Isospin Violating Dark Matter

David Sanford

Work with J.L. Feng, J. Kumar, and D. Marfatia
UC Irvine

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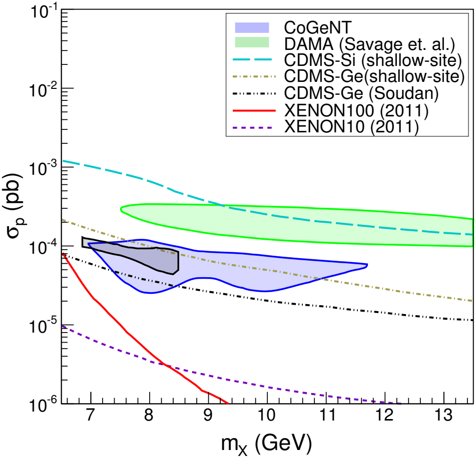
Current State of Light Dark Matter



- Great recent interest in light dark matter
- Major inconsistencies between experimental results
  - DAMA and CoGeNT regions do not agree
  - XENON10/XENON100 rule out DAMA and CoGeNT
  - **CDMS-Ge (Soudan)** rules out much of CoGeNT and all of DAMA
- Both DAMA and CoGeNT report annual modulation signals

Possible Explanations of the Discrepancy

Many theories have been put forward

- Inelastic dark matter
  - Tucker-Smith and Weiner (2001)
- Details of L_{eff} in liquid xenon at low recoil energy
  - Collar and McKinsey (2010)
- Channeling in NaI at DAMA
  - Bernabei et. al. [DAMA] (2007); Bozorgnia, Gelmini, Gondolo (2010)

We propose to rescind the assumption of isospin conservation

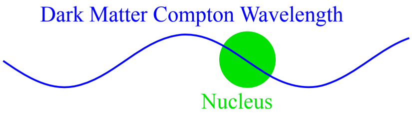
- Unfounded theoretical assumption
- Simple resolution of several discrepancies
- Also considered by Chang, Liu, Pierce, Weiner, Yavin (2010)

Isospin Conservation and Violation

- DM-nucleus scattering is coherent
- The single atom SI scattering cross-section is

$$\sigma_A \propto [f_p Z + f_n(A - Z)]^2$$
$$\propto f_p^2 A^2 \qquad (f_p = f_n)$$

- Well-known A^2 enhancement for $(f_p = f_n)$



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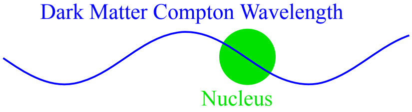

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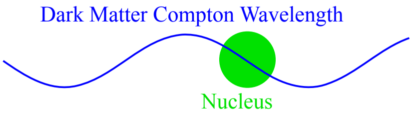

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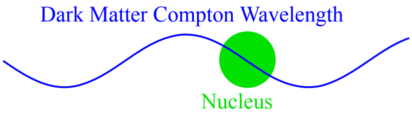

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- $\frac{Z}{A-Z}$ decreases for higher Z isotopes

Dark Matter Experiments and Proton/Neutron Ratio

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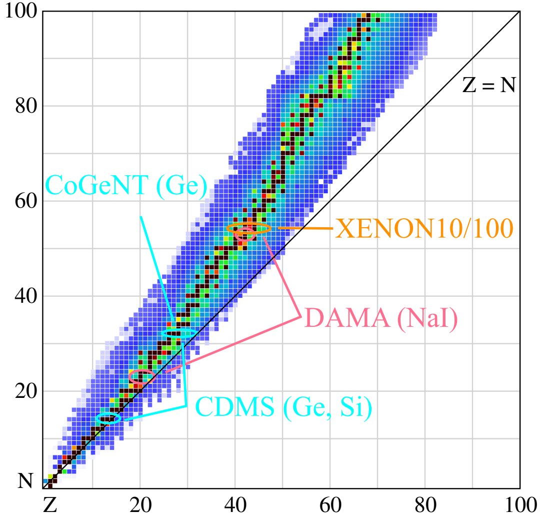

- National Nuclear Data Center

Effects of Multiple Isotopes

Stable isotopes of Xenon ($Z = 54$):

