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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

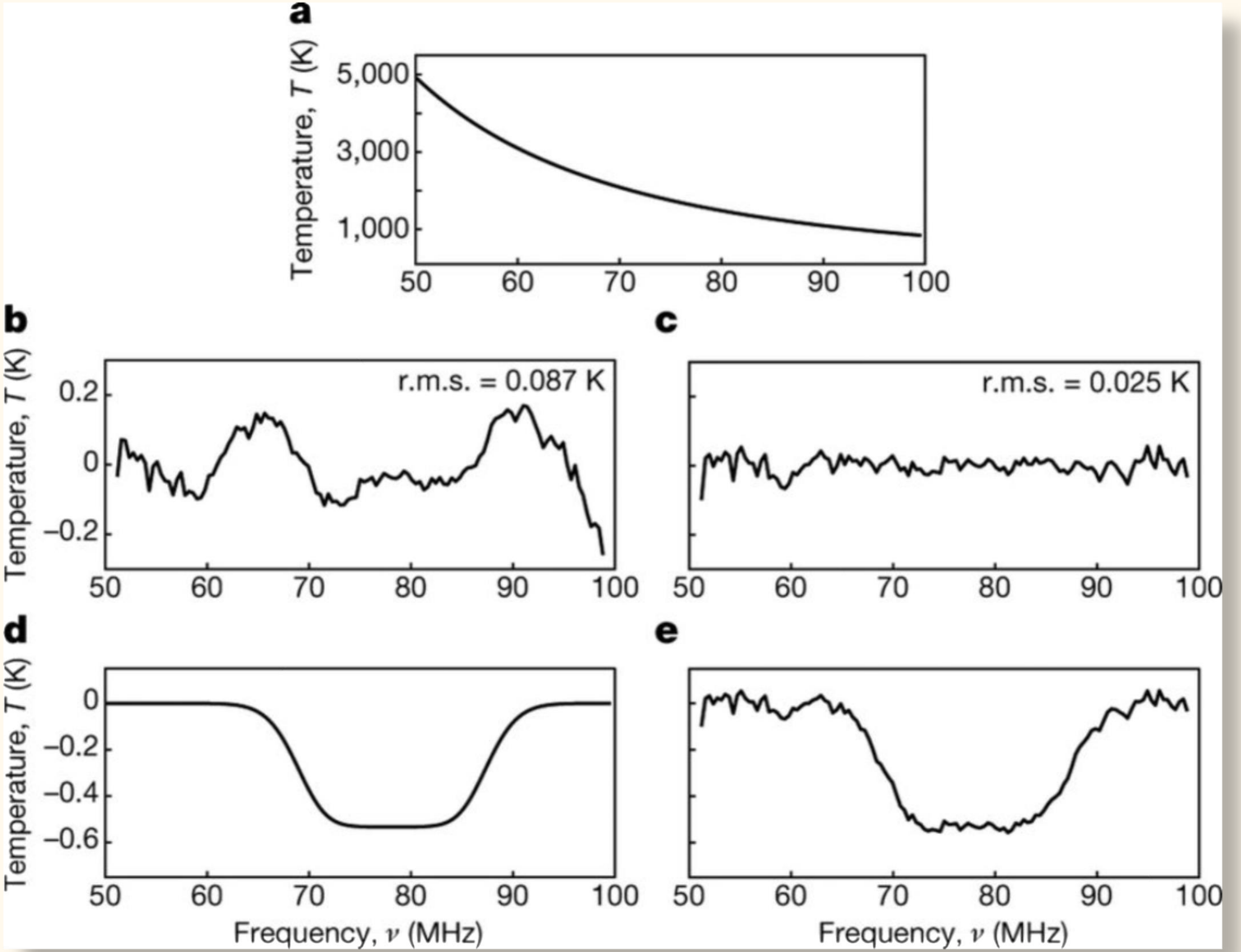
Outline

- 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?

