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Bounds on DM annihilations from 21cm data

based on GDA, Panci, Strumia
arXiv: 1803.03629

PACTS 2018, 19/6/2018

What happened in March

LETTER

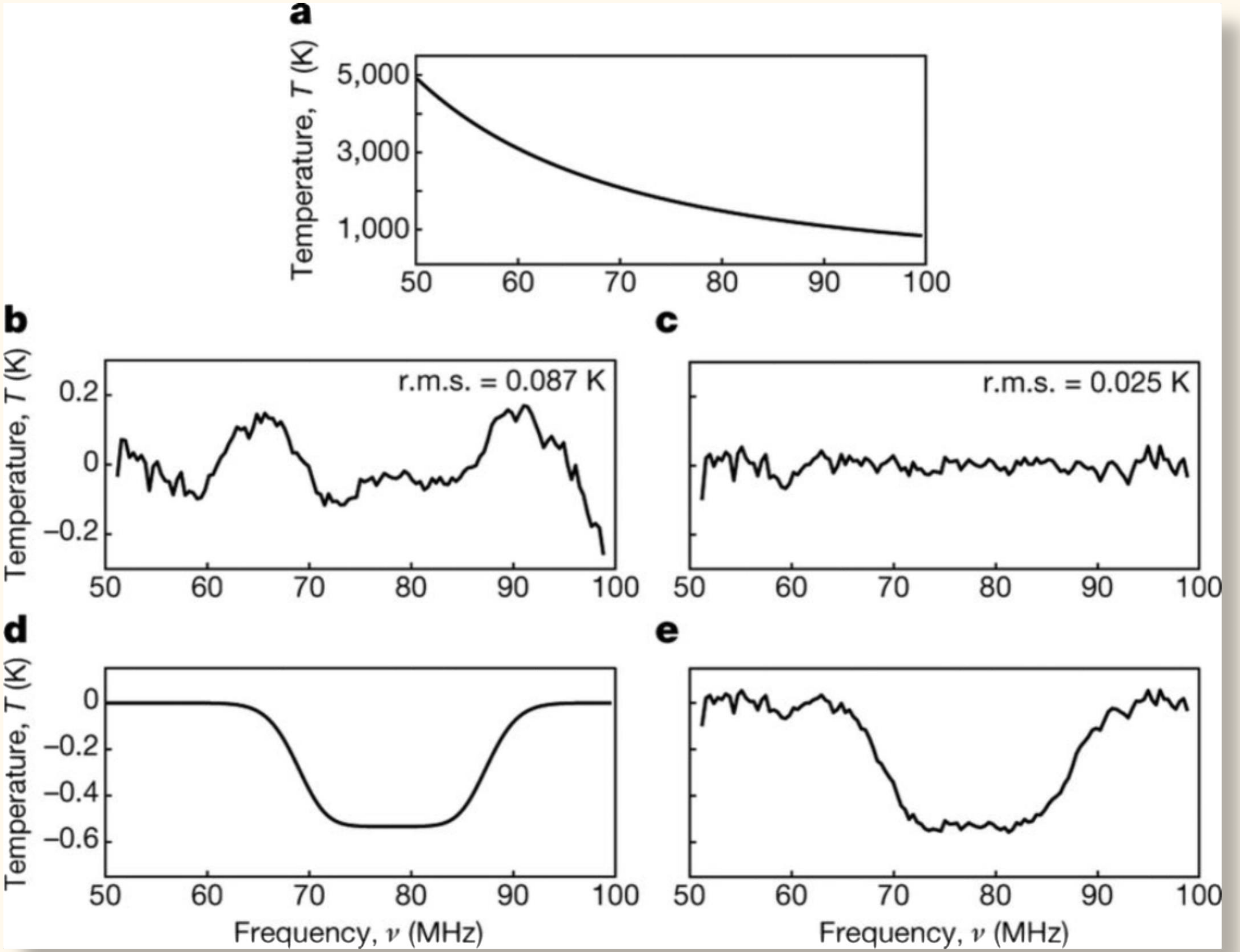
doi:10.1038/nature25792

An absorption profile centred at 78 megahertz in the sky-averaged spectrum

Judd D. Bowman[1], Alan E. E. Rogers[2], Raul A. Monsalve[1,3,4], Thomas J. Mozdzen[1] & Nivedita Mahesh[1]

