The EDGES 21cm Anomaly and Properties of Dark Matter

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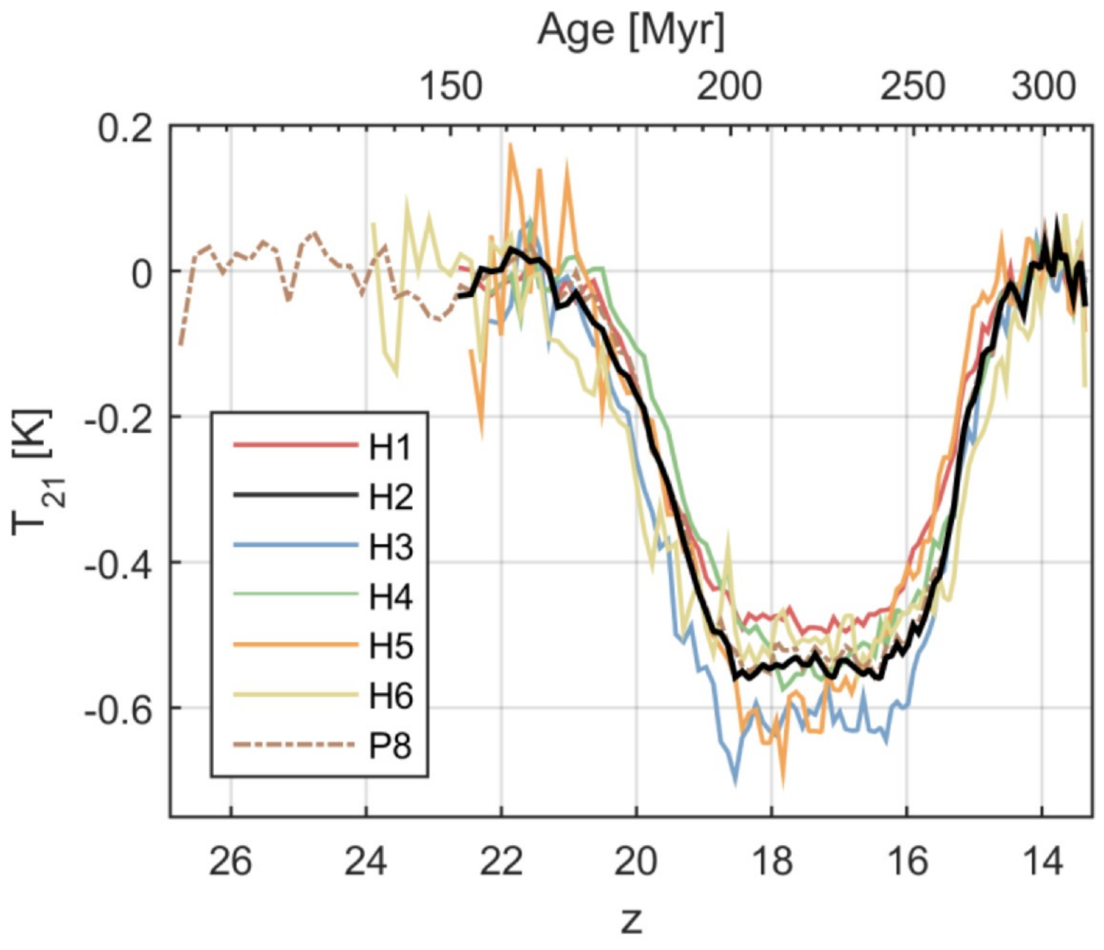
arXiv:1803.03245
arXiv:1803.09697

EDGES measured the 21 cm absorption signal



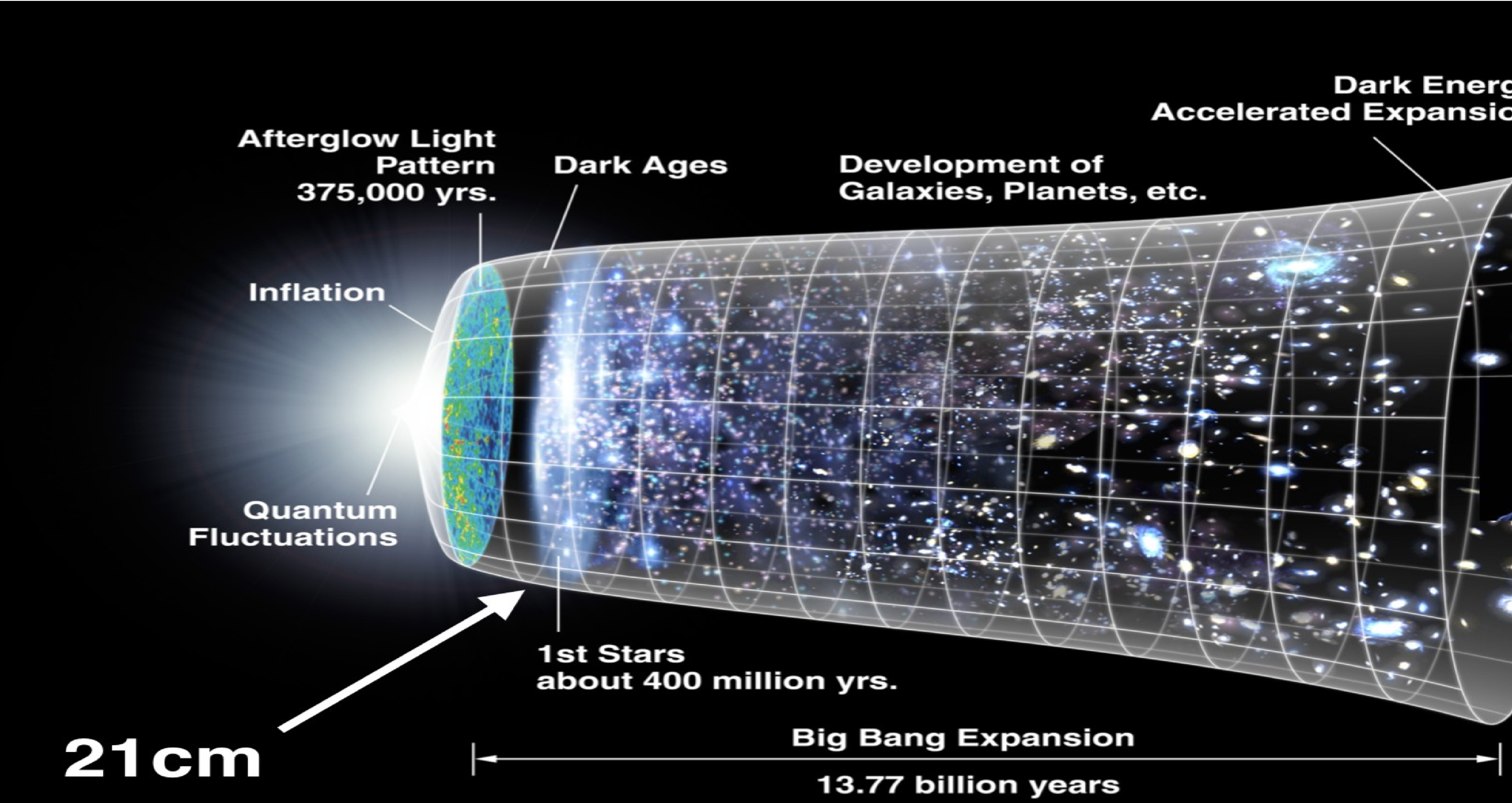
Nature 555 (2018) no.7694, 67-70

My plan today:

