Generalizing
Minimal Dark Matter
Millicharge or Decay

Eugenio Del Nobile
Università di Padova and INFN, Sezione di Padova
DM stability $\rightarrow$ Symmetries

$ad \ hoc$

accidental

**Minimal Dark Matter**

- Only SM gauge symmetries
- New DM multiplet under the SM gauge group
- Accidentally stable DM (up to dim. 5 in EFT)
- DM mass fixed by relic density
<table>
<thead>
<tr>
<th>Quantum numbers</th>
<th>DM can decay into</th>
<th>DD bound?</th>
<th>Stable?</th>
</tr>
</thead>
<tbody>
<tr>
<td>SU(2)$_L$</td>
<td>U(1)$_Y$</td>
<td>Spin</td>
<td>(LHHH*)</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>1/2</td>
<td>S</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>1/2</td>
<td>F</td>
</tr>
<tr>
<td>3</td>
<td>3</td>
<td>0</td>
<td>S</td>
</tr>
<tr>
<td>3</td>
<td>3</td>
<td>0</td>
<td>F</td>
</tr>
<tr>
<td>3</td>
<td>3</td>
<td>1</td>
<td>S</td>
</tr>
<tr>
<td>3</td>
<td>3</td>
<td>1</td>
<td>F</td>
</tr>
<tr>
<td>4</td>
<td>4</td>
<td>1/2</td>
<td>S</td>
</tr>
<tr>
<td>4</td>
<td>4</td>
<td>1/2</td>
<td>F</td>
</tr>
<tr>
<td>4</td>
<td>4</td>
<td>3/2</td>
<td>S</td>
</tr>
<tr>
<td>4</td>
<td>4</td>
<td>3/2</td>
<td>F</td>
</tr>
<tr>
<td>5</td>
<td>5</td>
<td>0</td>
<td>S</td>
</tr>
<tr>
<td>5</td>
<td>5</td>
<td>0</td>
<td>F</td>
</tr>
<tr>
<td>5</td>
<td>5</td>
<td>1</td>
<td>S</td>
</tr>
<tr>
<td>5</td>
<td>5</td>
<td>1</td>
<td>F</td>
</tr>
<tr>
<td>5</td>
<td>5</td>
<td>2</td>
<td>S</td>
</tr>
<tr>
<td>5</td>
<td>5</td>
<td>2</td>
<td>F</td>
</tr>
<tr>
<td>6</td>
<td>6</td>
<td>1/2, 3/2, 5/2</td>
<td>S</td>
</tr>
<tr>
<td>7</td>
<td>7</td>
<td>0</td>
<td>S</td>
</tr>
<tr>
<td>8</td>
<td>8</td>
<td>1/2, 3/2</td>
<td>S</td>
</tr>
</tbody>
</table>
Real scalar eptaplet

\[ \frac{1}{\Lambda} \chi^3 H^2 \]

This affects any scalar SU(2)_L multiplet with odd dimension and \( Y = 0 \)

(for the same reason, fermion MDM decays at most through the dimension-7 \( \chi^3 LH \) operator)
Majorana quintuplet

Constraints from Milky Way, $\gamma$–ray line

$\langle \sigma v \rangle_{\gamma+\gammaZ2}$ [cm$^3$/s]

$M_{DM}$ [TeV]

Filippo Sala CEA/Saclay

etc.
Minimal Dark Matter: assumptions

1. Thermal relic, all of DM (fixes DM mass)
2. Small Higgs-portal interactions for scalars
3. Cutoff at the Planck scale
4. Electrically neutral DM (forces $Y = 0$)
Minimal Dark Matter: assumptions

1. Thermal relic, all of DM (fixes DM mass)
2. Small Higgs-portal interactions for scalars
3. Cutoff at the Planck scale
4. Electrically neutral DM (forces $Y = 0$)

Giving up 1.