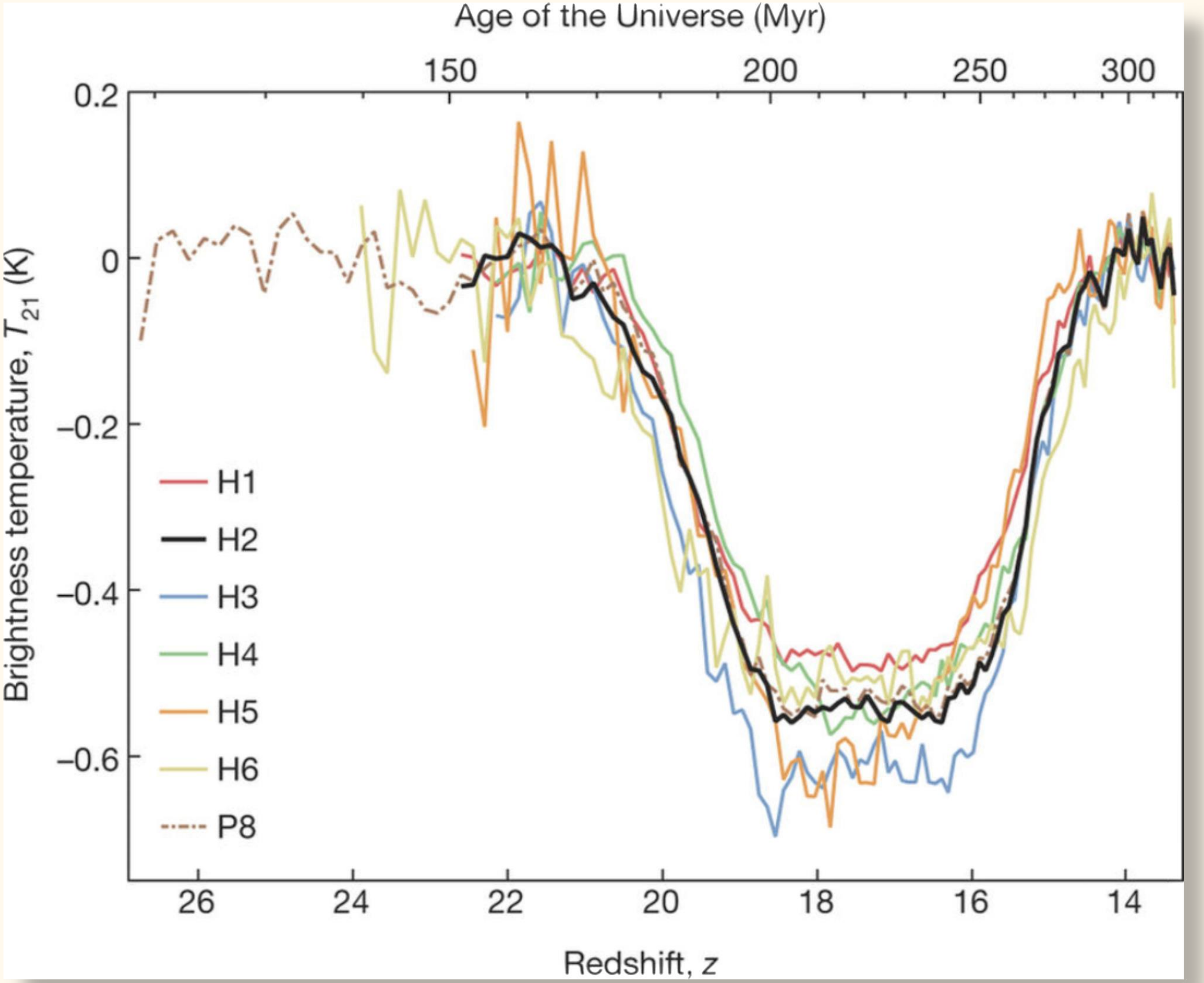
- A 21cm signal in *absorption*
- Between redshifts ~20 and 15
- Amplitude *twice* as large as predicted (~500 mK vs. ~200mK)

What did EDGES see?