- Give a particle physicist review of 21 cm physics

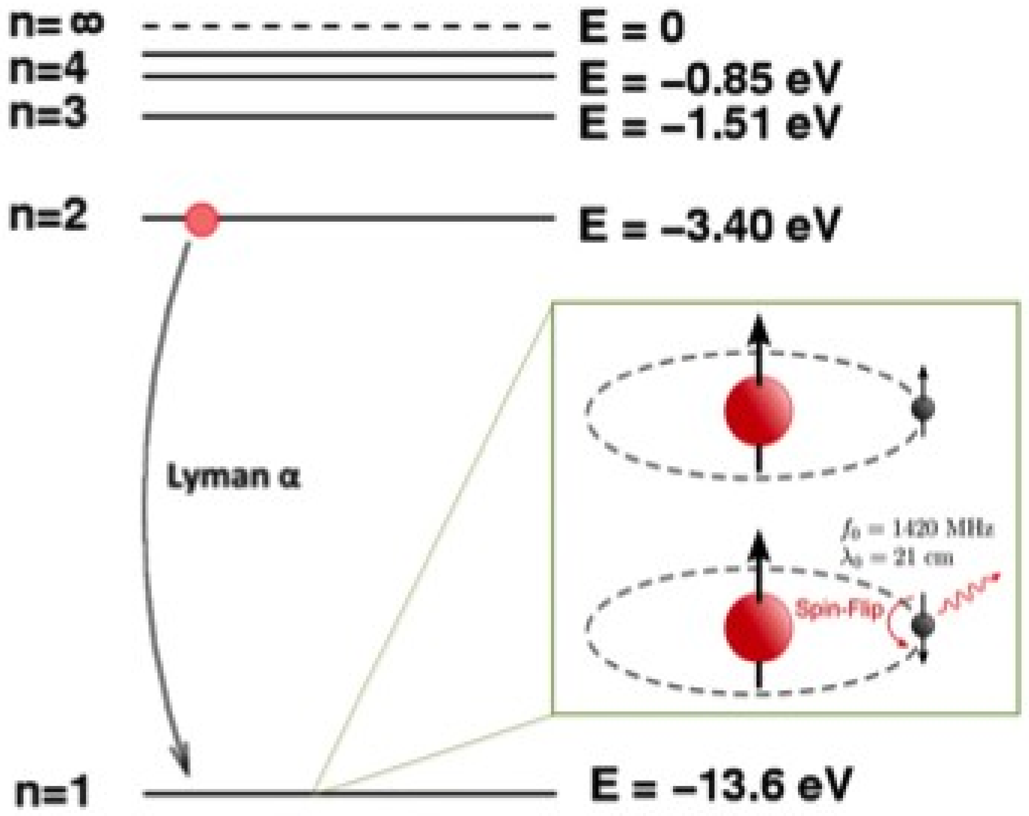
- Claim that the most natural NP explanation to the anomaly might require new soft photon background

Phys.Lett. B785 (2018) 159-164, arXiv:1803.03245


Dark Energ
Accelerated Expansio
Afterglow Light
Pattern
375,000 yrs.
Dark Ages
Development of
Galaxies, Planets, etc.
Inflation
Quantum
Fluctuations
1st Stars
about 400 million yrs.
Big Bang Expansion
13.77 billion years
21cm

The 21 cm line of hydrogen

- Hyperfine splitting of hydrogen 1s



$$\lambda = 21\,\mathrm{cm}$$

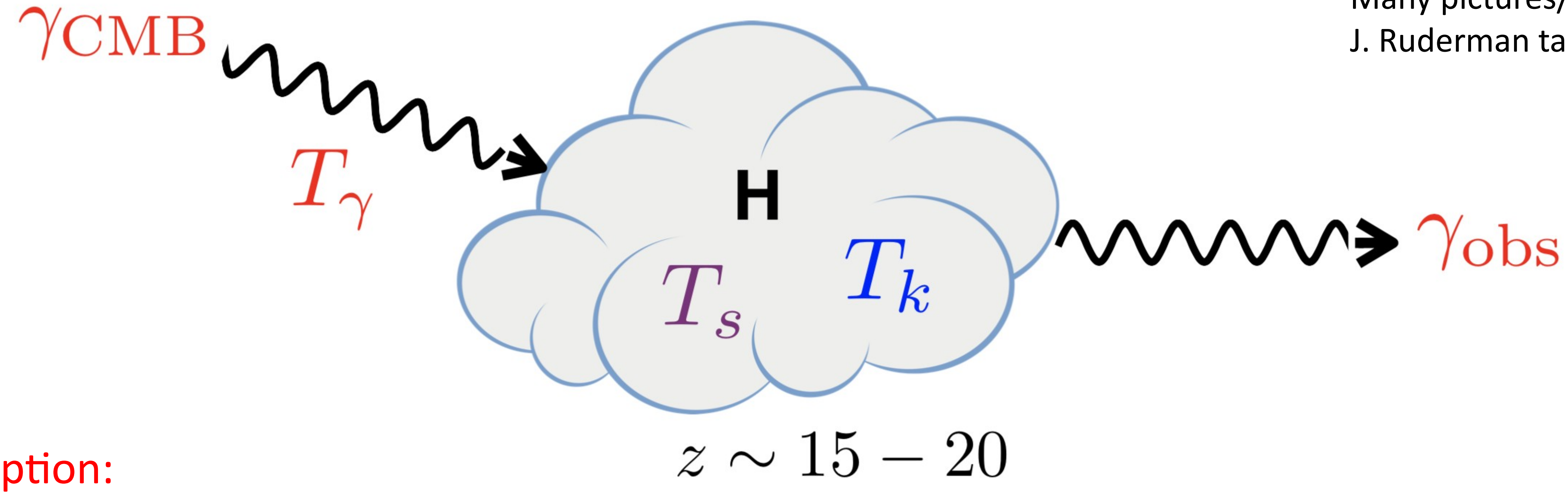
$$\omega_{21} = 5.9\,\mu\mathrm{eV}$$

Spin temperature:

$$\frac{n_t}{n_s} = 3\,e^{-\omega_{21}/T_S}$$

What is actually measured in absorption?

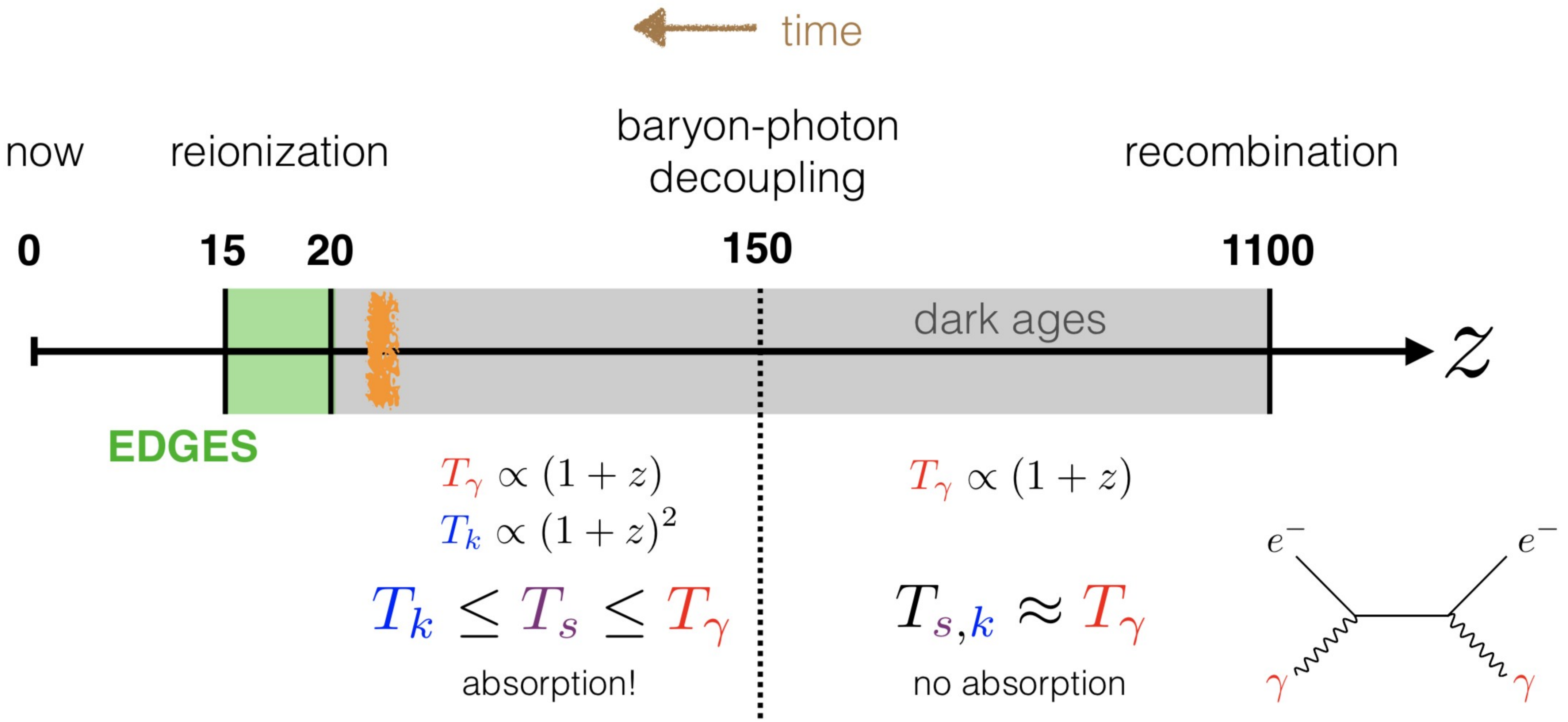
Many pictures/figs. from J. Ruderman talk at GGI