- Needs not being enforced
- Modern analyses consider the DM mass as a free parameter
Minimal Dark Matter: assumptions

1. Thermal relic, all of DM (fixes DM mass)
2. Small Higgs-portal interactions for scalars
3. Cutoff at the Planck scale
4. Electrically neutral DM (forces $Y = 0$)

Giving up 2.

- These couplings can change mass splittings and hierarchy and thus the phenomenology of the model
- They actually run very fast and induce low-energy Landau poles
- In any case, scalar MDM with $Y = 0$ decays too quickly
Minimal Dark Matter: assumptions

1. Thermal relic, all of DM (fixes DM mass)
2. Small Higgs-portal interactions for scalars
3. Cutoff at the Planck scale
4. Electrically neutral DM (forces $Y = 0$)

Giving up 3. and 4.

The remainder of this talk
Decaying Majorana quintuplet

\[ \frac{1}{(\Lambda_1^e)^2} \overline{\chi} L H H H H^\dagger \]

\[ \frac{1}{(\Lambda_2^e)^2} \overline{\chi} \sigma_{\mu\nu} L W^{\mu\nu} H \]

- Fermi 2015
- Total Flux
- ExGal Flux
- Gal Flux

\[ \Lambda_1^e = 1.59 \times 10^{16} \text{GeV} \]

\[ \Lambda_2^e = 8.19 \times 10^{16} \text{GeV} \]
Decaying Majorana quintuplet

\[
\frac{1}{(\Lambda^e)^2} \left( \overline{\chi} L H H H^\dagger + \frac{\alpha_2}{4\pi} \overline{\chi} \sigma_{\mu\nu} LW^{\mu\nu} H \right)
\]
Millicharged MDM

Automatically stable DM

No need to worry about higher order operators
Nor about Landau poles and cutoffs
In principle larger multiplets are possible

The millicharge $\epsilon$ must be small: only weak interactions matter
However, any $\epsilon \neq 0$ implies a **doubling of degrees of freedom**
This changes the relic density and therefore the DM mass
Also changes the bounds from indirect detection
Millicharged MDM

$\Omega_{DM} h^2$

DM mass in TeV

$0.1188 \pm 2\sigma$

Millicharge $\epsilon$

DM mass in TeV

Tight coupling

No DM in the disk

LUX
Millicharged MDM: Dirac singlet

\[ m_X \text{ (GeV)} \]

Bullet Cluster

NGC720 Ellipticity

Thermal Relic

Decoupling from DM virial process

Decoupling at Recombination epoch

arXiv:1011.2907
Millicharged MDM: Dirac triplet

excluded by HESS $\gamma$-line searches at 95% CL

All bounds to be multiplied by 2

arXiv:1401.6212
Millicharged MDM: Dirac quintuplet

All bounds to be multiplied by 2
Millicharged MDM: Complex scalar eptaplet

All bounds to be multiplied by 2

(SU(2)\textsubscript{L}-symmetric approximation)
Conclusions

MDM dead or close to discovery

MDM decays can give a handle on new physics scale

New host of millicharged MDM candidates to be probed
Backup slides
Majorana quintuplet

Fermion quintuplet with $Y = 0$
Majorana quintuplet

$\begin{align*}
\text{SU(2) Coupling Fraction } &\epsilon \\
\text{DM Mass } m_\chi [\text{GeV}] &
\end{align*}$
Summary of constraints (solid edge) and reaches (dashed edge)

Majorana quintuplet

$LHC$ - 8 TeV, 14 TeV

Antiprotons

MW diffuse - conservative, incl bkgd

$dSph$

MW line

GC line

$dSph$ line

$M_{DM} [TeV]$
Millicharged MDM

Fermion triplet with $Y \neq 0$ ('wino')

Fermion quintuplet with $Y \neq 0$

$\Omega_{\text{DM}} h^2$

$\Omega_{\text{DM}} h^2$

DM mass in TeV

DM mass in TeV

arXiv:1702.01141