The Recombination epoch of the Universe with dark matter: constraints on self-annihilation cross sections

Silvia Galli
Outline

• Motivations:
  • Pamela, Atic, Fermi + study of recombination model

• Theory:
  • Standard Recombination
  • Non standard Recombination: general case
  • NSR with DM annihilation

• Results
  • Constraints from WMAP5
  • Constraints from future experiments.

• Conclusions
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...

![Positron Electron Fraction](image1)

![Electron Spectrum](image2)

E. Mocchiutti et al.  
arXiv:0905.2551v1  
Pamela

Latronico et al. (Fermi Lat-collaboration)  
arXiv:0907.0452v1  
Atic, Fermi
Motivations

→ Thermal production of DM:
  \[ <\sigma v> \sim 10^{-26} \text{cm}^3/\text{s.} \] (WIMP)

→ Annihilation rate:
  \[ \Gamma \propto n^2 <\sigma v> \] \(n\) from dm simulations, models, observations

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

→ Thermal production of DM:

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

→ Annihilation rate:

\[ \Gamma \propto n^2 <\sigma v> \]. n 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 homogenous 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.
Standard Recombination

\[
\text{He}^+ + e^- \rightarrow \text{He} + \gamma
\]

\[
\text{He}^{++} + e^- \rightarrow \text{He}^{+} + \gamma
\]

\[
H^+ + e^- \rightarrow H + \gamma
\]

\[
x_e = \frac{n_e}{n_H}
\]

T = 3000K
z = 1000

Hu & White (2004), artist B. Christie/SciAm; available at http://background.uchicago.edu
Physics of recombination (Peebles (1968) and Zeldovich, Kurt & Sunyaev (1968))

Direct Recombination but NO NET recombination

\[ H_{1s} + \gamma \leftrightarrow H^+ + e^- \]

2-photon decay from metastable 2s states

\[ H^+ + e^- \leftrightarrow H_{2s} + \gamma \]

\[ H_{2s} \leftrightarrow H_{1s} + 2\gamma \]

Cosmological redshift of the Lyman alpha photons

\[ H^+ + e^- \leftrightarrow H_{2p} + \gamma \]

\[ H_{2p} \leftrightarrow H_{1s} + \gamma \]
Extra Lyman Alpha and ionizing photons in recombination: not only from dark matter

- Lyman alpha and ionizing photons are the most important in changing recombination
- Several possible Sources of extra ionizing and Lyman Alpha photons:


**Cosmic string decays, magnetic monopoles etc...**
Extra Ionizing and Lyman-alpha photons

- First approximation: constant injection of photons.
- Two parameters added to Standard Model

Extra Lyman-alpha photons

\[ \frac{dn_{\alpha}}{dt} = \varepsilon_{\alpha} n_H \ H(z) \]

Extra ionizing photons

\[ \frac{dn_i}{dt} = \varepsilon_i n_H \ H(z) \]
1) There is still room to believe in non standard recombination!
2) Results for Planck are valid if recombination is known less than percent level.

S. Galli, R. Bean, A. Melchiorri, J. Silk
Testing a specific Model:
Dark Matter annihilation

- Lyman alpha and ionizing photons affects $x_e$ and $T$

\[ \frac{dE}{dt} = \rho_c^2 c^2 \Omega_{DM} (1+z)^6 \left[ f \frac{\langle \sigma v \rangle}{m_\chi} \right] \]

Redshift dependence of the injection rate of Lyman alpha ($\varepsilon_{\alpha}$), ionizing ($\varepsilon_i$) photons and heating term that changes matter temperature

\[
\varepsilon_{\alpha}(z) = C \chi_{\alpha} \frac{dE}{dt} \frac{1}{n_H(z) E_{\alpha} H(z)}
\]

\[
\varepsilon_i(z) = C \chi_i \frac{dE}{dt} \frac{1}{n_H(z) E_i H(z)}
\]

\[
\kappa_h = \chi_h \frac{dE}{dt} \frac{1}{n_H(z)}
\]

Energy injection rate

One new parameter that contain:
- $f$ = energy fraction to plasma
- $\langle \sigma v \rangle$ = cross section
- $m_\chi$ = mass of the annihilating particle
CMB Angular Power Spectra