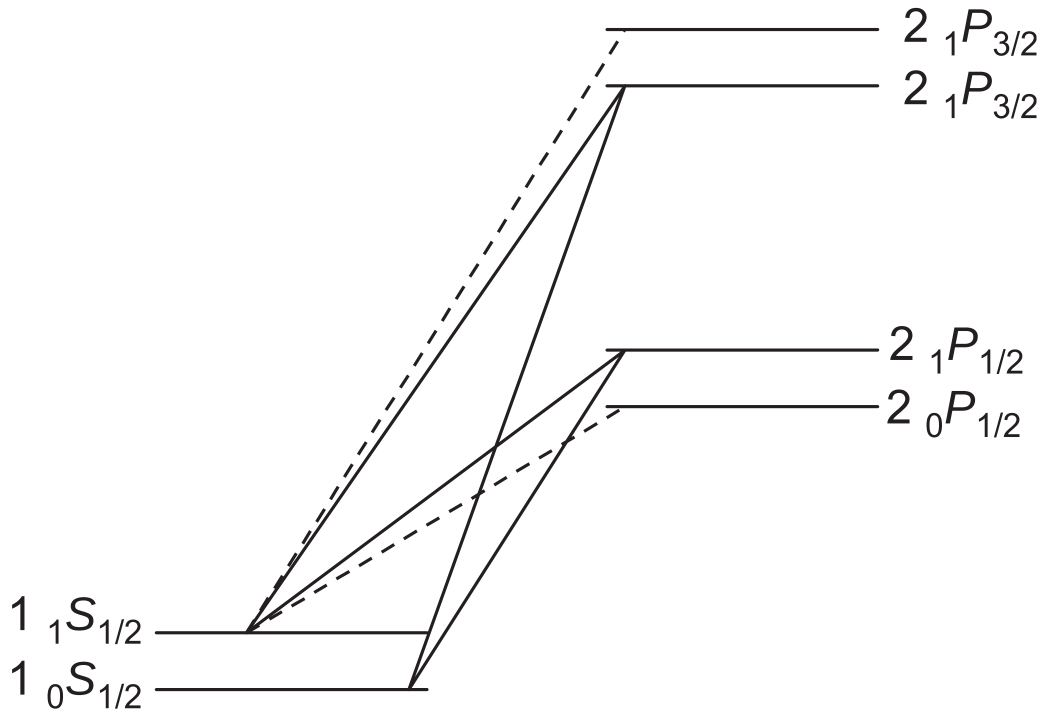
Absorption:

$$\Delta T_{21}(z) = 32\,\mathrm{mK} \times \left(1 - \frac{T_\gamma(z)}{T_s(z)}\right) \sqrt{\frac{1+z}{18}}$$

Evolution of temperatures at early Universe



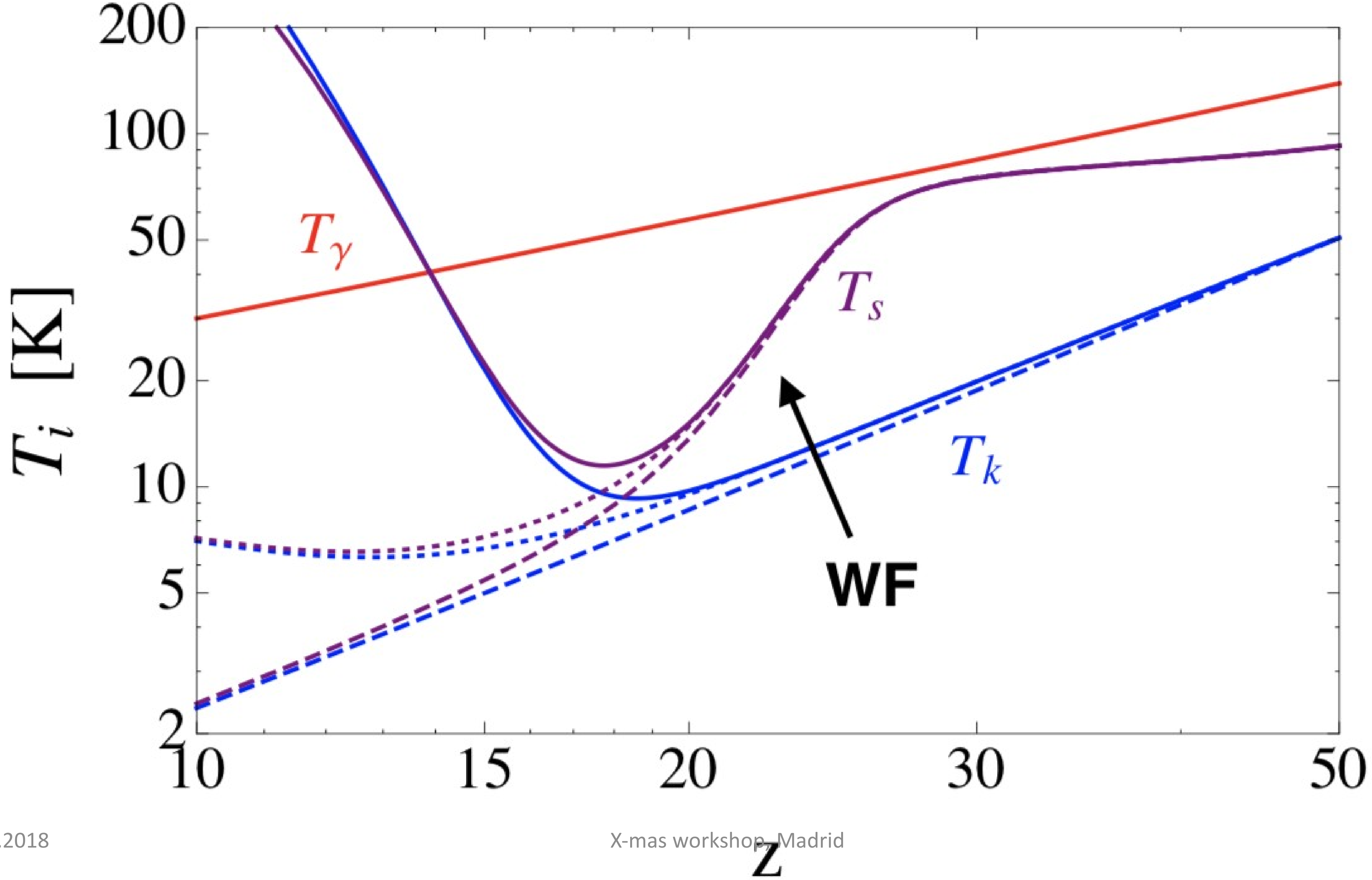
Woutuysen-Field effect (WF-effect)