Bowman et al., Nature, 2016

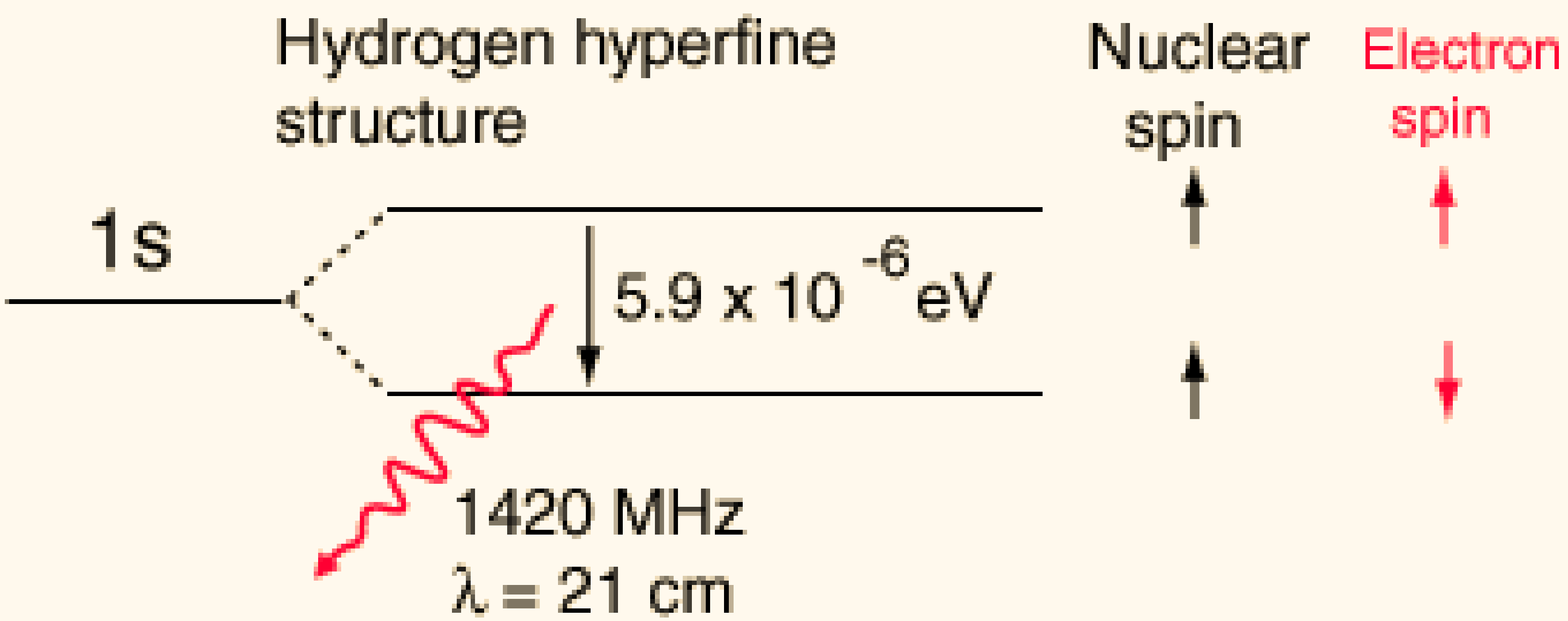
What did EDGES see?



Bowman et al., Nature, 2016

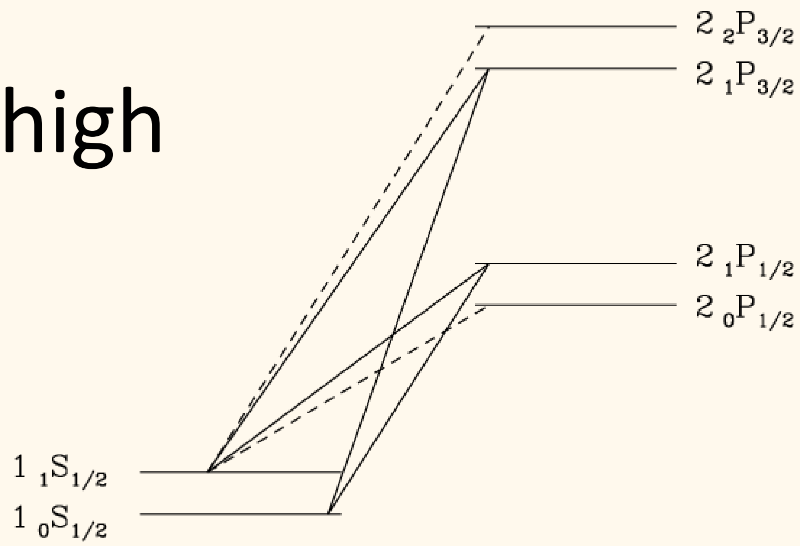
What is this 21cm line?

- 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)