- Temperatura TT
- Polarizzazione EE
- Cross Temp-Pol TE
Results on dark matter annihilation

Constraints on the $p_{\text{ann}}$ parameter = fraction of DM annihilation energy that goes into the plasma times DM cross section divided by DM mass using Wmap5 data, Planck mock and a hypothetical Cosmic Variance limited experiment

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

<table>
<thead>
<tr>
<th>Experiment</th>
<th>$p_{\text{ann}}$ 95% c.l.</th>
</tr>
</thead>
<tbody>
<tr>
<td>WMAP</td>
<td>$&lt; 2.4 \times 10^{-6}$ m$^3$/s/kg</td>
</tr>
<tr>
<td>Planck</td>
<td>$&lt; 1.7 \times 10^{-7}$ m$^3$/s/kg</td>
</tr>
<tr>
<td>CVl</td>
<td>$&lt; 5.9 \times 10^{-8}$ m$^3$/s/kg</td>
</tr>
</tbody>
</table>

Coupling with gas: constant $f$

- Assuming constants $f=0.5$
- Runs with a more proper redshift-variable coupling with the plasma are on going.
- Depends on annihilation channel, mass of the particle (Based on T.R. Slatyer, N. Padmanabhan, P. D. Finkbeiner, arXiv:0906.1197)
Future constraints (preliminary results)


- Adding lensing extraction will improve Planck data by 10%.

- ACT will measure TT till $l_{\text{max}} \sim 2500$ and EE~till $l_{\text{max}} \sim 3500$ due to foregrounds. ACT will improve Planck Data by 20%.

- CMBpol with lensing extraction will constrain DM annihilation to a level comparable to the CVI case.

<table>
<thead>
<tr>
<th>Experiment</th>
<th>$\rho_{\text{ann}}$ 95% c.l.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Planck</td>
<td>$&lt; 1.5 \times 10^{-7}$ m$^3$/s/kg</td>
</tr>
<tr>
<td>Planck+ACT</td>
<td>$&lt; 1.2 \times 10^{-7}$ m$^3$/s/kg</td>
</tr>
<tr>
<td>CMBpol</td>
<td>$&lt; 6.3 \times 10^{-8}$ m$^3$/s/kg</td>
</tr>
</tbody>
</table>

Squares: PAMELA only. Diamonds: PAMELA and Fermi. Crosses: PAMELA and ATIC

Red data points taken from:
P. Grajek, et al. (2008), 0812.4555.
I. Cholis, et al. (2008), 0811.36
Slatyer, T.~R. et al. (2009), PRD, 80, 043526

Dependence on the Recombination knowledge

- All the constraints presented assumes a perfect knowledge of recombination.

Difference between recfast 1.4 and 1.5

Rubiño-Martín J. A. et al., arxiv:0910.4383v1
Conclusions

- CMB is a very interesting probe for dark matter annihilation.
- The interpretation of the Pamela, Atic and (Fermi) anomalies seems to be disfavoured by CMB data.
- The Planck Forecast suggests that there will be an improvement of 1 order of magnitude on the constraints.
- All the results are based on the assumption that we perfectly know standard recombination. This is not completely true!
Standard Recombination

$xe = \frac{n_e}{n_H}$

$T = 3000K$
$z = 1000$

$CMB$

Hu & White (2004), artist B. Christie/SciAm; available at http://background.uchicago.edu
Extra Ionizing and Lyman-alpha photons

- First approximation: constant injection of photons.
- Two parameters added to Standard Model

\[
\frac{dn_\alpha}{dt} = \varepsilon_\alpha n_H H(z)
\]

\[
\frac{dn_i}{dt} = \varepsilon_i n_H H(z)
\]

\[
- \frac{dx_e}{dt} = \left. \frac{dx_e}{dt} \right|_{std} - C \varepsilon_i H - \left(1 - C\right) \varepsilon_\alpha H
\]

Transparency of the Universe & structure formation

HE shower gets efficiently absorbed only at high $z$

Structure formation takes place in a late Universe ($z < 60$)

Credit: Fabio Iocco