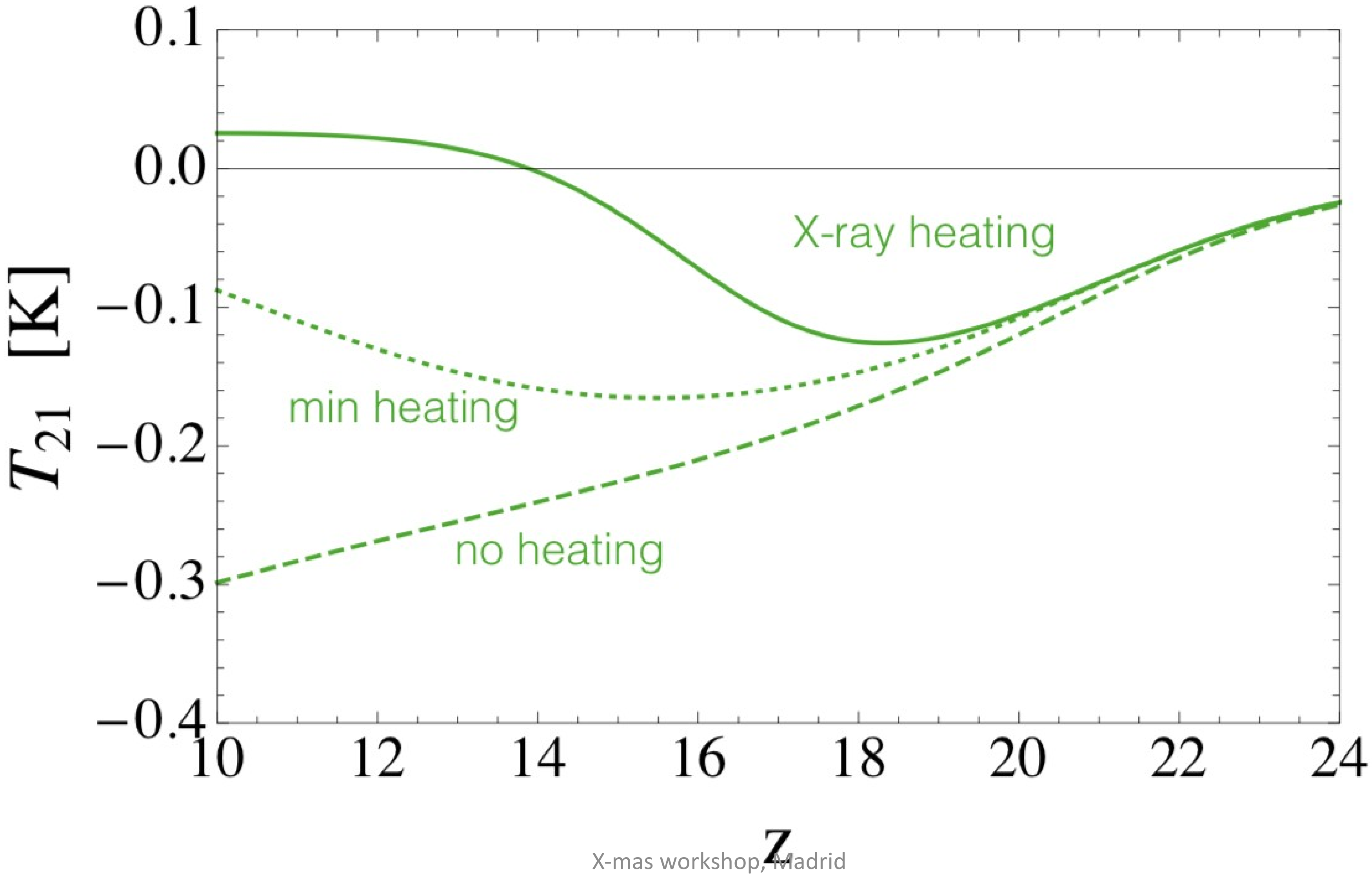
Lyman-α photons open new transitions between different hydrogen energy levels