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

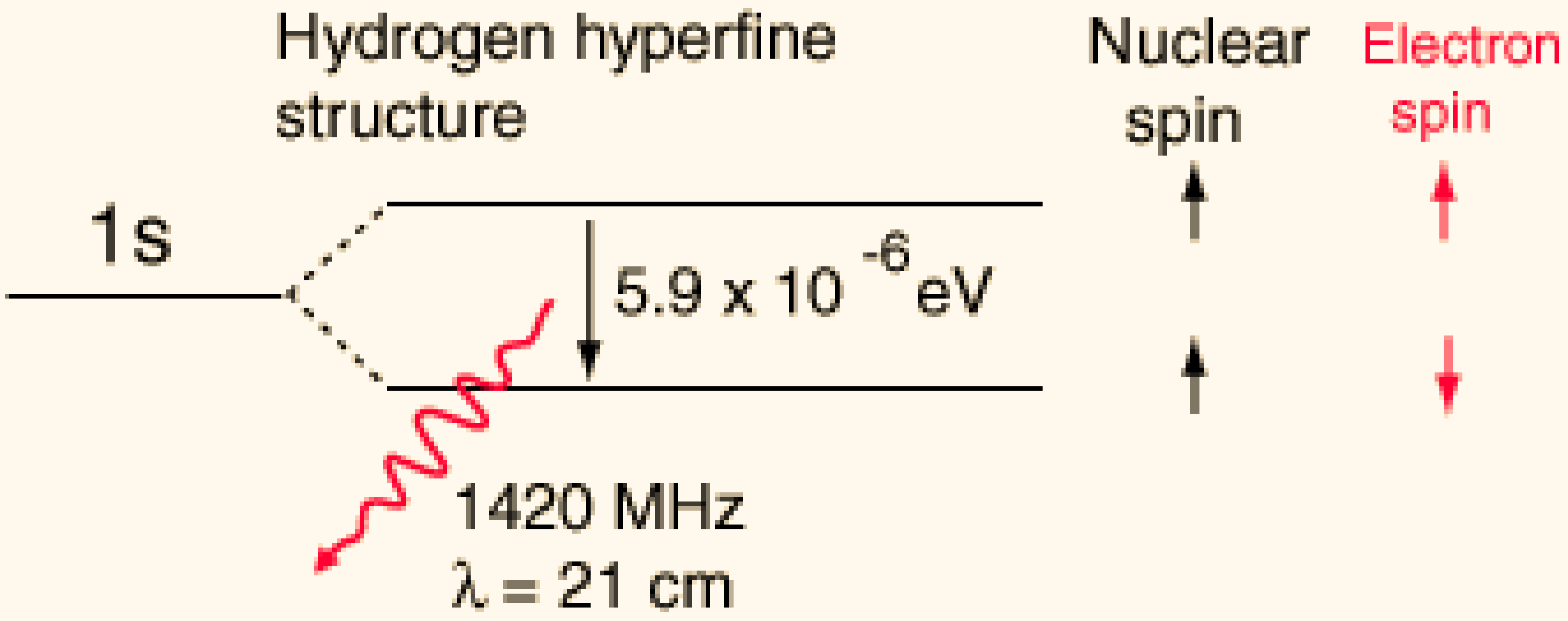
What did EDGES see, exactly?



Bowman et al., Nature, 2016

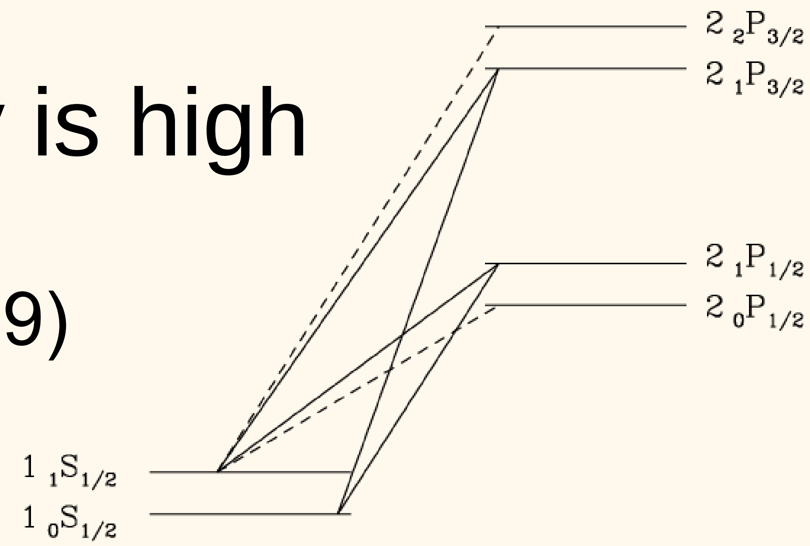
What is this 21cm line?

