WIMP Theory Review

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What do we know about DM?

- WIMPs
  - Effectively Neutral
  - Abundance of 25-27%
  - Stable
  - Weakly Interactive?
- Axions
  - may or may not be related to the strong QCD problem
- SIMPLe
  - related to a strong dynamics
  - See Sannino's talk
- KeV neutrinos
  - Ameliorate the missing satellite problem
Basic Concepts

A. dark matter particles could interact with standard model particles and reach thermal equilibrium. Non-thermal processes are also OK.

B. As the universe cools down and expands, eventually the expansion rate equals the interaction rate → freeze-out.

C. After the freeze-out the dark matter particles cluster forming the structures we observe today.

D. In the WIMP paradigm the abundance is straightforwardly connected to the annihilation cross section.

[Diagram: Dark Matter Abundance]

- **Time**
  - $t (ns)$
  - $m_x = 100$ GeV

- **Number density**
  - $\Omega_x$
  - $\Omega_x$

- **Temperature**
  - $T (GeV)$

- **Increasing Cross section**
Basic Concepts

A. There is a smooth halo of dark matter particles in our galaxy described by a Maxwell velocity distribution.  
(Kelso+, 1601.04725)

B. Due to the rotation of the Galactic Disk the solar system experiences an effective WIMP wind, which leads to an annual modulation due to Earth’s orbital motion.  
(Lee+, 1308.1953; Del Nobile+, 1512.03961)

C. The nucleus is described by the Helm form factor.  
(Fitzpatrick+, 1308.6288/1405.6690)

Differential scattering rate

\[ \frac{dR}{dE}(E, t) = \frac{\rho_0}{m_\chi \cdot m_A} \cdot \int v \cdot f(v, t) \cdot \frac{d\sigma}{dE}(E, v) \, d^3v \]

Velocity distribution

Differential cross section

Spin-Independent

\[ \sigma_0^{SI} = \sigma_p \cdot \frac{\mu_A^2}{\mu_p^2} \cdot [Z \cdot f^p + (A - Z) \cdot f^n]^2 \quad f^p = f^n \]

Spin-Dependent

\[ \sigma_0^{SD} = \frac{32}{\pi} \mu_A^2 \cdot G_F^2 \cdot \left[a_p \cdot \langle S^p \rangle + a_n \cdot \langle S^n \rangle \right]^2 \cdot \frac{J + 1}{J} \]
Basic Concepts

A. Dark matter is cosmologically stable, therefore is “seen” as missing energy at colliders, mono-X searches.

B. The observation relies on the detection of the accompanying particles/jets

For a scan over several simplified dark matter models see:

The ATLAS/CMS Dark Matter Forum, 1507.00966

Collider Searches

Note: New resonance searches provide stringent limits on new gauge bosons often used as mediators between the dark and visible sectors.
Basic Concepts

A. The dark matter particles might still be able to interact with standard model particles and produce an observable signal.

B. We know how to account for hadronization and final state radiation well up to the dark matter mass which can be very heavy.

\[
\frac{d\phi}{d\Omega dE} = \frac{\langle \sigma v_{\text{rel}} \rangle}{8\pi m^2_{\chi}} \frac{dN_\gamma}{dE} \times \int_{\text{l.o.s.}} ds \rho(\vec{r}[s, \Omega])^2
\]
WIMP Review -

Farinaldo Queiroz - MPIK

The Waning of the WIMP?
A Review of Models, Searches, and Constraints

arxiv:1703.07364
First Observation: Possible Evidence for Dark Matter Annihilation In The Inner Milky Way

Fermi-LAT Observations of High-Energy Gamma-Ray Emission Toward the Galactic Center

“After subtracting the interstellar emission and point-source contributions from the data a residual is found that is a sub-dominant fraction of the total flux”.

Fermi-LAT, 1511.02938

Is the GeV gamma-ray excess excluded by Dwarf Galaxies Data?

The best-fit regions can move downwards by a factor of two-three

With the recent discovery of several dwarf galaxies Fermi-LAT limit improved

The GeV excess probably will not be fully tested in the Fermi’s era
Other potential signals

Reticulum-II Dwarf Galaxy

Fermi-LAT collab. Reported a 2sigma upward fluctuation.
A. Geringer-Sameth+, 1503.02320

Subhalo in the Fermi-LAT Catalog

Gamma-ray emission roughly consistent with galactic center excess.
B. Bertoni+, 1602.07303

AMS-02

Excess in anti-protons
A. Cuoco+, 1704.08258
A. Cuoco+, 1610.03071
Search for Neutrino Lines with Gamma-rays

Neutrino telescopes have the advantage of being sensitive to both the WIMP-nucleus scattering and dark matter self-annihilation cross section.

Several searches for neutrinos flavors from dark matter annihilations have been conducted by Super-K, IceCube and ANTARES collab. as well as by independent groups.

Please notice that weak corrections are important and a neutrino final state also gives rise to a gamma-ray emission which can be probed by Fermi-LAT/H.E.S.S. instruments.

As for dark matter decays, neutrino telescopes remain the most promising instruments.

El Aisati et al, 151005008
A New Test Toward the Nature of WIMP Dark Matter

\[\sigma_{SI}^M = \frac{4\mu^2}{\pi} \left[ \lambda_p^M Z + \lambda_n^M (A - Z) \right]^2\]

\[\left[ \lambda_p^M Z_X + \lambda_n^M (A_X - Z_X) \right]^2 = \frac{\pi \tilde{\sigma}_X}{4\mu^2},\]

\[\left[ \lambda_p^M Z_Y + \lambda_n^M (A_Y - Z_Y) \right]^2 = \frac{\pi \tilde{\sigma}_Y}{4\mu^2}.\]

\[
\begin{align*}
A + B &= 10 \\
2A + B &= 15
\end{align*}
\]

find A and B

Exploit the fact that different isotopes lead to different solutions

<table>
<thead>
<tr>
<th>Nucleus</th>
<th>(Z/(A - Z))</th>
</tr>
</thead>
<tbody>
<tr>
<td>(\text{Xe})</td>
<td>0.69</td>
</tr>
<tr>
<td>(\text{Ge})</td>
<td>0.76</td>
</tr>
<tr>
<td>(\text{Si})</td>
<td>1.00</td>
</tr>
<tr>
<td>(\text{Ca})</td>
<td>1.00</td>
</tr>
<tr>
<td>(\text{I})</td>
<td>0.72</td>
</tr>
<tr>
<td>(\text{O})</td>
<td>1.00</td>
</tr>
<tr>
<td>(\text{Na})</td>
<td>0.92</td>
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<tr>
<td>(\text{Ar})</td>
<td>0.82</td>
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<tr>
<td>(\text{F})</td>
<td>0.90</td>
</tr>
<tr>
<td>(\text{W})</td>
<td>0.67</td>
</tr>
</tbody>
</table>

Arxiv:1706.07819
Conclusions

WIMP paradigm remains strong

There is a possible way (not easy) to determine the fundamental nature of WIMP dark matter

Let’s be Optimistic
A WIMP Model at the Neutrino Floor

couplings of order one
mediator of \(~10\text{GeV}\)

Backup slides

XENONnT full exposure
On the residual see by Fermi-LAT. Interestingly the trend is evident: each model over-predicts the data below $\sim 2$ GeV and underpredicts above $\sim 2$ GeV.