$$T_s \rightarrow T_k$$

Evolution of temperatures



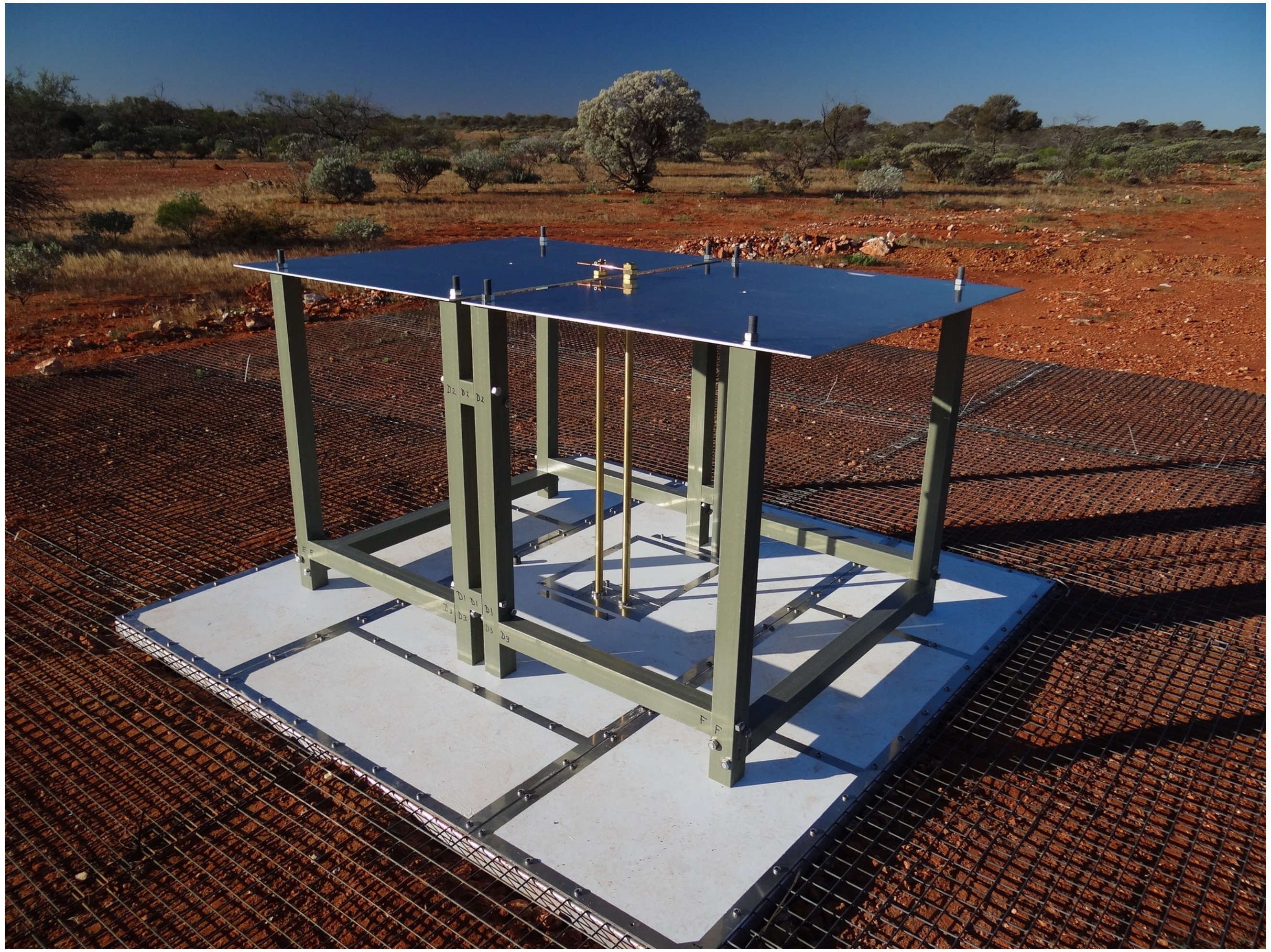
Behaviour of 21 cm absorption



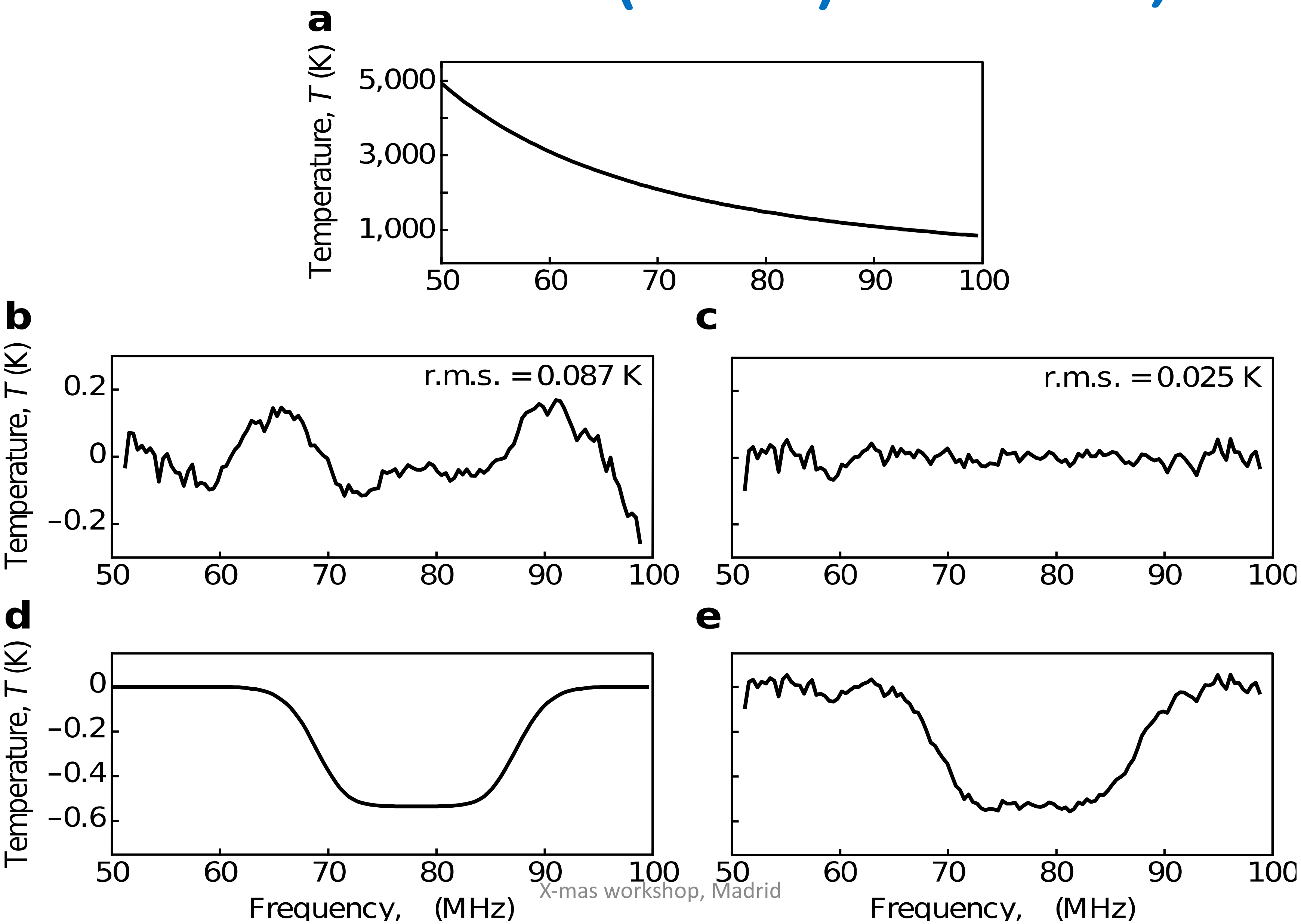
Lots of unknown astrophysics:

Perform the measurement and learn!

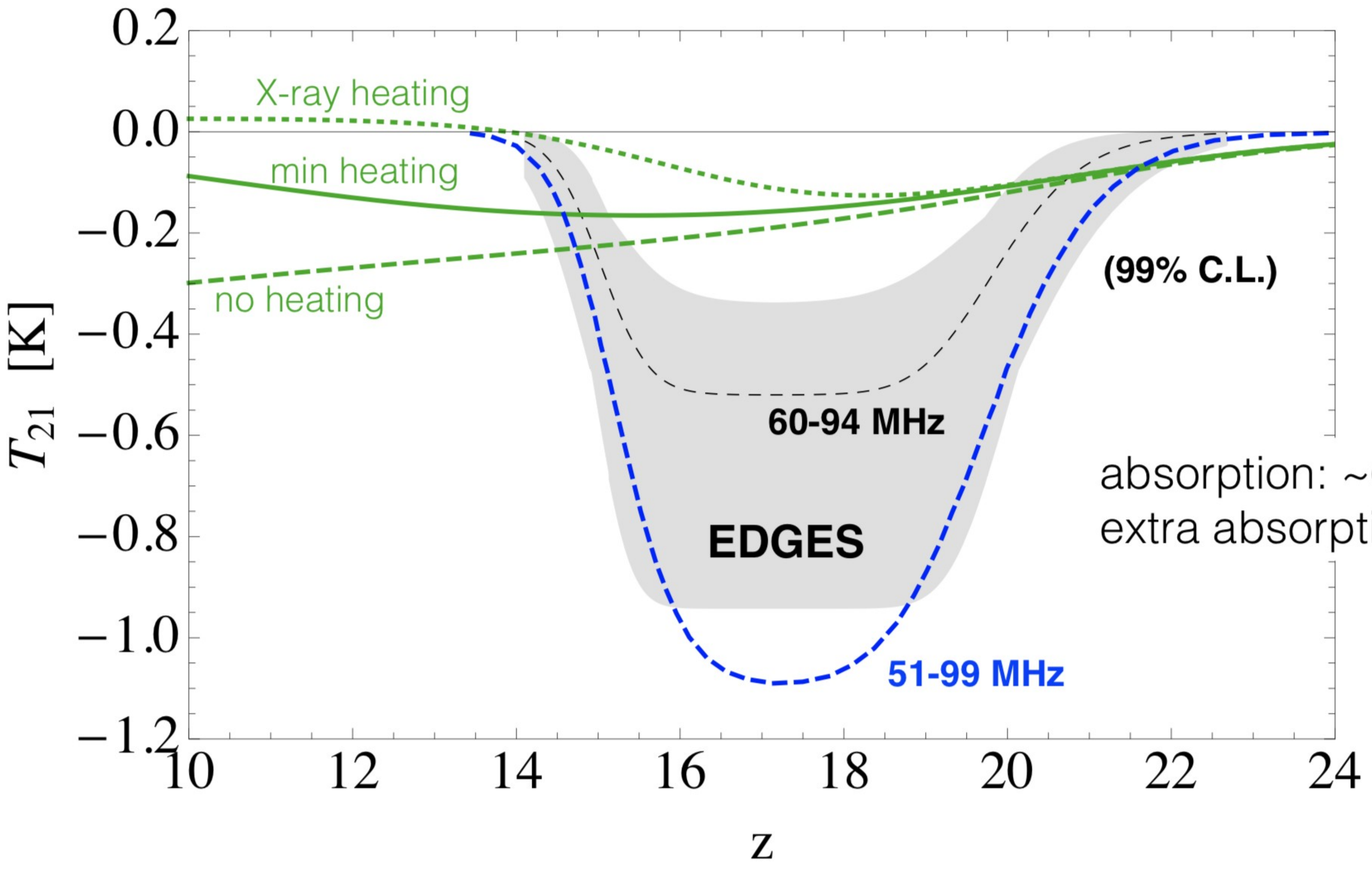
EDGES: Experiment to Detect the Global Epoch of reionization Signatures



Results: Nature 555 (2018) no.7694, 67-70



EDGES – twice the expected absorption strength



absorption: ~6σ
extra absorption: ~4σ

Possible explanations of the result

- Unknown foregrounds 1805.01421
  - The result is biased by the foreground choice
- Instrumental effect 1810.09015 (the experiment is crap)
  - EDGES collaboration claims that this is not a problem
- Unexpected long-waited new physics signal?
- There are several planned experiments to test this signal

Logical possibilities to explain the result with NP

1) Cooling hydrogen from the standard temperature 7K to 3.5K

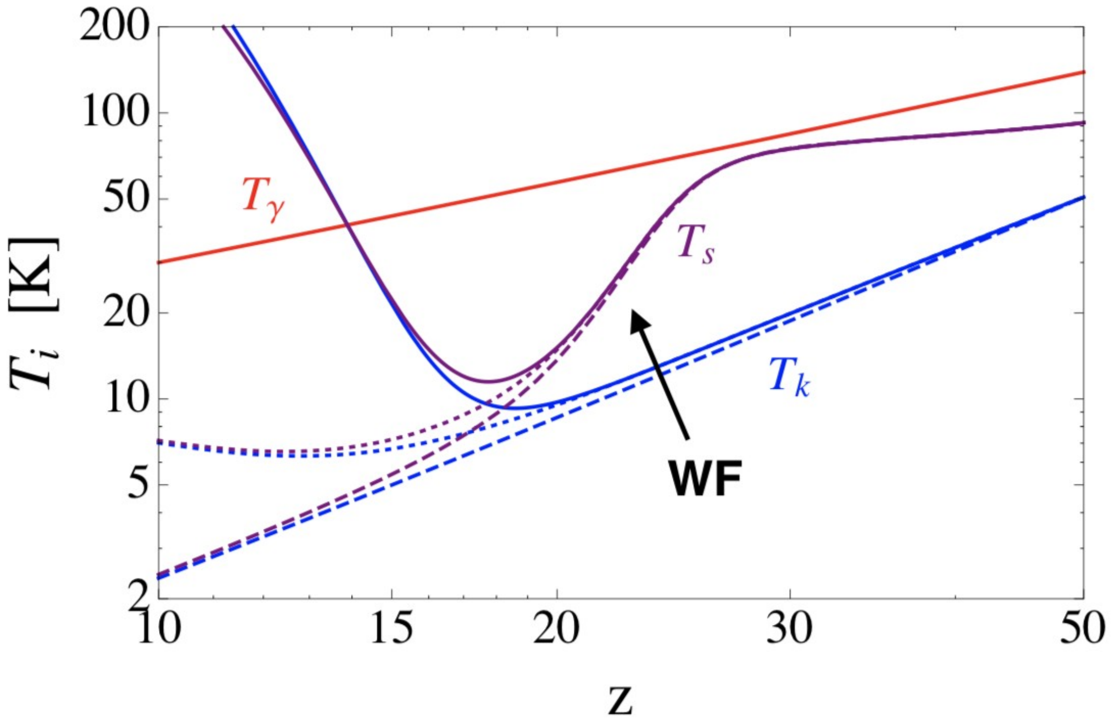
- This is the “original” proposal by Barkana appearing simultaneously with the EDGES result