- Triplet-to-singlet transition of 1s level of atomic hydrogen
- Define *spin temperature* by $\frac{n_1}{n_0} = 3e^{-E_{21}/T_S}$
- 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)



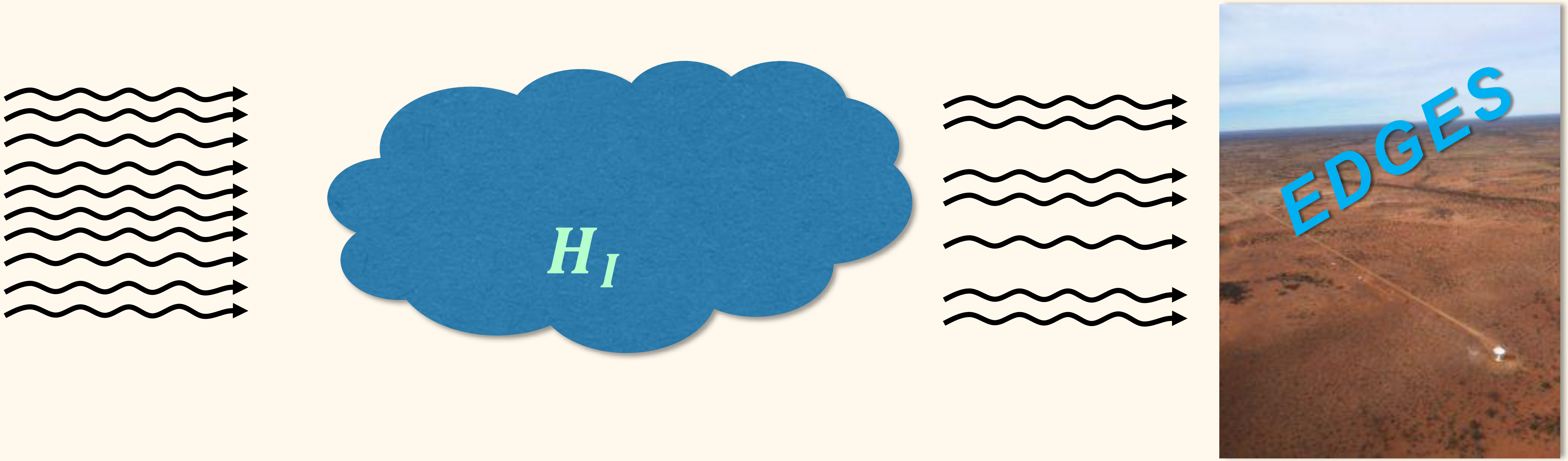
- Equilibrium implies

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

- 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



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

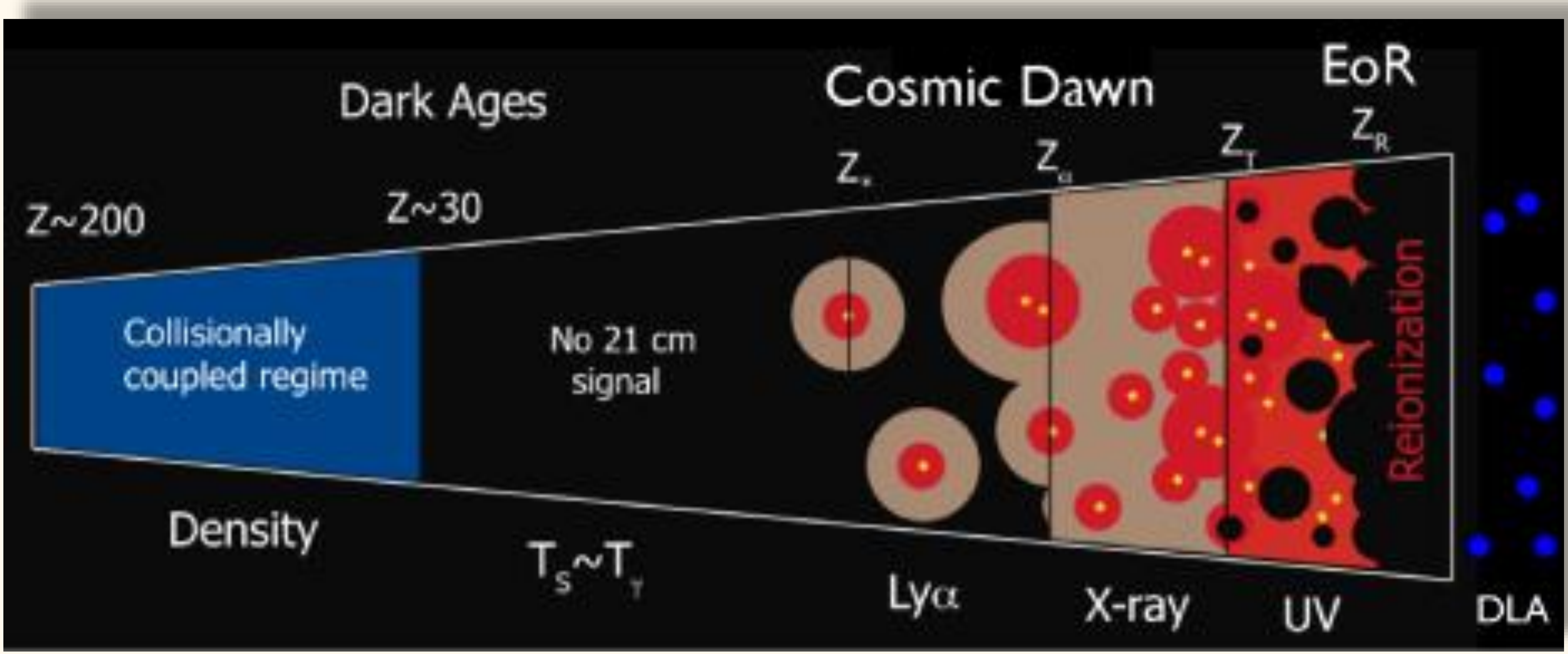
A short history of the IGM