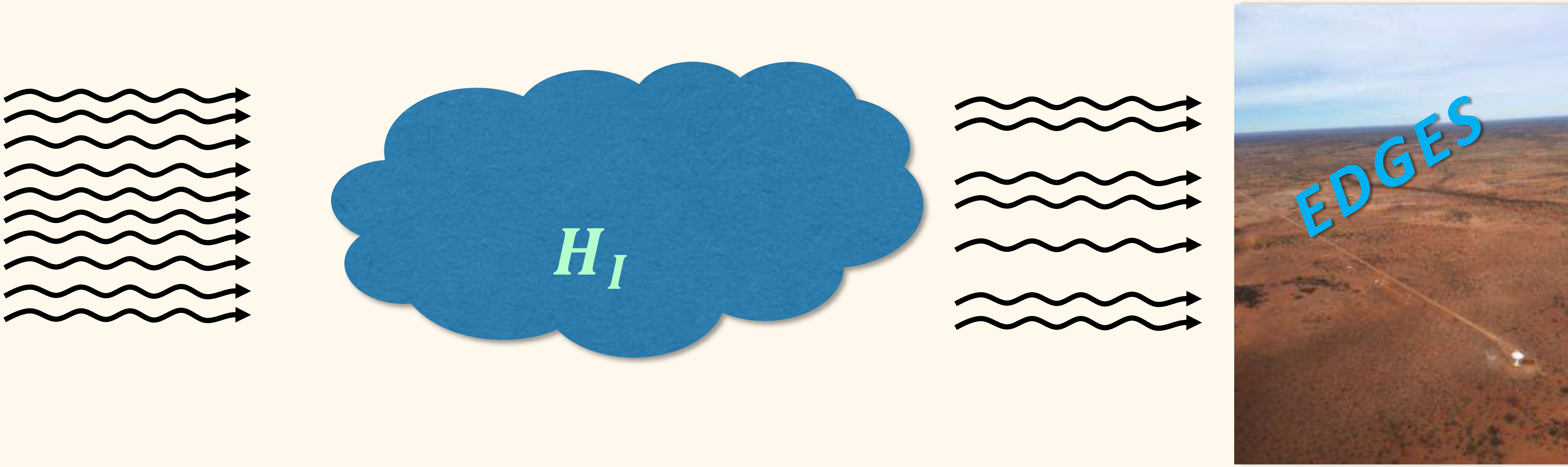
- Equilibrium implies

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

- In terms of temperatures

$$T_S^{-1} = \frac{T_\gamma^{-1} + x_c T_{gas}^{-1} + x_\alpha T_\alpha^{-1}}{1 + x_c + x_\alpha}$$

What we see

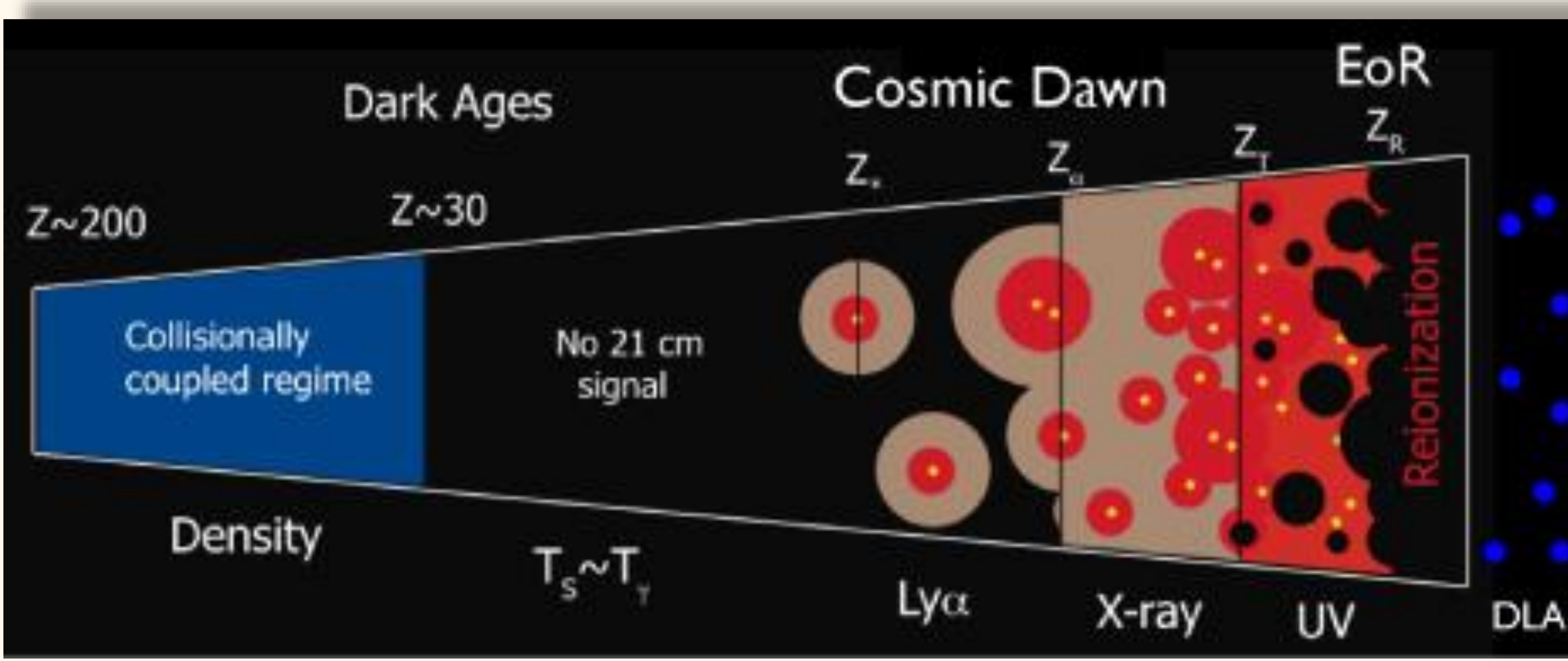


$$\delta T_b \approx 21\mathrm{mK}\, x_{\mathrm{H_I}} \left(1 - \frac{T_\gamma}{T_S}\right) \sqrt{\frac{1+z}{10}}$$

