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Bounds on DM annihilations from 21cm data

based on GDA, Panci, Strumia
arXiv: 1803.03629

Probing fundamental physics with CMB spectral distortions
16/3/2018
Outline

• What did EDGES see?
• Quick physics of the 21cm line
• A short history of the IGM
• Dark Matter annihilations
• Bounds
• Outlook
What did EDGES see?

- A 21cm signal in absorption
- Between redshifts ~20 and 15
- Amplitude twice as large as predicted (~500 mK vs. ~200mK)
What did EDGES see?

Bowman et al., Nature, 2016
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What is this 21 cm line?

- Triplet-to-singlet transition of 1s level of atomic hydrogen
- Define spin temperature by \( \frac{n_1}{n_0} = 3e^{-T_*/T_S} \)
- What sets the relative occupation?
**Excitement by what?**

1. Absorption of background CMB light
2. Collisions: important when density is high
3. Ly-α pumping (Wouthuysen ’52, Field ‘59)

- Equilibrium implies

\[ n_1(C_{10} + P_{10} + A_{10} + B_{10}I_\gamma) = n_0(C_{01} + P_{01} + B_{01}I_\gamma) \]

- In terms of temperatures

\[ T_S^{-1} = \frac{T_\gamma^{-1} + x_c T_{gas}^{-1} + x_\alpha T_\alpha^{-1}}{1 + x_c + x_\alpha} \]
\[ \delta T_b \approx 21 \text{mK} \, x_{H_1} \left(1 - \frac{T_y}{T_S}\right) \sqrt{\frac{1 + z}{10}} \]
A short history of the IGM

- At $z \sim 1100$, CMB and IGM *kinetically decouple*: the Universe becomes neutral.

- However, temperatures are still the same, because of efficient Compton scattering.

- Finally, around $z \sim 150$, IGM *thermally decouples*: it thereafter cools down as $T_{IGM} \sim a^{-2}$.

- At some point, lights turn on: X-rays and Ly-α photons go around the Universe, heat the IGM, finally reaching $T_{IGM} > T_{CMB}$.

- Reionization: the Universe becomes ionized again, no HI anymore.
A figure is better

Pritchard & Loeb 2011
(1109.6012)
A short history of $T_S$

- Nothing happens until IGM thermally decouple, temperatures are all the same, zero signal
- After $z \sim 200$ until $z \sim 30$, collisions keep $T_S \sim T_{IGM}$: since the IGM is colder, I have a signal in absorption
- After, no collisions, no other radiation: $T_S \sim T_{CMB}$, and I have zero signal
- And then? At some point, Ly-$\alpha$ photons recouple $T_S \sim T_{IGM}$, so I start decreasing $\delta T_b$ and I get absorption
- Finally, as $T_{IGM}$ goes up, I increase $\delta T_b$ and get an emission until signal finally dies after full reionization
Example history and signal

Ly$\alpha$ start recoupling $T_{\text{gas}}$ and $T_S$

Collisions become ineffective

From absorption to emission

Reionization kills the signal

$X$-rays start heating the gas

Taylor et al. 2012 (1206.6733)
Evolution with annihilating DM

\[ \frac{dT_{\text{gas}}}{dt} = -2HT_{\text{gas}} + H\gamma C\left(T_{\gamma}(z) - T_{\text{gas}}\right) + \]
\[ + \frac{dE}{dV dt} \frac{1 + 2x_e}{3n_H} \frac{2}{3(1 + x_e + f_{\text{He}})} \]

\[ \frac{dxe}{dt} = \mathcal{P}_2 \left[ -\alpha_H(T_{\text{gas}})n_H x_e^2 B + \beta_H(T_{\text{gas}})e^{-E_\alpha/T_{\text{gas}}} (1 - x_e) \right] + \]
\[ + \frac{dE}{dV dt} \frac{1 - x_e}{3n_H} \left( \frac{1}{E_0} + \frac{1 - \mathcal{P}_2}{E_\alpha} \right) \]

\[ \frac{dE}{dV dt} = \rho_{\text{DM}}^2 B f_{\text{DM}}^2 f_{\text{eff}} \frac{\langle \sigma v \rangle}{M_{\text{DM}}} \]
How do we put bounds

• Signal is lower than expected. *We do not try to explain it!*

• DM can (and will if it’s thermal) annihilate into SM: as any energy injection, it will heat the IGM, so $\delta T_b$ increases

• Hence, we can infer bounds. But we cannot use the observed signal: already the standard model is out at 3.8$\sigma$...

• Our strategy: assume standard evolution, $T_S = T_{IGM}$ to get strongest absorption, $\delta T_b \approx -200$ mK. *What should I require of DM to get heated to no more than 50% $\delta T_b$ or 25% $\delta T_b$?*
Our bounds

Bounds from Planck 2015
Efficiency factors

![Graph showing efficiency factors for different processes against DM mass. The graph plots the efficiency factor $f_{\text{eff}}$ against the DM mass (GeV). The processes include $e^+e^-$, $\gamma\gamma$, $b\bar{b}$, and $\mu^+\mu^-$.](image-url)
Our bounds, more explicitly

$T_{21} \simeq -100 \text{ mK}$

$\langle \sigma v \rangle_{\text{cosmo}}$
Outlook

• We (hopefully) have started probing the Universe by 21cm

• DM annihilation is an heat source: it can be seen in the signal

• In general, one should consider both scattering and annihilations when analyzing DM models

• Some uncertainty from astrophysics, may be constrained by full shape of observed signal

• Can the monopole 21 cm alone shed light on dark matter?
Thank you!