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Radiation Injection as a Solution to the EDGES 21 cm Anomaly

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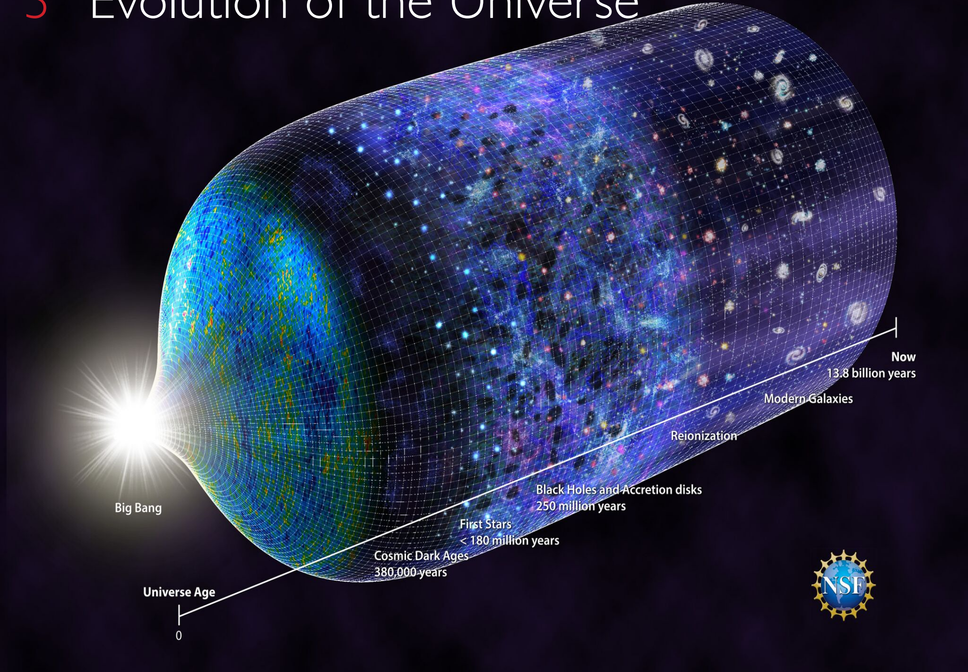
arXiv:1803.03245

Planck 2018, Bonn ✧ May 24, 2018

2 EDGES Signal from Cosmic Dawn

- The EDGES radio telescope has detected a signal from the cosmic dawn
- The absorption in the 21 cm signal at $z = 17$ is unexpectedly strong

3 Evolution of the Universe



4 Intensity of the Signal

The intensity of the 21 cm signal is proportional to

$$\delta T \propto 1 - \frac{T_R(z)}{T_S(z)} \approx 1 - \frac{T_R(z)}{T_K(z)}$$

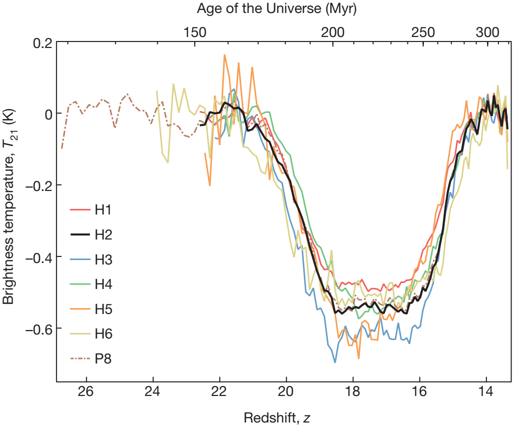
due to Lyman-α

- If $T_R > T_S$ then $\delta T < 0$: absorption
- If $T_R < T_S$ then $\delta T > 0$: emission

5 Changes in T_S

- Scattering with gas,
  free electrons & protons ($T_S \to T_K$)
- Interaction with the soft
  radiation background ($T_S \to T_R$)
- Interaction with UV-photons,
  mainly Lyman-α ($T_S \to T_L \approx T_K$)

6 EDGES Signal



Bowman 2018

$$\delta T_{\rm EDGES} = -500^{+200}_{-500}\ \text{mK}, \quad \delta T_{\Lambda\rm CDM} = -200\ \text{mK}$$

7 Possible explanations

$$\delta T \propto 1 - \frac{T_R(z)}{T_S(z)} \approx 1 - \frac{T_R(z)}{T_K(z)}$$

- Cool hydrogen by scattering with dark matter; keep $T_R = T_{\mathrm{CMB}}$
- Increase soft photon background $T_R > T_{\mathrm{CMB}}$

8 Cooling of Hydrogen T_S?

- New baryon-dark matter velocity dependent interaction with $\sigma \propto \frac{1}{v^4}$
- Enhanced at the dark ages – the coldest ever era of the Universe

Barkana 1803.06698

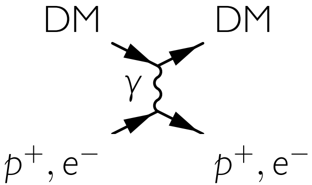
9 Cooling of Hydrogen T_S?