2) Extra soft photon background which heats the CMB tail

- Fraser et al, **Phys. Lett. B785 (2018) 159,**

  arXiv:1803.03245

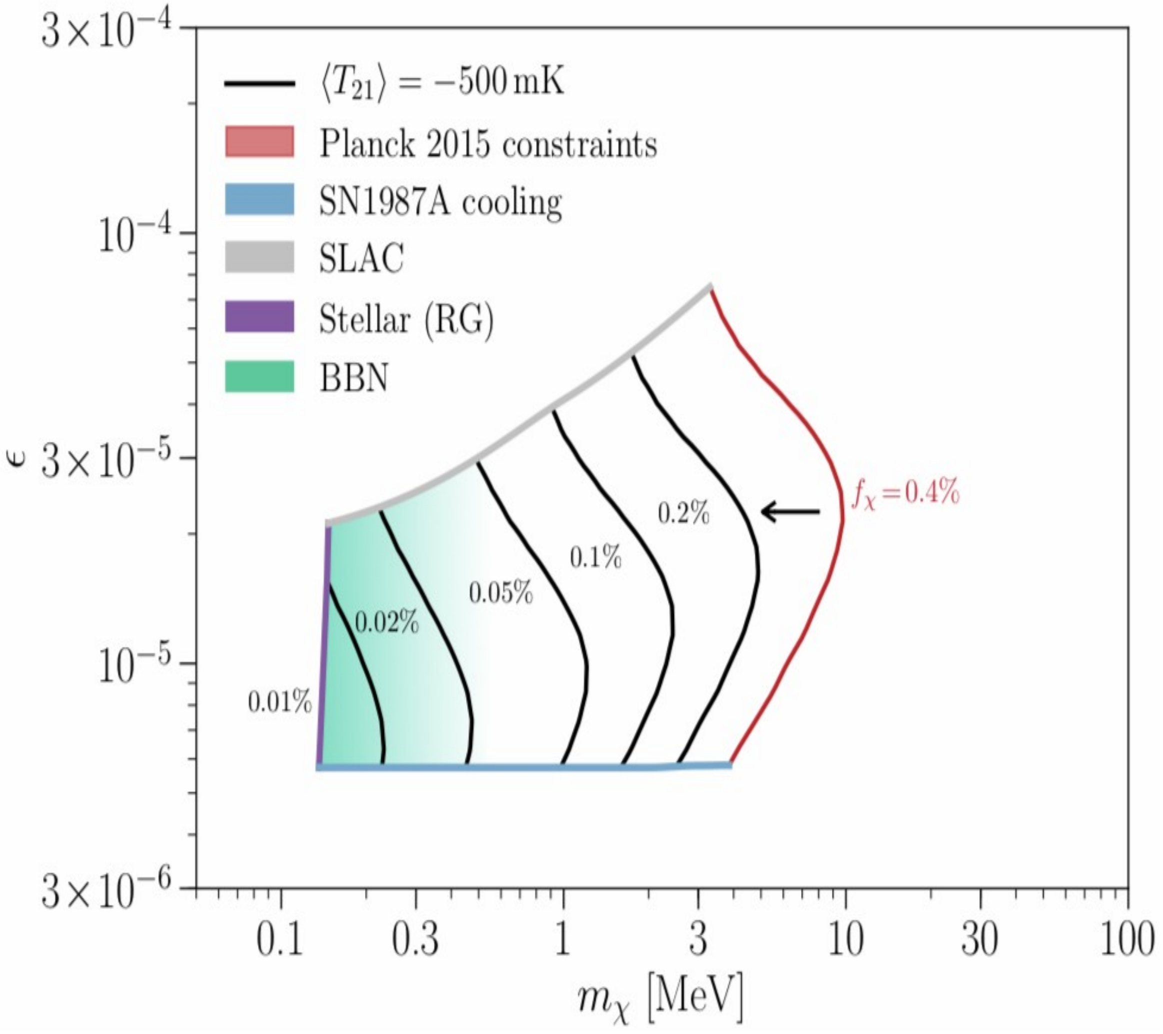
$$T_{21} \propto 1 - \frac{T_\gamma}{T_s}$$



Cooling hydrogen

- Use the cold DM bath to cool the gas in entire Universe
  - Requires DM-H coupling (postulated) that is very much constrained
  - Favours millicharged DM scenario that is severely constrained

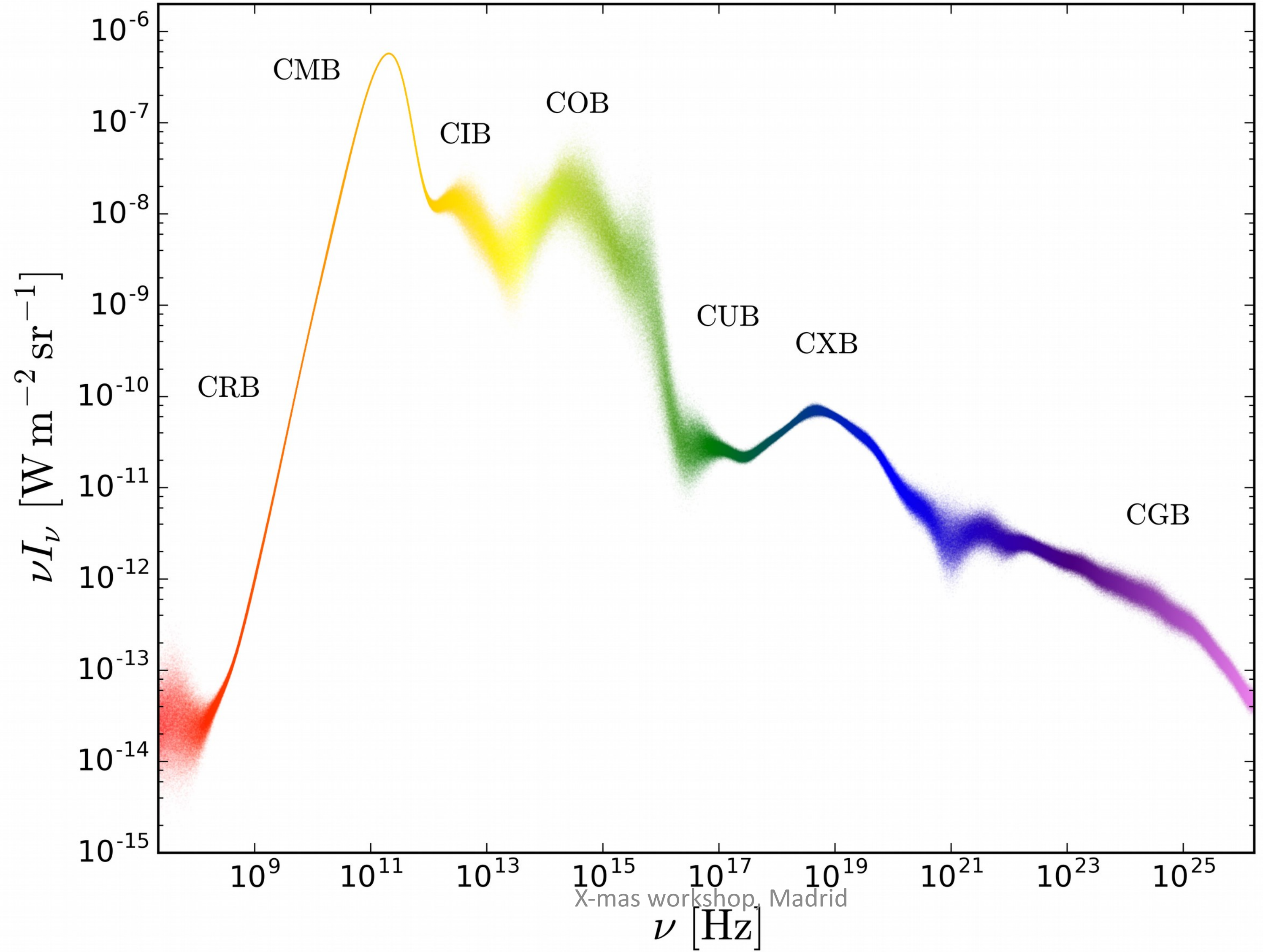
- Arrange baryon-photon decoupling earlier than z=150 so that gas has more time to cool
  - Requires new interaction with free electrons, also constrained