A	128	129	130	131	132	134	136
Abundance (%)	1.9	26.4	4.1	21.2	26.9	10.4	8.9
$\sigma_A = 0$ at $f_n/f_p =$				-0.70			

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- Cannot have completely destructive interference for more than one isotope of an element
- We define the "per-nucleon cross-section" measured by experiments

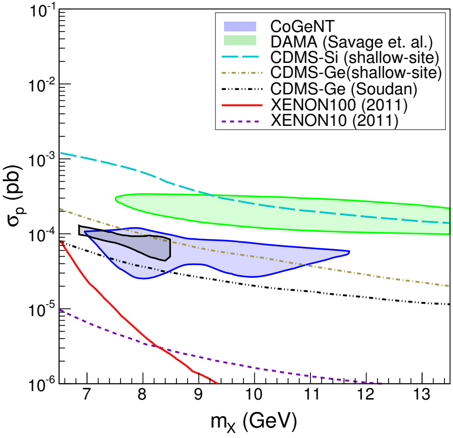
$$\sigma_N^Z = \sigma_p \frac{\sum_i \eta_i {\mu_{A_i}}^2 \left[Z + (A_i - Z) f_n/f_p\right]^2}{\sum_i \eta_i {\mu_{A_i}}^2 A_i^2}$$

σ_p: DM-proton cross-section

η_i: Relative abundance of an isotope

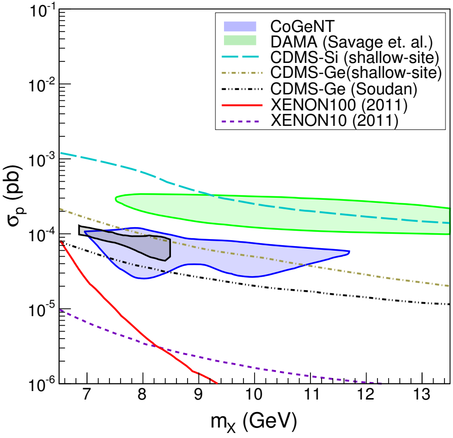
μ_{A_i}: Reduced nucleon-DM mass for an isotope

Light DM for $f_n/f_p = 1$



$f_n/f_p = 1$

Light DM for $f_n/f_p = 1$ and $f_n/f_p = -0.7$



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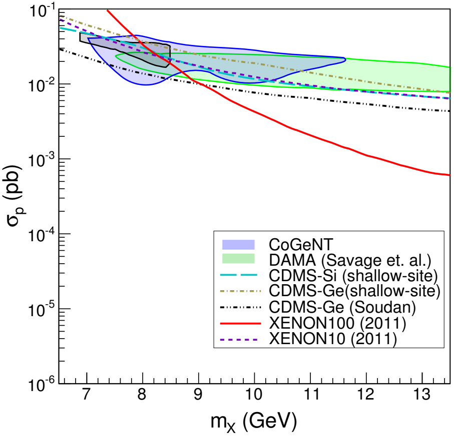

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Comparing Direct Detection Experiments

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How tight does the XENON constraint have to be?

- Scan over f_n/f_p to maximize the apparent discrepancy between the values σ_N^Z for two elements
- CoGeNT (Ge) can consistently exceed XENON100 bounds by a factor of 23.5
- DAMA (Na) can consistently exceed XENON100 bounds by a factor of 103.1

Maximum Enhancement of Cross-Sections

Element (Z,A)	Xe	Ge	Si	Ca	W	Ne
Xe (54, *)	1.0	8.9	169.5	169.5	9.92	42.2
Ge (32, *)	23.5	1.0	76.9	77.5	117.6	19.2
Si (14, *)	172.4	30.2	1.0	1.1	666.7	1.05
Ca (20, *)	178.6	30.5	1.1	1.0	666.7	1.07
W (74, *)	3.5	16.1	238.1	238.1	1.0	59.2
Ne (10, *)	166.7	28.9	4.0	4.0	666.7	1.0
I (53, 127)	1.9	5.7	147.1	147.1	18.0	36.4
Cs (55, 133)	1.1	7.4	158.7	161.3	10.7	39.5
O (8, 16)	181.8	31.5	1.1	1.1	714.3	1.1
Na (11, 23)	103.1	13.2	9.7	10.3	416.7	2.8
Ar (18, 40)	181.9	31.5	1.1	1.03	714.3	1.1