A short history of the IGM

- At z~1100, CMB and IGM *kinetically decouple*: the Universe becomes neutral
- However, temperatures are still the same, because of efficient Compton scattering
- Finally, around z~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

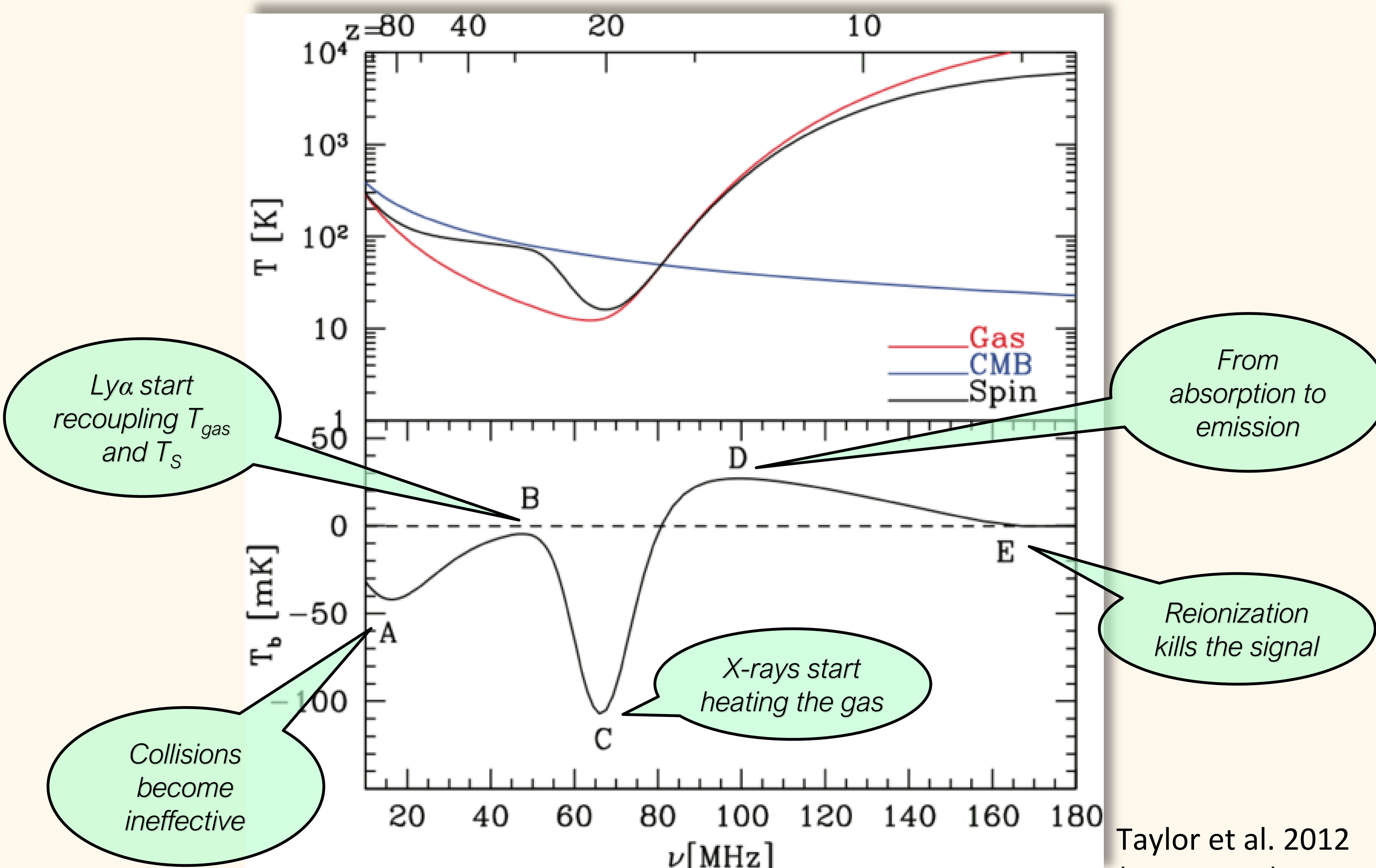


Pritchard & Loeb 2011
(1109.6012)

A short history of T_S

- Nothing happens until IGM thermally decouple, temperatures are all the same, zero signal
- After z~200 until z ~ 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-α photons recouple $T_S \sim T_{IGM}$, so I start decreasing δT_b and I get absorption
- Finally, as T_{IGM} goes up, I increase δT_b and get an emission until signal finally dies after full reionization

Example history and signal



Taylor et al. 2012
(1206.6733)