- 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 short (standard) history of T_S

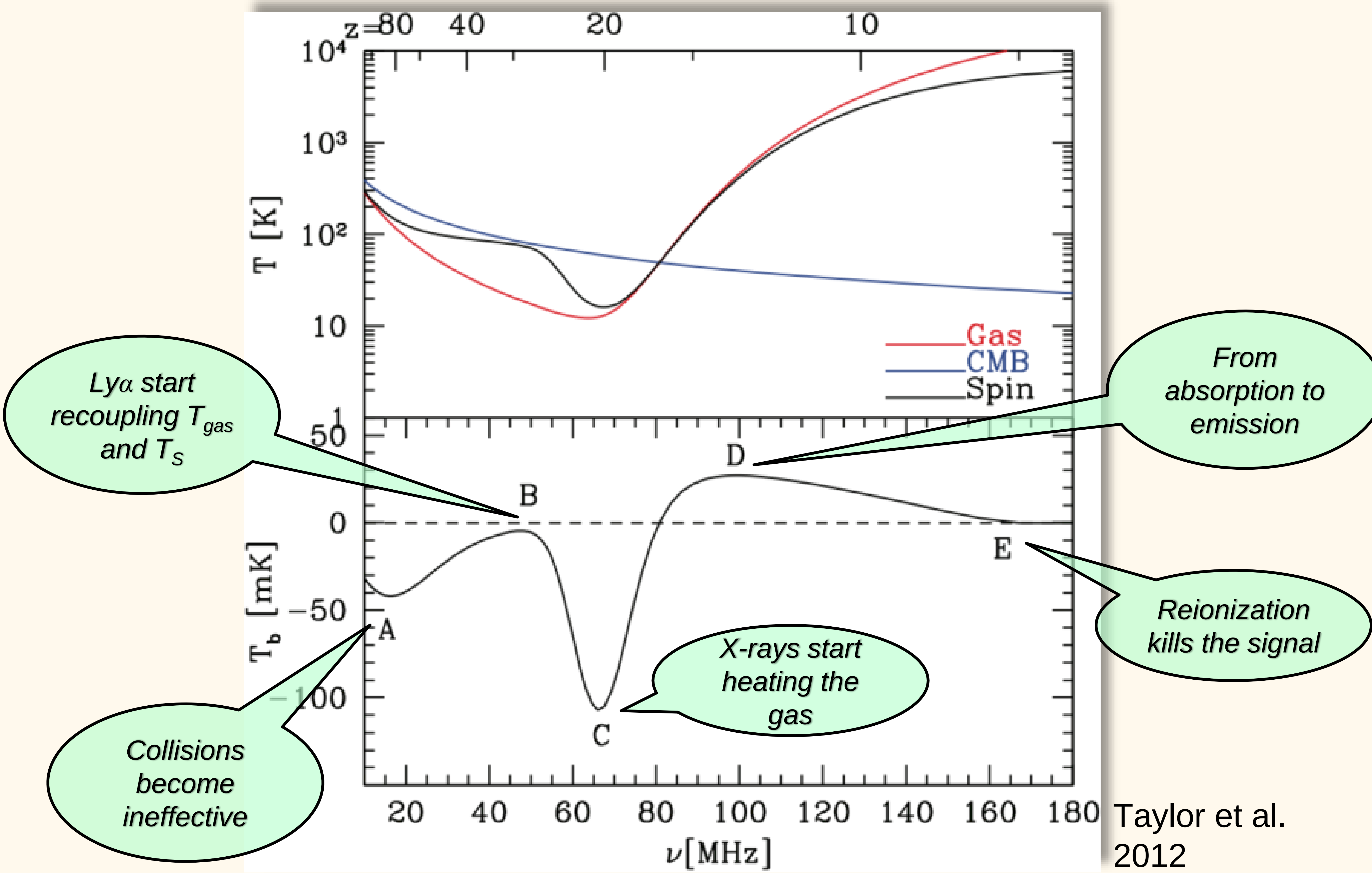
- Nothing happens until IGM thermally decouple, temperatures are all the same, zero signal
- After z~200 until z ~ 30, collisions keep $T_S \sim T_{IGM}$: since the IGM is colder, I have a signal *in absorption*
- After, no collisions, no other radiation: $T_S \sim T_{CMB}$, and I have zero signal
- And then? At some point, Ly-α photons recouple $T_S \sim T_\alpha \sim T_{IGM}$, 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