- Milli-charged dark matter fraction O(1%)

  Muños & Loeb 1802.10094

- Momentum transfer cross section

$$\sigma_t = x_e \frac{2\pi\alpha^2\varepsilon^2\xi}{\mu_{\xi,t}^2 v^4}$$



- E.g. $m_{\mathrm{DM}} = 10$ MeV, $f_{\mathrm{DM}} = 0.1$, $\varepsilon = 10^{-6}$

Cooling of Hydrogen T_S?

- Scattering only on ionised fraction of gas $x_e \approx 10^{-4}$
- EDGES requires

$$\sigma_t(z = 20) = 4 \times 10^{-12}\ \mathrm{cm}^2$$

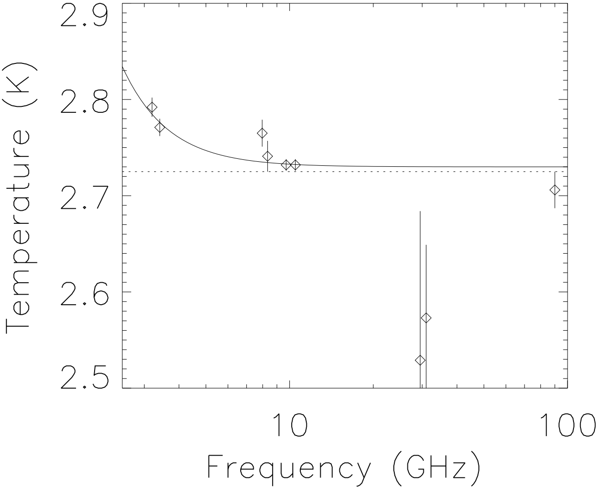
- Scaling to recombination ($z = 1100$) with $x_e = 1$ gives

$$\sigma_t(z = 1100) = 5 \times 10^{-20}\ \mathrm{cm}^2,$$

  much larger than the CMB bound $10^{-26}\ \mathrm{cm}^2$ for $m_{\mathrm{DM}} = 10$ MeV
- Barely possible for $10 \times$ smaller f_{DM}

Berlin et al. 1803.02804

Raising of Radiation T_R?



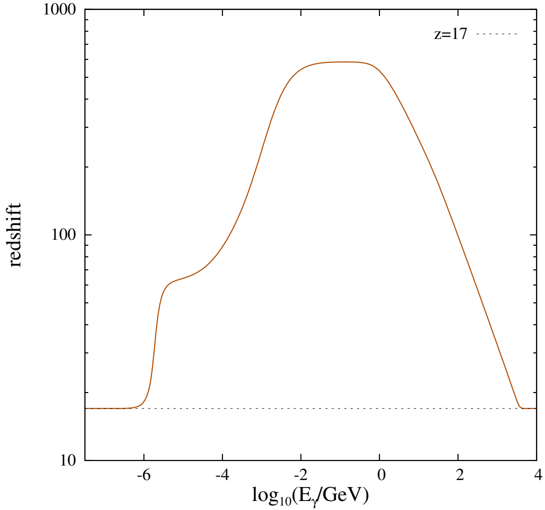
ARCADE2 did measure a photon excess…

Fixsen et al. 0901.0555

12 Raising of Radiation T_R

- Difficult: need to avoid extra heating of hydrogen gas
- The amount of soft photons in the $65 - 90 \times (1 + z)$ MHz ranges must be approx. doubled

13 Photosphere at $z = 17$

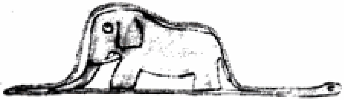


- For a wide spectrum ($I \approx \nu^{-1}$), lots of radiation is absorbed and heats the gas in the UV

14 Photosphere at $z = 17$

I showed my masterpiece to the grown-ups and asked them if my drawing frightened them.

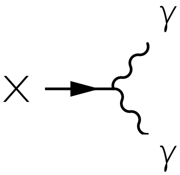
They answered: 'Why should anyone be frightened by a hat?' My drawing did not represent a hat. It was supposed to be a boa constrictor digesting an elephant. So I made another drawing of the inside of the boa constrictor to enable the grown-ups to understand. They always need explanations. My drawing No. 2 looked like this:



15 Raising of Radiation T_R

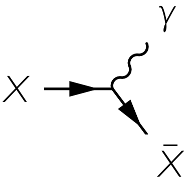
- Annihilation or decay of light WIMPs?
- Axions, ALPs, light oscillating spin-2 dark matter, light excited dark matter

