Constraining Dark Matter annihilation cross-sections with the CMB

Silvia Galli

IAP-Paris
**Motivations**

- **Anomalies**: excess in the positron electron fraction and in the energy spectrum of electrons.
- Several explanations: pulsar emission, dark matter decay, dark matter annihilation etc...

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**Positron Electron Fraction**

Adriani et al. 2009
Ackermann et al. 2011, Gaggero 2011

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**Electron Spectrum**

Adriani et al. 2009
Ackermann et al. 2011, Gaggero 2011

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Fermi Lat-collaboration arXiv:1008.3999
**Motivations**

→ Thermal production of DM:

\[ <\sigma v> \sim 3 \times 10^{-26} \text{ cm}^3/\text{s}. \] (WIMP)

→ Annihilation rate:

\[ \Gamma \propto n^2 <\sigma v> \]  

n from dm simulations, models, observations

Astrophysical or Particle Physics **BOOST** to explain the data.

Profumo, S. 2005, PRD, 72, 103521

Motivations

→ Thermal production of DM:

\[ <\sigma v> \sim 10^{-26} \text{ cm}^3/\text{s.} \ (\text{WIMP}) \]

→ Annihilation rate:

\[ \Gamma \propto n^2 <\sigma v> \]. \ n \text{ from dm simulations, models, observations} \]

**BOOST** of the cross section to explain the data, depends on mass of DM and **annihilation channel**.

Dark Matter annihilation should leave a signature in CMB:

→ At (z~1000), when CMB forms, the homogeneous dark matter density is \( n(z=1000) = n_{\text{today}} (1+z)^3 \sim n_{\text{today}} \times 10^9 \)

→ DM mean velocity \( \beta \sim 10^{-8} \). Favours Sommerfeld Enhancement.
DM annihilation in the recombination epoch

\[
\frac{dE}{dt} = \rho c^2 \Omega_{DM}^2 (1+z)^6 f(z) \frac{\langle \sigma v \rangle}{m_X}
\]

- The CMB can only constrain \( p_{\text{ann}} \), which is the combination of \( f(z) \), i.e. the fraction of DM annihilation energy that goes into the plasma, of the cross section and of the mass.

- \( f(z) \) depends on model, mass of dm, annihilation channel, redshift.

\begin{align*}
\text{Primaries} & : W^\pm, b\bar{b}, Z, h, \tau^\pm, e^\pm, ... \\
\text{Final Products} & : p\bar{p}, \nu\bar{\nu}, e^\pm, \gamma
\end{align*}
Free Electron Fraction (constant $f$)

$\rho_{\text{ann}} = 1 \times 10^{-5}$

$\rho_{\text{ann}} = 5 \times 10^{-6}$

$\rho_{\text{ann}} = 1 \times 10^{-6}$

$\rho_{\text{ann}} = 0$

$p_{\text{ann}} [\text{m}^3/\text{s}/\text{Kg}]$
CMB Angular Power Spectra

Temperature TT

Polarization EE

Cross Temp-Pol TE
Results on DM annihilation with constant $f$

\[ p_{\text{ann}} = \frac{f \langle \sigma v \rangle}{m_\chi} \]

- Wmap5 data already puts stringent constraints on the cross section/mass, i.e. on the properties of dark matter particles.
- WMAP7 improves of a factor 1.4, thanks to better measurements at higher $l$ in TT, TE.
- Dark Matter models favoured by Pamela almost excluded by WMAP.
- Planck will improve results thanks to polarization data.

\[
\begin{align*}
    p_{\text{ann}}[m^3/s/Kg] & \text{ at } 95\% \text{ c.l.} \\
    \text{WMAP5} & < 2.0 \times 10^{-6} \\
    \text{WMAP7} & < 1.4 \times 10^{-6} \\
    \text{WMAP7+ACT} & < 1.2 \times 10^{-6} \\
    \text{Planck} & < 1.7 \times 10^{-7} \\
    \text{CV1} & < 5.9 \times 10^{-8}
\end{align*}
\]
Improving the constraints: $f(z)$

$$\frac{dE}{dt} = \rho_c^2 c^2 \Omega_{dm} (1+z)^6 f(z) \frac{\langle \sigma v \rangle}{m_\chi}$$

$f(z)$ depends on the mass, model and annihilation channel of the DM particle considered.

Slatyer et al. 2009
**A second approach: constraints with variable $f(z)$**

For each specific $f(z)$ one can set constraints on the cross-section.

**Constraints on $\langle \sigma v \rangle$ [cm$^3$/s] using WMAP7+ACT**

<table>
<thead>
<tr>
<th>$m_\chi$</th>
<th>channel</th>
<th>Variable $f(z)$</th>
<th>Constant $f$</th>
<th>$f(z = 600)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 GeV</td>
<td>$e^+e^-$</td>
<td>$\leq 2.41 \times 10^{-27}$</td>
<td>$\leq 2.41 \times 10^{-27}$</td>
<td>0.87</td>
</tr>
<tr>
<td>100 GeV</td>
<td>$e^+e^-$</td>
<td>$\leq 3.55 \times 10^{-25}$</td>
<td>$\leq 3.35 \times 10^{-25}$</td>
<td>0.63</td>
</tr>
<tr>
<td>1 TeV</td>
<td>$e^+e^-$</td>
<td>$\leq 3.80 \times 10^{-24}$</td>
<td>$\leq 3.48 \times 10^{-24}$</td>
<td>0.60</td>
</tr>
</tbody>
</table>

$$\frac{dE}{dt} = \rho_c^2 c^2 \Omega_{dm} (1 + z)^6 f(z) \frac{\langle \sigma v \rangle}{m_\chi}$$

$$\langle \sigma v \rangle = \frac{p_{ann}^\text{const}}{f(z = 600)} m_\chi$$

For WMAP7 and WMAP7+ACT, knowing the overall normalization $f(z=600)$ is sufficient. This might not be the case for Planck!

A general approach to \( f(z) \): Principal Components

1) For each experiment (WMAP, Planck, CVL etc...) find a basis of deposition histories using PCA.
2) Measure the amplitude of the best measurable principal components with the data.
3) Reconstruct back the deposition histories

\[
p_{ann}(z) = f(z) \frac{<\sigma \nu>}{m_\chi} = \sum_{i=1}^{N} \varepsilon_i e_i(z)
\]

\[
= \varepsilon_1 + \varepsilon_2 + \varepsilon_3 + \ldots
\]

Best determined

Worst determined

Detectability of PC's with future experiments

Assuming a dark matter annihilation signal at the 2-sigma current WMAP7 bound, Planck could detect up to 3 PC's. A CVL experiment would detect ~6 PC's.

Conclusions on Dark Matter annihilation

- **CMB** is a very good DM annihilation probe, independent from the knowledge of DM distribution.
- **WMAP** already puts strong constraints, that are already used to rule out DM models that fit Pamela data.
- We provided a general accurate approach to model the problem.
- **Planck** will need this accurate approach. It will improve constraints by one order of magnitude thanks to polarization measurements.