Evolution with annihilating DM

$$\frac{\mathrm{d}T_{\mathrm{gas}}}{\mathrm{d}t} = -2HT_{\mathrm{gas}} + H\gamma_{\mathrm{C}}\left(T_\gamma(z) - T_{\mathrm{gas}}\right) + \\ + \frac{\mathrm{d}E}{\mathrm{d}V\mathrm{d}t}\frac{1+2x_e}{3n_H}\frac{2}{3(1+x_e+f_{\mathrm{He}})}$$

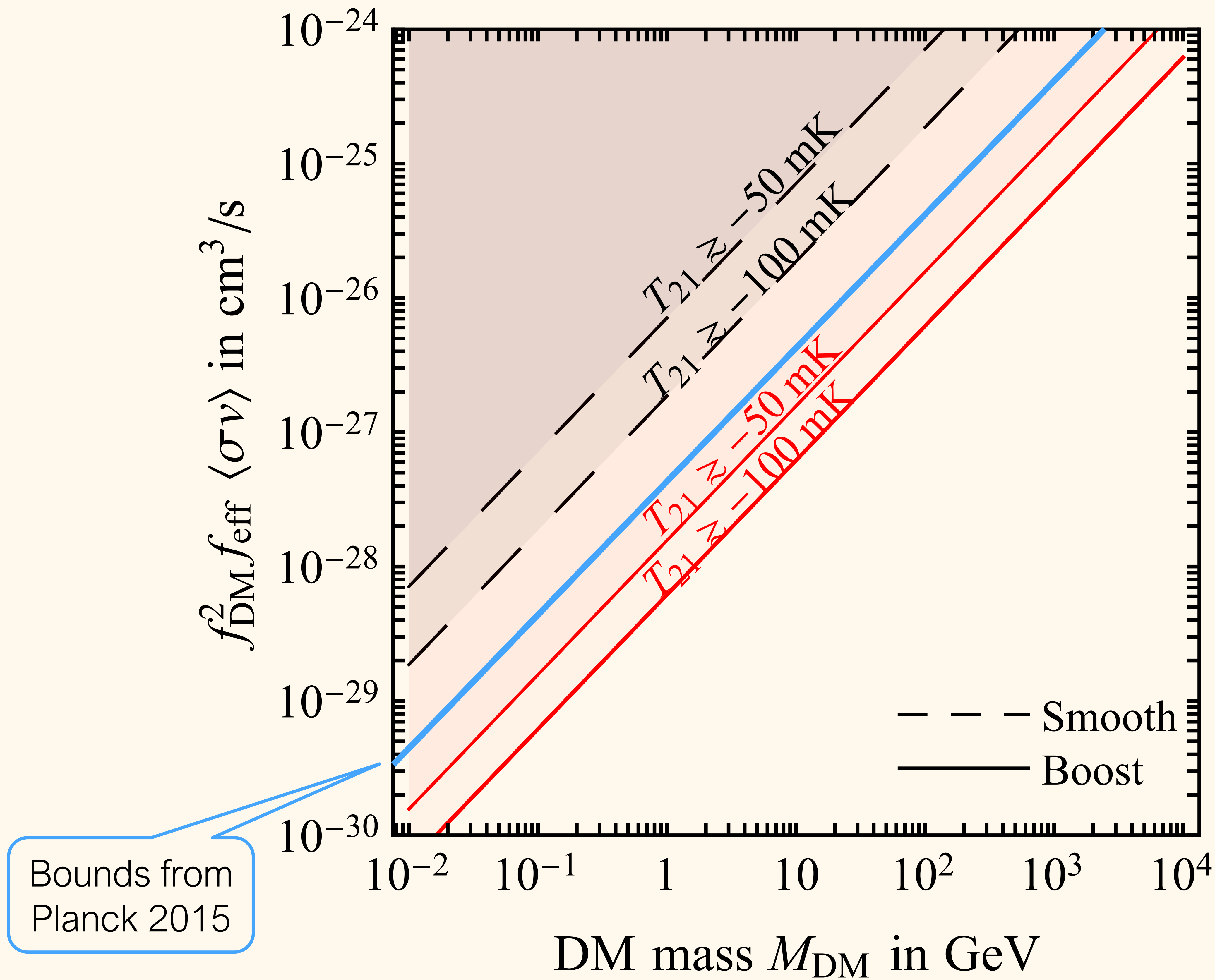
$$\frac{\mathrm{d}x_e}{\mathrm{d}t} = \mathcal{P}_2\left[-\alpha_H(T_{\mathrm{gas}})n_{\mathrm{H}}x_e^2 B + \beta_H(T_{\mathrm{gas}})e^{-E_\alpha/T_{\mathrm{gas}}}(1-x_e)\right] \\ + \frac{\mathrm{d}E}{\mathrm{d}V\mathrm{d}t}\frac{1-x_e}{3n_H}\left(\frac{1}{E_0} + \frac{1-\mathcal{P}_2}{E_\alpha}\right)$$

$$\frac{\mathrm{d}E}{\mathrm{d}V\mathrm{d}t} = \rho_{\mathrm{DM}}^2 B f_{\mathrm{DM}}^2 f_{\mathrm{eff}}\frac{\langle\sigma v\rangle}{M_{\mathrm{DM}}}$$