16 Raising of Radiation T_R



Dark matter decay

$E_\gamma = m_X/2$



Dark matter de-excitation

$E_\gamma = m_X - m_{\bar{X}}$

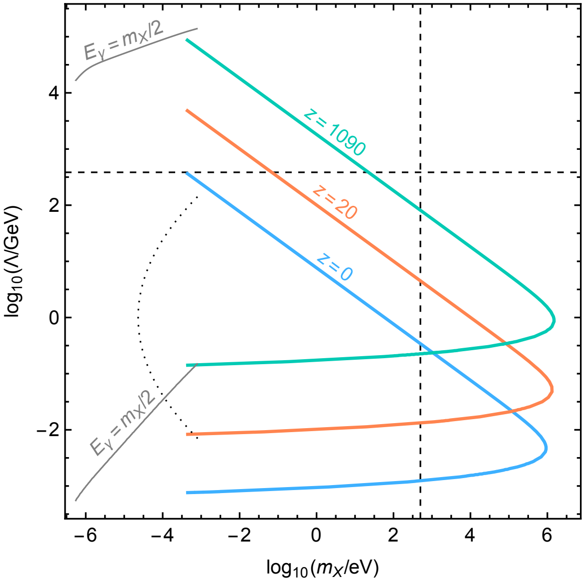
We parameterise

$$\Gamma_X = \frac{E_\gamma^3}{\Lambda^2}$$

Photons must be in the energy window

3×10^{-7} eV $< E_\gamma < 4 \times 10^{-4}$ eV *today*

Raising of Radiation T_R



Raising of Radiation T_R: Scalar DM

$$\frac{1}{4} g_V X F^{\mu\nu} F_{\mu\nu} + \frac{1}{4} g_A X F^{\mu\nu} \tilde{F}_{\mu\nu}$$

The corresponding decay width is

$$\Gamma_X = \frac{E_\gamma^3}{8\pi} (g_V^2 + g_A^2)$$

with $E_\gamma = m_X/2$

- Axion-photon coupling is severely constrained by helioscope experiments: $g_A, g_V \ll 10^{-10}\,\mathrm{GeV}^{-1}$
  Patrignani et al. (PDG) 2016; Inoue et al. 0806.2230;
  Masso & Toldra hep-ph/9503293
- Implied $\sqrt{8\pi/(g_V^2 + g_A^2)} = \Lambda > 10^{10}\,\mathrm{GeV}$ is much larger than $\Lambda < 10^5\,\mathrm{GeV}$ needed

Raising of Radiation T_R: Spin-2 DM

- $\mathcal{L} \supset \frac{a}{M_P} X_{\mu\mu} T^{\mu\nu}_{EM}$ and $\Gamma_X = \frac{E_{\gamma^3}}{10\pi} \frac{a^2}{M_P^2}$ with $E_\gamma = m_X/2$
- Fifth force searches require $a \leq 10^{-2}$ for $m_X \leq 10^{-3}$ eV, implying $\Lambda > 10^{21}$ GeV

Raising of Radiation T_R: Excited DM

$$-\frac{i}{2}F_{\mu\nu}\bar{X}\sigma^{\mu\nu}(\mu_X + d_X\gamma^5)\tilde{X} + \text{h.c.} \quad \text{with} \sigma^{\mu\nu} \equiv i[\gamma^\mu, \gamma^\nu]/2$$

- Decay rate into photons

$$\Gamma_X = \frac{E_\gamma^3}{\pi}(\mu_X^2 + d_X^2)$$

  with $E_\gamma = m_X - m_{\tilde{X}}$

- EW precision measurements imply $\Lambda > 400$ GeV or $m_X < 20$ eV: DM decouples too late and is too warm Sigurdson et al. astro-ph/0406355

Enhanced ALP Collective Decay

- Enhanced collective decay (parametric resonance)
- Gravitationally bound ALP mini-clusters that explode into photons

  Tkachev 1986; Hogan 1988; Kolb 1993; Tkachev 2014
- Mini-clusters of ALPs with mass in the $10^{-6} - 10^{-3}$ eV range

22 Enhanced ALP Collective Decay

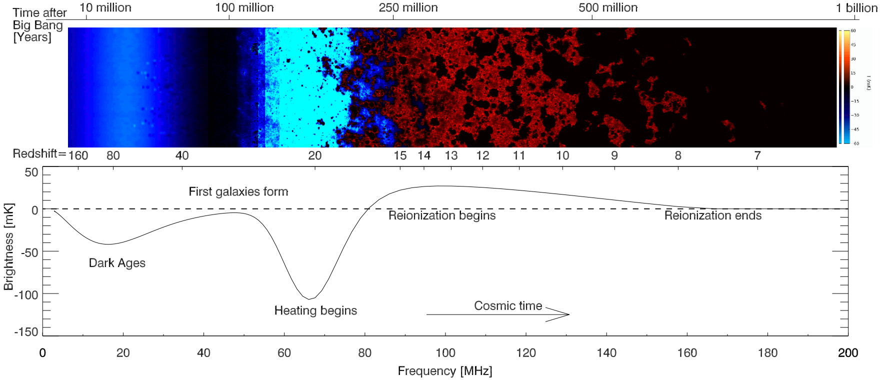
When you have eliminated all which is impossible, then whatever remains, however improbable, must be the truth.

—Sherlock Holmes

Conclusions

- The EDGES 21 cm measurement hints at new physics
- Cooling hydrogen by dark matter scattering may be possible but highly constrained
- Injection of energy into radiation – perhaps by enhanced decay of very light dark matter – looks like a better solution

Cosmological 21 cm Signal



Pritchard & Loeb 2011