New Physics Interpretation of DAMA
Discussion

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work in collaboration with
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Potential Models of Discussion

- Published Work
  - Light Dark Matter
  - Inelastic Dark Matter

- Work in progress
  - Inelastic Dark Matter with light mediator
  - Electron Interacting Dark Matter

Note: Won't discuss spin-dependent cases
DAMA Goggles

- DAMA/LIBRA data is now good enough to pin down parameter space of dark matter candidates
- What is new
  - Single hit, unmodulated spectra
  - Finely binned modulation spectra
### Data Consistent with DM modulation

![Graph showing residuals and time (day)]

<table>
<thead>
<tr>
<th></th>
<th>$A$ (cpd/kg/keV)</th>
<th>$T = \frac{2\pi}{\omega}$ (yr)</th>
<th>$t_0$ (day)</th>
<th>C.L.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>DAMA/NaI</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(2–4) keV</td>
<td>0.0252 ± 0.0050</td>
<td>1.01 ± 0.02</td>
<td>125 ± 30</td>
<td>5.0σ</td>
</tr>
<tr>
<td>(2–5) keV</td>
<td>0.0215 ± 0.0039</td>
<td>1.01 ± 0.02</td>
<td>140 ± 30</td>
<td>5.5σ</td>
</tr>
<tr>
<td>(2–6) keV</td>
<td>0.0200 ± 0.0032</td>
<td>1.00 ± 0.01</td>
<td>140 ± 22</td>
<td>6.3σ</td>
</tr>
<tr>
<td><strong>DAMA/LIBRA</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(2–4) keV</td>
<td>0.0213 ± 0.0032</td>
<td>0.997 ± 0.002</td>
<td>139 ± 10</td>
<td>6.7σ</td>
</tr>
<tr>
<td>(2–5) keV</td>
<td>0.0165 ± 0.0024</td>
<td>0.998 ± 0.002</td>
<td>143 ± 9</td>
<td>6.9σ</td>
</tr>
<tr>
<td>(2–6) keV</td>
<td>0.0107 ± 0.0019</td>
<td>0.998 ± 0.003</td>
<td>144 ± 11</td>
<td>5.6σ</td>
</tr>
<tr>
<td><strong>DAMA/NaI+ DAMA/LIBRA</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(2–4) keV</td>
<td>0.0223 ± 0.0027</td>
<td>0.996 ± 0.002</td>
<td>138 ± 7</td>
<td>8.3σ</td>
</tr>
<tr>
<td>(2–5) keV</td>
<td>0.0178 ± 0.0020</td>
<td>0.998 ± 0.002</td>
<td>145 ± 7</td>
<td>8.9σ</td>
</tr>
<tr>
<td>(2–6) keV</td>
<td>0.0131 ± 0.0016</td>
<td>0.998 ± 0.003</td>
<td>144 ± 8</td>
<td>8.2σ</td>
</tr>
</tbody>
</table>

**Expectations**

1 152
Overall Rate

Modulation Amplitude
My Mantra

• Overall rate has very little background discrimination
  – Expect O(1) contamination
  – But can be agnostic about its form as long as you don't exceed it

• Modulation rate spectra is detailed
  – Predicts preferred regions of DM
  – Can then check if other experiments are consistent
Elastic DM

DAMA spectra for different masses (GeV)

Data points pick out preferred mass regions

Fact that the first few points are “low” drives the fit
Spectral information disfavors $m < 10 \text{ GeV}$
Need nonstandard astrophysics/expt'l issues for consistency
Inelastic Dark Matter

- Models where dark matter scatters dominantly inelastically off nuclei
- Adds extra parameter $\delta$, mass splitting to heavier state
- Kinematics produces a few effects
Distinct Spectra

\[ \beta_{\text{min}} = \frac{1}{\sqrt{2} m_N E_R} \left( \frac{m_N E_R}{\mu_N} + \delta \right) \]