A figure is better



Pritchard & Loeb 2011 (1109.6012)

Example history and signal



Taylor et al. 2012 (1206.6733)

And where does DM enter?

- DM can (and will if it’s thermal) annihilate into SM: as any energy injection, it will heat the IGM in 2 ways
- Annihilations around thermal decoupling (z~150) *increase* the ionization fraction ⇒ IGM decouples later ⇒ it has less time to cool
- More importantly, annihilations directly heat the gas by energy injection
- We generically expect an increase of δT_b

Evolution with annihilating DM

$$\frac{\mathrm{d}x_e}{\mathrm{d}z} = \frac{\mathcal{P}_2}{(1+z)H(z)} \left[\alpha_H(T_{\rm gas}) n_{\rm H} x_e^2 - \beta_H(T_{\rm gas}) e^{-E_\alpha/T_{\rm gas}} (1-x_e) \right] + \\ - \frac{1}{(1+z)H(z)} \left. \frac{\mathrm{d}E}{\mathrm{d}V\mathrm{d}t} \right|_{\rm inj} \frac{1}{n_H} \left(\frac{f_{\rm ion}(z)}{E_0} + \frac{(1-\mathcal{P}_2) f_{\rm exc}(z)}{E_\alpha} \right)$$

$$\frac{\mathrm{d}T_{\rm gas}}{\mathrm{d}z} = \frac{1}{1+z} \left[2T_{\rm gas} - \gamma_{\rm C} \left(T_\gamma(z) - T_{\rm gas} \right) \right] + \\ - \frac{1}{(1+z)H(z)} \left. \frac{\mathrm{d}E}{\mathrm{d}V\mathrm{d}t} \right|_{\rm inj} \frac{1}{n_H} \frac{2 f_{\rm heat}(z)}{3(1 + x_e + f_{\rm He})}.$$

$$\left. \frac{\mathrm{d}E}{\mathrm{d}V\mathrm{d}t} \right|_{\rm inj} = \rho_{\rm DM}^2 f_{\rm DM}^2 \frac{\langle \sigma v \rangle}{M_{\rm DM}} \qquad \rho_{\rm DM}^2 \to \langle \rho_{\rm DM}^2 \rangle = B(z) \langle \rho_{\rm DM} \rangle$$