Severe experimental constraints exist on modifying the hydrogen properties:

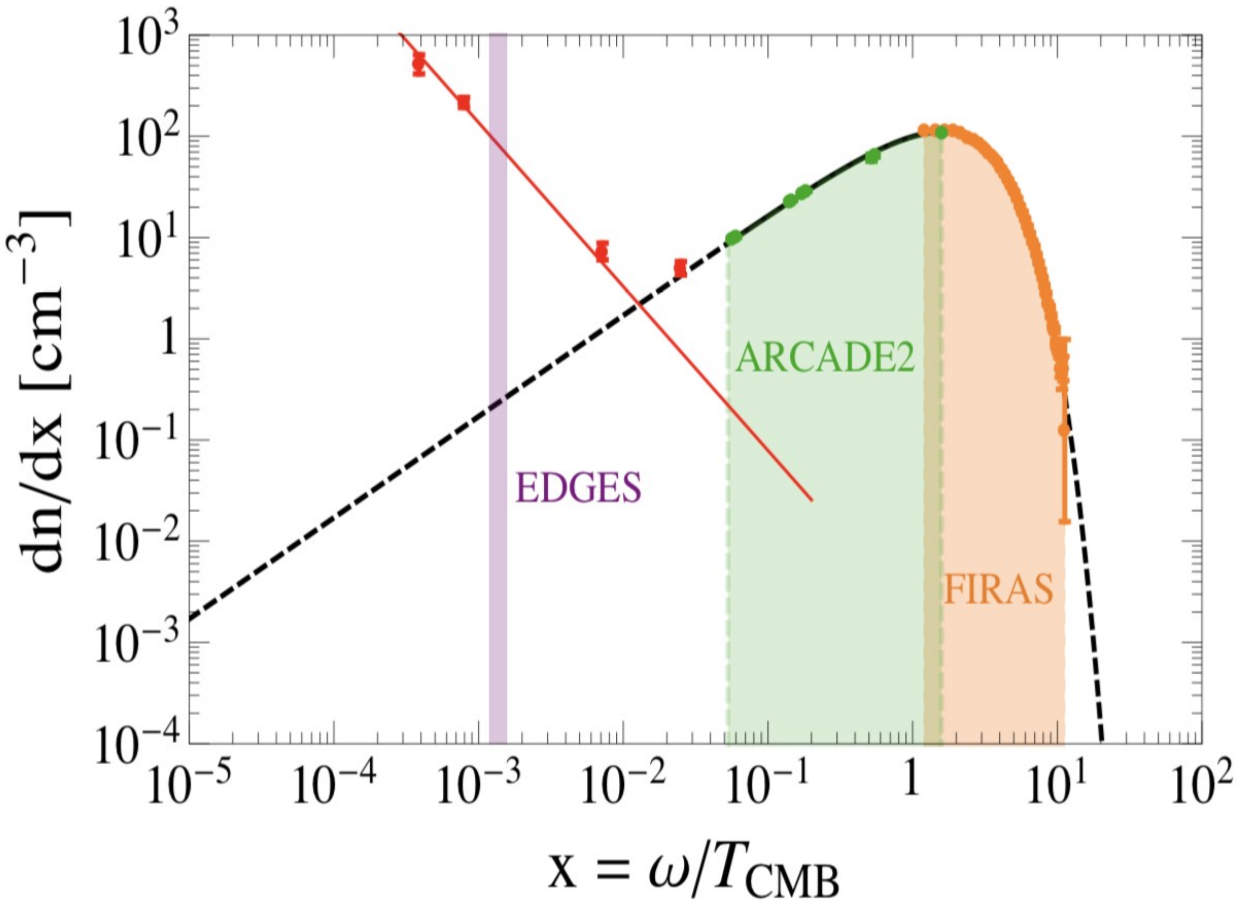
Choose the second option, the extra soft photons!

The photon spectrum of the Universe



The radio excesses

- ARCADE 2 claimed excess at radio frequencies, 0901.0555
- EDGES seems to require extra soft photons too
- The two signals can be compatible:
  - Most ARCADE2 photons are Galactic astrophysical foreground
  - Just a small fraction of EDGES photons are of cosmological origin



What if DM produces the extra soft photons?

Soft vs hard photons

Fitting the signal

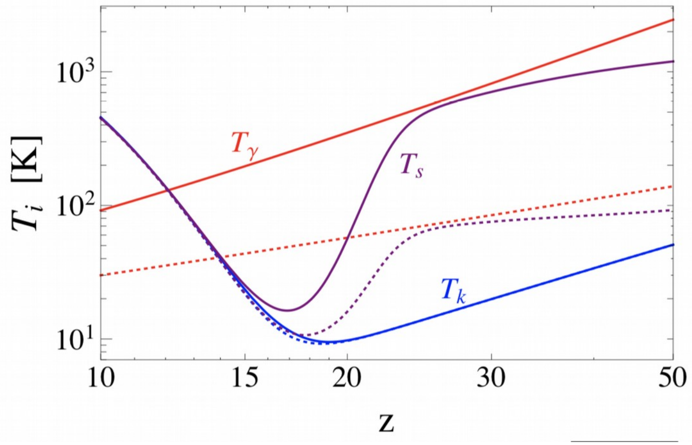
$$(E_{\min}, E_{\max}) = (65\,\mathrm{MHz}, 90\,\mathrm{MHz})$$

The injected photon energy must be:

$$3 \times 10^{-7}\,\mathrm{eV} < E_\gamma < 4 \times 10^{-4}\,\mathrm{eV}$$

The number of CMB photons must be doubled

$$\sim 3/4\,T_{\mathrm{CMB}}$$



Constraints

- Most DM candidates inject wide spectrum including hard photons that will heat the gas
- Typical WIMP annihilations or decays lead to 21 cm constraints
- PBH DM accretion of gas will produce hard spectrum and will heat the gas. PBHs are not good candidates to explain the 21 cm Hektor, **Phys.Rev. D98 (2018) 023503**

Viable DM scenarios I: light scalars and axions

$$X \to \gamma\gamma$$

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

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

EDGES implies:

$$\Lambda < 2\,\mathrm{TeV}\sqrt{\frac{A f_X}{m_X/\mathrm{eV}}}$$

Axion constraints imply:

