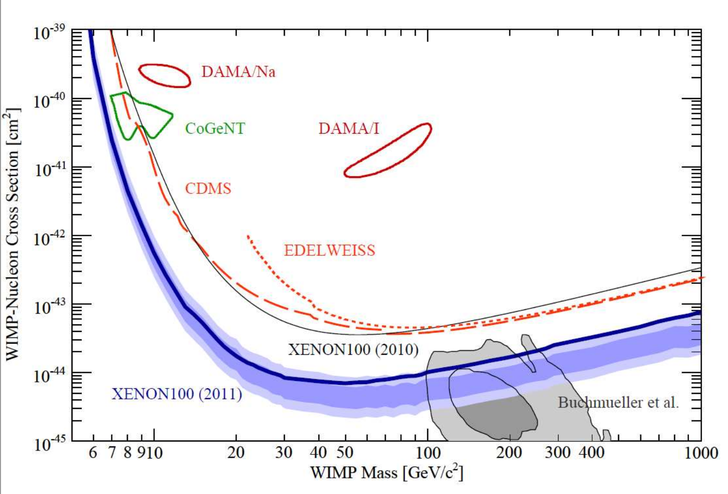
$$W^{extra} = \frac{1}{2}\mu_S \hat{S}^2 + \mu \hat{H}_u \hat{H}_d$$

$$\mathcal{L}^{extra}_{soft} = v_S^3 S + B_\mu H_u H_d + \frac{1}{2} B_S S^2$$

Just NMSSM:

P.Draper et al, Phys.Rev.Lett.106:121805,2011

XENON100 exclusion plots



Possible explanation of the discrepancy between XENON100 and CoGeNT

- Vary couplings to protons and neutrons f_n and f_p
- Vary the parameters of the thermal distribution of dark matter in the halo and the distribution itself

- Implications of CoGeNT and DAMA for Light WIMP Dark Matter. A.L.Fitzpatrick, D.Hooper, K.M.Zurek Phys.Rev. D81 (2010) 115005
- Isospin-Violating Dark Matter. J. L. Feng, J. Kumar, D. Marfatia, D. Sanford, arXiv:1102.4331

Conclusion

Models in which the MSSM is extended by a chiral singlet superfield contain a light singlino-like neutralino, which interacts with nuclei through the exchange of a largely singlet-like, scalar higgs. Such a neutralino can possess an elastic scattering cross section capable of generating the observations reported by CoGeNT and DAMA/LIBRA.