Efficiency factors

- CMB analyses sometimes use *instantaneous deposition* and *SSCK* prescription

$$f_{\rm ion}^{\rm SSCK} = f_{\rm exc}^{\rm SSCK} = f_{\rm eff}\frac{1-x_e}{3} \qquad f_{\rm heat}^{\rm SSCK} = f_{\rm eff}\frac{1+2x_e}{3}$$

- Our case (because of lower z and boost factor) is not so simple. Need to consider the *delayed deposition* in the *specific channels*

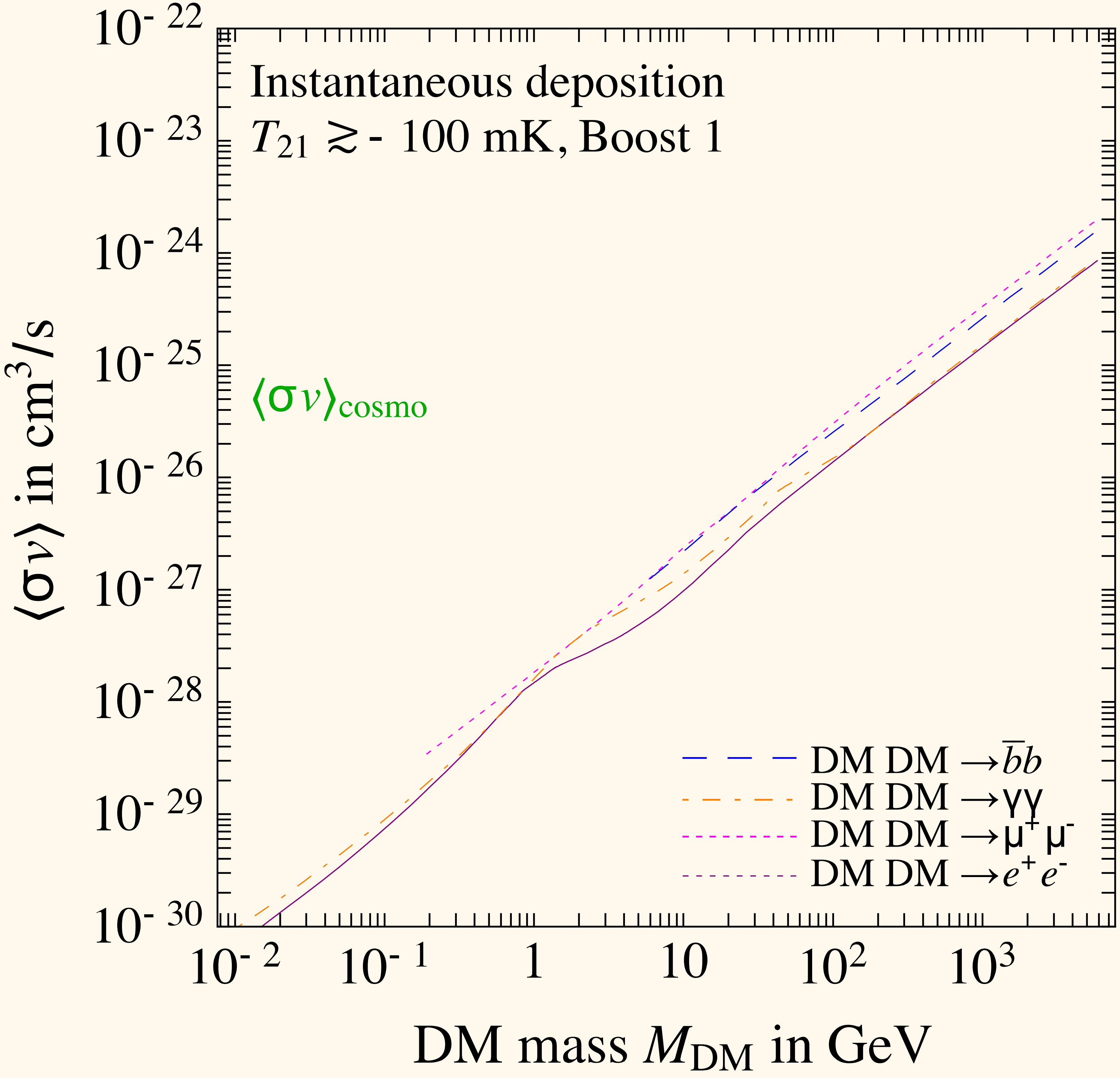
$$f_{\rm c}(z) = \frac{\int {\rm d}\ln(1+z')\int {\rm d}E\, T_{\rm c}(z,E,z') E\frac{{\rm d}N}{{\rm d}E{\rm d}V{\rm d}t}(E,z') H^{-1}(z')(1+z')^{-3}}{H^{-1}(z)(1+z)^{-3}\int {\rm d}E E\frac{{\rm d}N}{{\rm d}E{\rm d}V{\rm d}t}(E,z')}$$

