UNLOCKING THE MYSTERIES OF THE FIRST STARS AND DARK MATTER

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21-cm Cosmology

\[ T_{21} = 26.8 x_{\text{HI}} \frac{\rho_g}{\bar{\rho}_g} \left( \frac{\Omega_b h}{0.0327} \right) \left( \frac{\Omega_m}{0.307} \right)^{-1/2} \left( \frac{1 + z}{10} \right)^{1/2} \left( \frac{T_S - T_{\text{CMB}}}{T_S} \right) \text{ mK} \]

- Cosmic Reionization
- Cosmic Dawn
  - Lyman-\( \alpha \) Coupling
  - Cosmic Heating (X-rays)

![Diagram showing parallel and opposite spins with wavelengths labeled as Ly\( \alpha \), X-rays, and UV.]

Parallel spins: higher-energy configuration

Opposite spins: lower-energy configuration

Photon, wavelength = 21 cm
Global 21-cm Experiments

SARAS

EDGES high

LEDA
Global 21-cm

193 parameter combinations

Cohen, Fialkov, RB, & Lotem 2017
$1 + z_{\text{max}}^{lo}$

(Hot gas, No reion)

$\tau = 6 - 7.5\%$ ○

8 – 9% △

9 – 11% x

Cohen, Fialkov, RB, & Lotem 2017
High-z Max  
Low-z Max  
\[ \tau = 6 \text{ – } 7.5\% \circ \]  
\[ 8 \text{ – } 9\% \ \triangle \]  
\[ 9 \text{ – } 11\% \ \times \]  
(\text{Hot gas, No reion})  

Cohen, Fialkov, RB, & Lotem 2017
EDGES-Low
EDGES-Low

Based on:
Bowman et al. 2018
\[ \left( \frac{T_s - T_{\text{CMB}}}{T_s} \right) \]

\[ m_\chi < \text{a few GeV} \]

RB, Nature 2018

ACE

Nenufar

DM cooling fluctuations only

Fialkov,
RB, Cohen,
PRL 2018
Alternative explanation

\[
\left( \frac{T_S - T_{\text{CMB}}}{T_S} \right) \quad T_{\text{rad}}
\]

Bowman et al. 2018
Feng & Holder 2018

10% of extragalactic radio excess

Subrahmanyan & Cowsik 2013

Realistic Galactic modeling => no excess.

Mirocha & Furlanetto 2018: \( \varepsilon \times 10^3 \)
Alternative explanation

$k=0.1 \text{ Mpc}^{-1}$

- DM cooling
- Regular models
- Extra radio

Fialkov & RB 2019
Alternative explanation

Fialkov & RB 2019
21-cm Tomography

\[ \Delta T_b [\text{mK}] \]

\[ 1 + z \]

R=20 Mpc

Banet, RB, Fialkov, Guttman 2019
21-cm Tomography

\[ \Delta T_b [\text{mK}] \]

- Standard case
- Low efficiency case

\[ 1 + z \]

R = 20 Mpc

Banet, RB, Fialkov, Guttman 2019
21-cm Tomography

$\Delta T_b [\text{mK}]$

$1 + z$

R=20 Mpc

Banet, RB, Fialkov, Guttman 2019
Summary

21-cm Cosmology
- Epoch of Reionization and Cosmic Dawn

EDGES-Low
- Very strong absorption
- Gas cooled by dark matter
- Or: enhanced radio background

Tomography
- Spherical averages
- Non-Gaussianity