- Maximum factor by which the reported σ_N^Z of elements listed in rows can exceed that of those listed in columns
- Scattering off single-isotope elements can always be arbitrarily suppressed

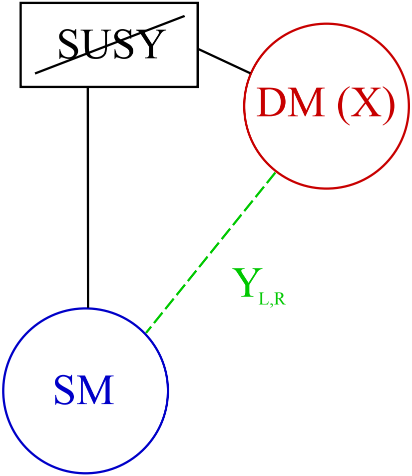
Quark-Level Realization

We desire a quark level realization of isospin-violation

- Provides a proof-of-concept
  - Already present in the MSSM, but not typically destructive
    - Cotta, Gainer, Hewett, Rizzo (2009)
- Required for comparison to other types of detection
  - Collider bounds
  - Spin-dependent direct detection
  - Indirect detection
- Isospin violation is found only in couplings to up and down quarks

Quark-Level Realization: WIMPless Models

$$W \supset \sum_i \left(\lambda_q^i X Y_{q_L} q_L^i + \lambda_u^i X Y_{u_R} u_R^i + \lambda_d^i X Y_{d_R} d_R^i \right)$$



- SUSY model w/ DM (X) in a hidden sector
- GMSB provides naturally similar masses, providing the "WIMPless" miracle in the hidden sector
- X couples to SM through mediator Y and yukawa terms
- All quark/lepton couplings to vanish except those to up and down quarks for simplicity

Collider Constraints

- Collider single-jet searches constrain the operator $X\bar{X}q\bar{q}$
  - Goodman et. al. (2010); Bai, Fox, and Harnik (2010)
- There is no destructive intereference in collider searches, so bounds become much stronger

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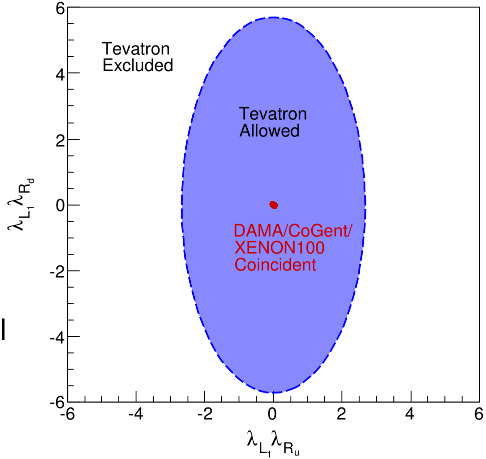
- There is no destructive intereference in collider searches, so bounds become much stronger
- Coincident region still well within experimental bounds

$$\lambda_{L_1}\lambda_{R_u} \sim \pm 0.02$$
$$\lambda_{L_1}\lambda_{R_d} \sim \mp 0.02$$



$M_X = 8\ \mathrm{GeV},\ M_Y = 400\ \mathrm{GeV}$

Conclusion

- Dark matter may generically couple in a way that violates isospin
- For $f_n/f_p \sim -0.7$, CoGeNT and DAMA results agree for a significant mass range and are partially unbounded by XENON
- The possibility of IVDM motivates the use of a variety of materials in experimental searches
- A WIMPless (or other) realization provides for consistent constraints on IVDM from other sources

Extra Slides: Isotope Abundances

Xe	Ge	Si	Ca	W	Ne
128 (1.9)	70 (21.2)	28 (92.2)	40 (96.9)	182 (26.5)	20 (90.5)
129 (26.4)	72 (27.7)	29 (4.7)	44 (2.1)	183 (14.3)	22 (9.3)
130 (4.1)	73 (7.7)	30 (3.1)		184 (30.6)	
131 (21.2)	74 (35.9)			186 (28.4)	
132 (26.9)	76 (7.4)				
134 (10.4)					
136 (8.9)					