Slatyer
1506.03811,
1506.03812

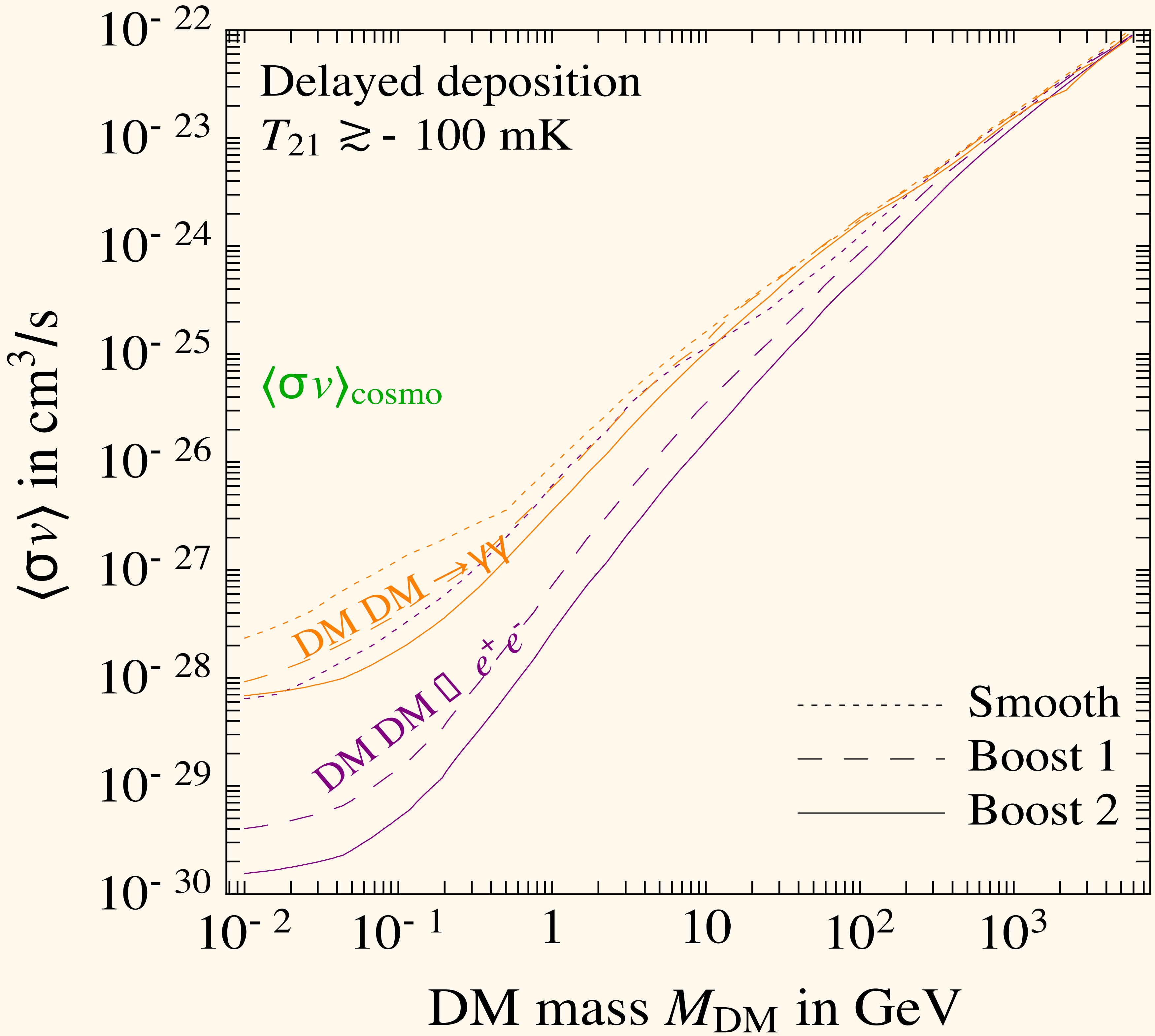
How do we put bounds

- Signal is lower than expected (and maybe not even cosmological?). *We do not try to explain it!*
- From annihilation, we expect an increase in δT_b
- 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, $T_S = T_{IGM}$ which gives me the strongest absorption $\delta T_b \approx -200\mathrm{mK}$.
  What should I require of DM to get heated to no more than $50\%\ \delta T_b$ or $25\%\ \delta T_b$?