How do we put bounds

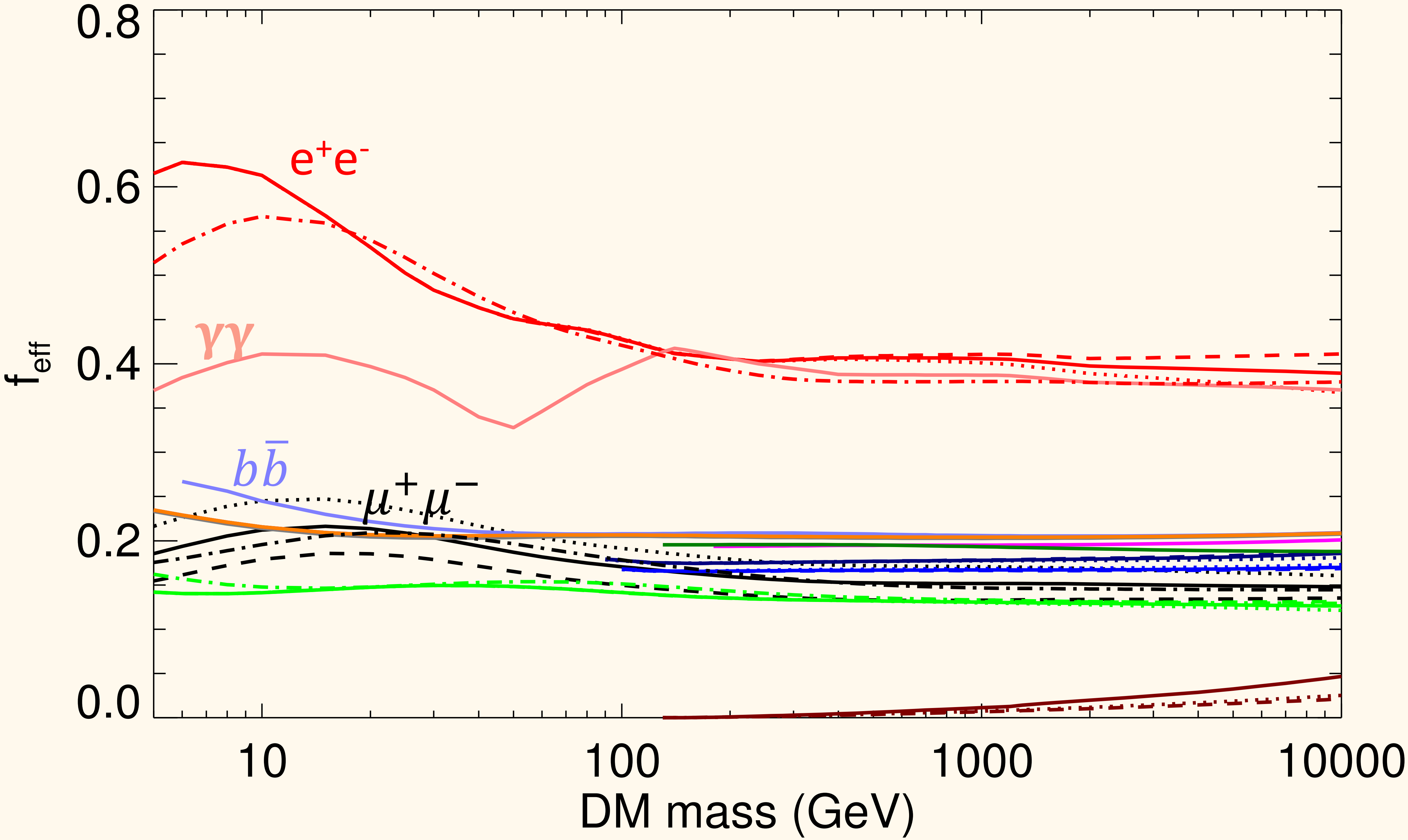
- Signal is lower than expected. *We do not try to explain it!*
- DM can (and will if it's thermal) annihilate into SM: as any energy injection, it will heat the IGM, so δT_b increases
- Hence, we can infer bounds. But we cannot use the observed signal: already the standard model is out at 3.8σ…
- Our strategy: assume standard evolution, $T_S = T_{IGM}$ to get strongest absorption, $\delta T_b \approx -200\mathrm{mK}$. What should I require of DM to get heated to no more than 50% δT_b or 25% δT_b?