- Minimum velocity is changed
  - Low Energy recoils suppressed b/c they require higher velocity
  - Heavier targets have smaller threshold velocity
Enhanced Modulation

- Sampling of higher velocity tail, means more modulation
- Expt: Dates of data taking crucial to setting limits. Can search for enhanced modulation

Modulation in observed DAMA range

Preferred Splitting
For different dark matter masses, each fit prefers a range for $\delta$, as it shifts the peak.
IDM Plots

Constraints are $p_{\text{max}}$ (Yellin)

CRESST and ZEPLIN strongest!
XENON Data

Analysis region (< 27 keV) misses most of the IDM recoils
CRESST Data

Form factor behavior is crucial

Events inconsistent with expected background
# Benchmark Values

<table>
<thead>
<tr>
<th>#</th>
<th>$m_\chi$ (GeV)</th>
<th>$\sigma_n$ ((10^{-40} \text{ cm}^2))</th>
<th>$\delta$ (keV)</th>
<th>DAMA 2-6 keVee ((10^{-2} \text{ dru}))</th>
<th>XENON 4.5-45 keV (\text{counts})</th>
<th>CDMS 10-100 keV (\text{counts})</th>
<th>ZEPLIN 5-20 keVee ((10^{-2} \text{ dru}))</th>
<th>KIMS 3-8 keVee (\text{counts})</th>
<th>CRESST 12-100 keV (\text{counts})</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>70</td>
<td>11.85</td>
<td>119</td>
<td>0.89</td>
<td>1.39</td>
<td>0</td>
<td>8.46</td>
<td>0.65</td>
<td>8.76</td>
</tr>
<tr>
<td>2</td>
<td>90</td>
<td>5.75</td>
<td>123</td>
<td>1.21</td>
<td>5.52</td>
<td>0</td>
<td>14.40</td>
<td>1.52</td>
<td>9.75</td>
</tr>
<tr>
<td>3</td>
<td>120</td>
<td>3.63</td>
<td>125</td>
<td>1.22</td>
<td>9.06</td>
<td>0.13</td>
<td>18.09</td>
<td>2.18</td>
<td>10.7</td>
</tr>
<tr>
<td>4</td>
<td>150</td>
<td>2.92</td>
<td>126</td>
<td>1.18</td>
<td>11.17</td>
<td>0.95</td>
<td>19.93</td>
<td>2.53</td>
<td>11.2</td>
</tr>
<tr>
<td>5</td>
<td>180</td>
<td>2.67</td>
<td>126</td>
<td>1.15</td>
<td>12.46</td>
<td>1.93</td>
<td>21.01</td>
<td>2.74</td>
<td>11.6</td>
</tr>
<tr>
<td>6</td>
<td>250</td>
<td>2.62</td>
<td>127</td>
<td>1.11</td>
<td>14.01</td>
<td>3.60</td>
<td>23.32</td>
<td>3.00</td>
<td>12.1</td>
</tr>
</tbody>
</table>
Theory of Dark Matter

- Dark matter mass due to ATIC is 800 GeV – 1 TeV
- Attempts to get DAMA by inelastic scattering
  - Plots from before rule out $m > 250$ GeV
- However, the inelastic scattering is mediated by light vector $\phi$, giving $1/(q^2 - m_\phi^2)^2$ in rate
Preliminary Results: Pushes to larger $\delta$

$m_\phi \sim 8$ MeV

$m_\phi \sim 80$ MeV
Electron Recoils

- My suspicion is that the spectra does not fit for weak scale DM masses
- If interested, let's talk offline
Conclusions

- DAMA's new data is predictive enough to set up a (hopefully) non-moving target
- Light Dark Matter
  - Low threshold expts: CDMS, CoGeNT, and even XENON will further constrain
- Inelastic Dark Matter
  - Heavy target expts: CRESST, XENON, LUX, KIMS, ZEPLIN should see high energy events and possibly modulation