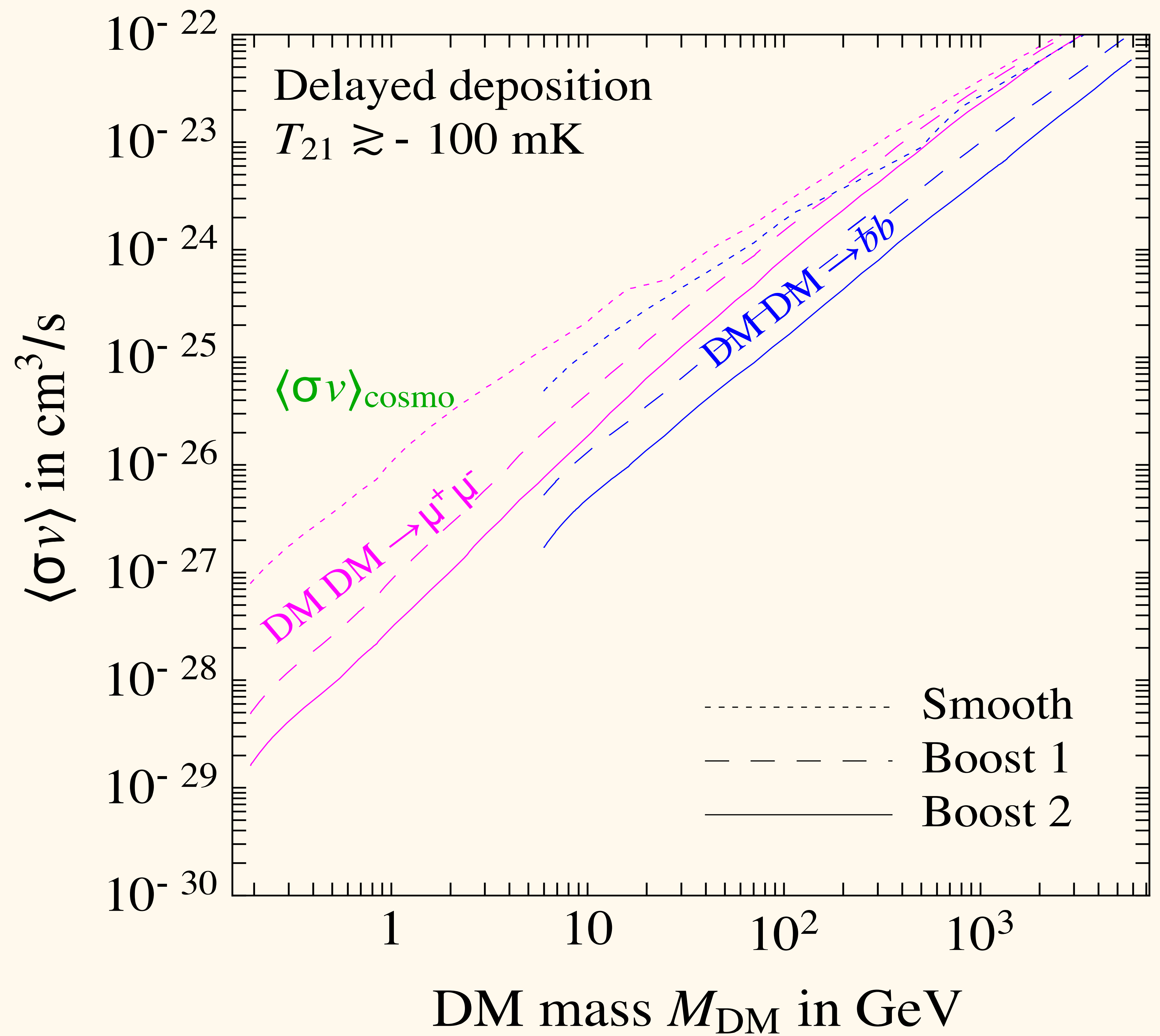
Our bounds, instantaneous deposition



Our bounds: $\gamma\gamma$ and e^+e^-



Our bounds: $b\bar{b}$ and $\mu^+\mu^-$



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?
  Stay tuned for developments!

Thank you!