Our bounds



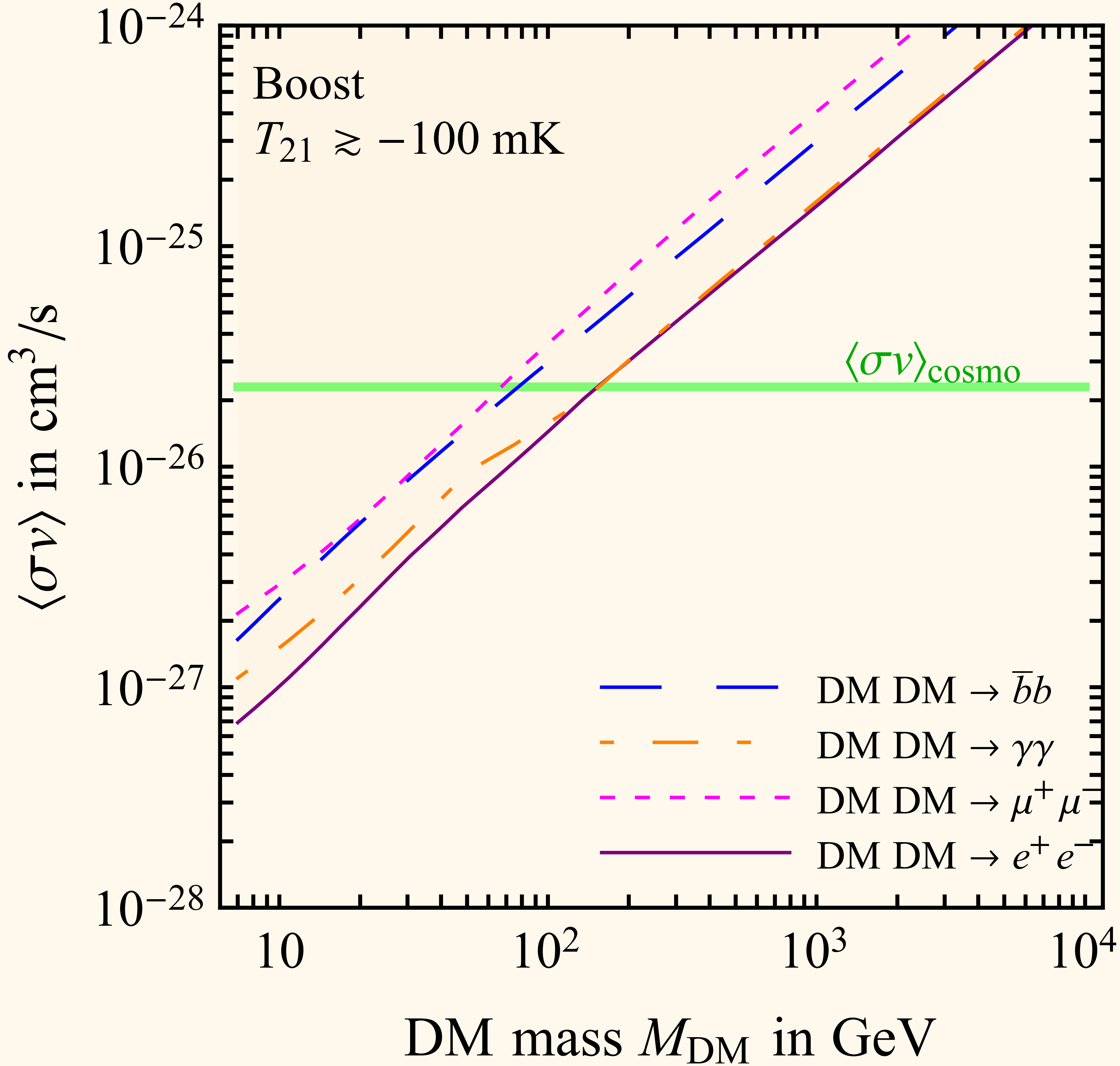
10^{-24}
10^{-25}
10^{-26}
10^{-27}
10^{-28}
10^{-29}
10^{-30}
$f_{\rm DM}^2 f_{\rm eff}\ \langle\sigma v\rangle$ in cm^3/s
$T_{21} \gtrsim -50$ mK
$T_{21} \gtrsim -100$ mK
$T_{21} \gtrsim -50$ mK
$T_{21} \gtrsim -100$ mK
Smooth
Boost
10^{-2}
10^{-1}
1
10
10^2
10^3
10^4
DM mass $M_{\rm DM}$ in GeV
Bounds from Planck 2015

Efficiency factors



Slatyer 2015
(1506.03811)

Our bounds, more explicitly



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!