$$\Lambda \gtrsim 10^{10}\,\mathrm{GeV}$$

Naïve expectation that light axions decay to photons is firmly ruled out

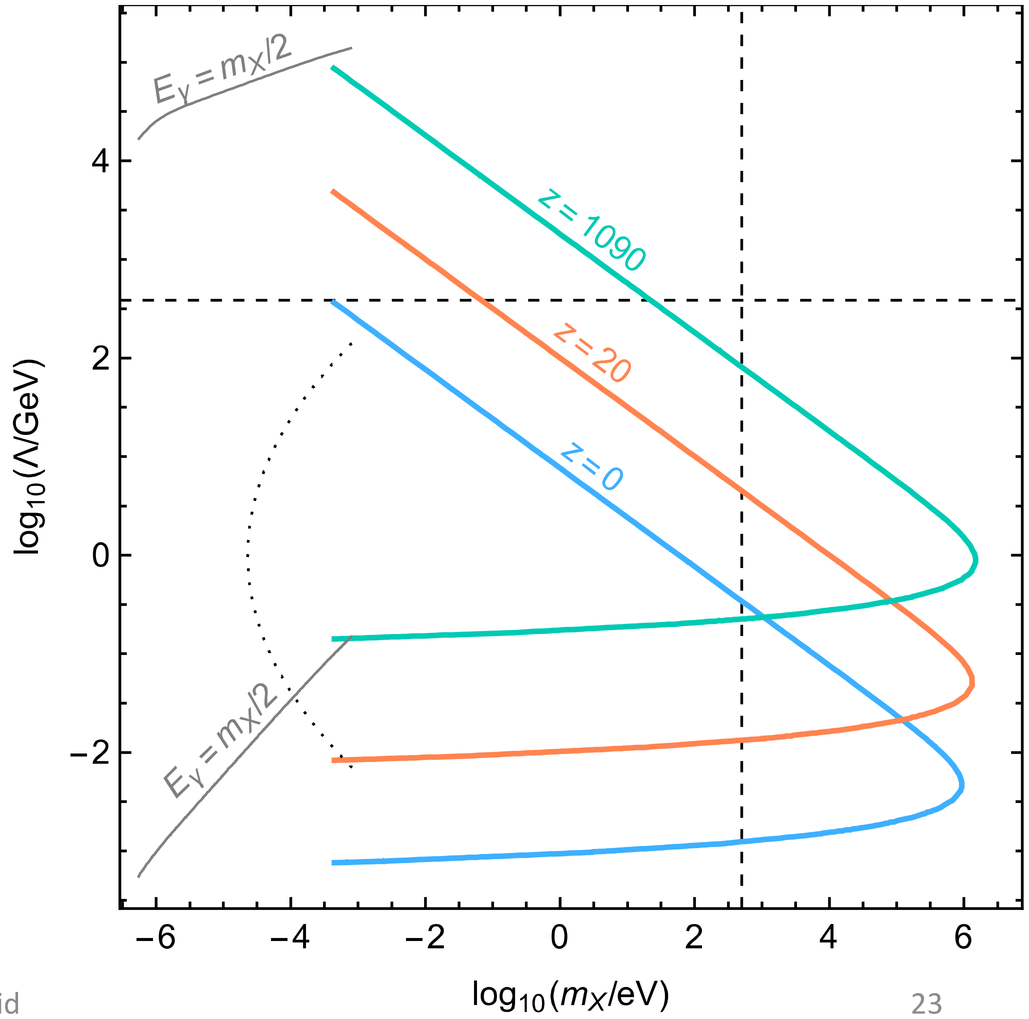
Viable DM scenarios II: excited DM

$$X \to \gamma \tilde{X}$$

$E_\gamma = m_X - m_{\tilde{X}}$ mass scale might be increased

$$-\frac{i}{2} F_{\mu\nu} \bar{X} \sigma^{\mu\nu} (\mu_X + d_X \gamma^5) \tilde{X} + \text{h.c.}$$

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



Again, too low NP scale is needed

The main message from EDGES:

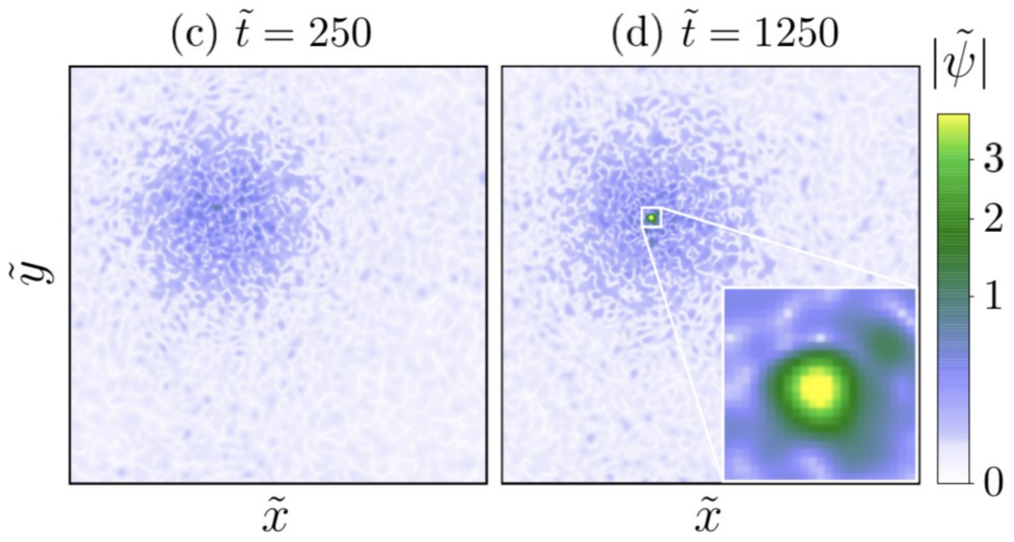
enhancement/resonant mechanism is needed to convert light DM into photons

Axion stars/mini-clusters

- Simulations: Axion DM haloes collapse to condensed Bose stars due to gravity only.

$$\tau_{gr} \sim \frac{10^9\,\mathrm{yr}}{\Phi^3(1+\Phi)}\left(\frac{M_c}{10^{-13}\,M_\odot}\right)^2\left(\frac{m}{26\,\mu\mathrm{eV}}\right)^3$$

- Those clumps convert axions to photons
- The fraction of DM in axion clumps is yet unknown, could be as large as 50%



Phys.Rev.Lett. 121 (2018) no.15, 151301

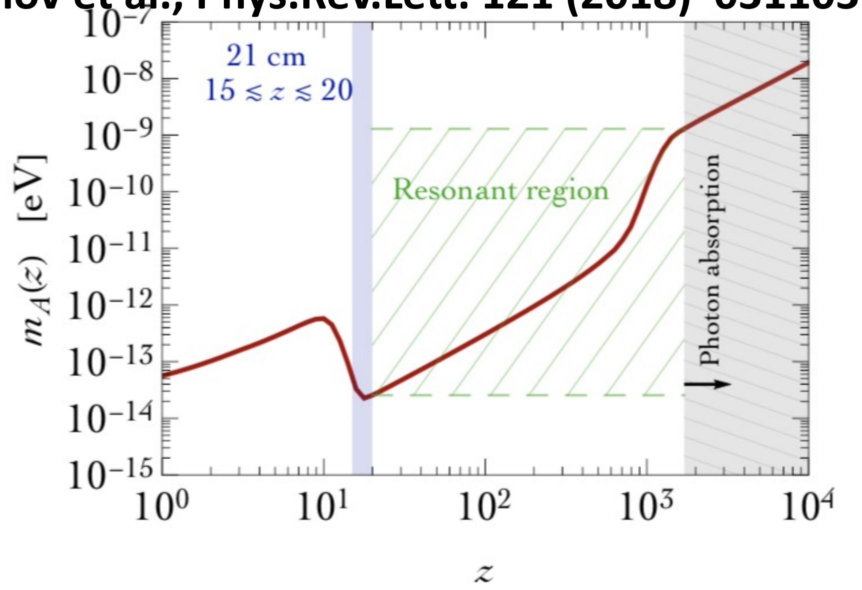
Condensed axion stars provide a viable boost to DM conversion to soft photons

Resonant dark photon conversion to photons

Pospelov et al., Phys.Rev.Lett. 121 (2018) 031103

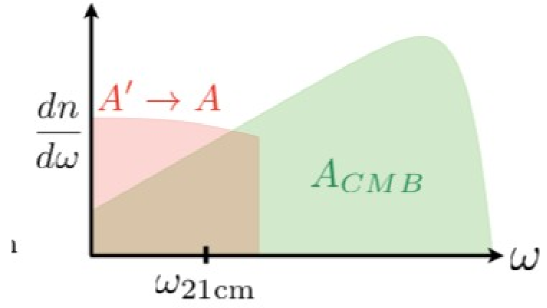
- Universe filled with nonthermal dark photons
  - No constraints on their abundance
- Their mixing is constrained

$$\mathcal{L}_{AA'} = -\frac{1}{4}F_{\mu\nu}^2 - \frac{1}{4}(F'_{\mu\nu})^2 - \frac{\epsilon}{2}F_{\mu\nu}F'_{\mu\nu} + \frac{1}{2}m_{A'}^2(A'_\mu)^2 \,.$$



$$m_A(z) \simeq 1.7 \times 10^{-14}\,\mathrm{eV} \times (1+z)^{3/2} X_e^{1/2}(z)$$

- Resonance condition due to photon plasma mass $[m_A(z) = m_{A'}]$



- A viable resonant conversion mechanism for EDGES

Conclusions

- EDGES 21 cm absorption signal must be checked with future experiments
- The excess of soft photons seems to be the more promising solution to the anomalous absorption signal (out of the two)
- Enhancement mechanism is needed to convert light DM into photons