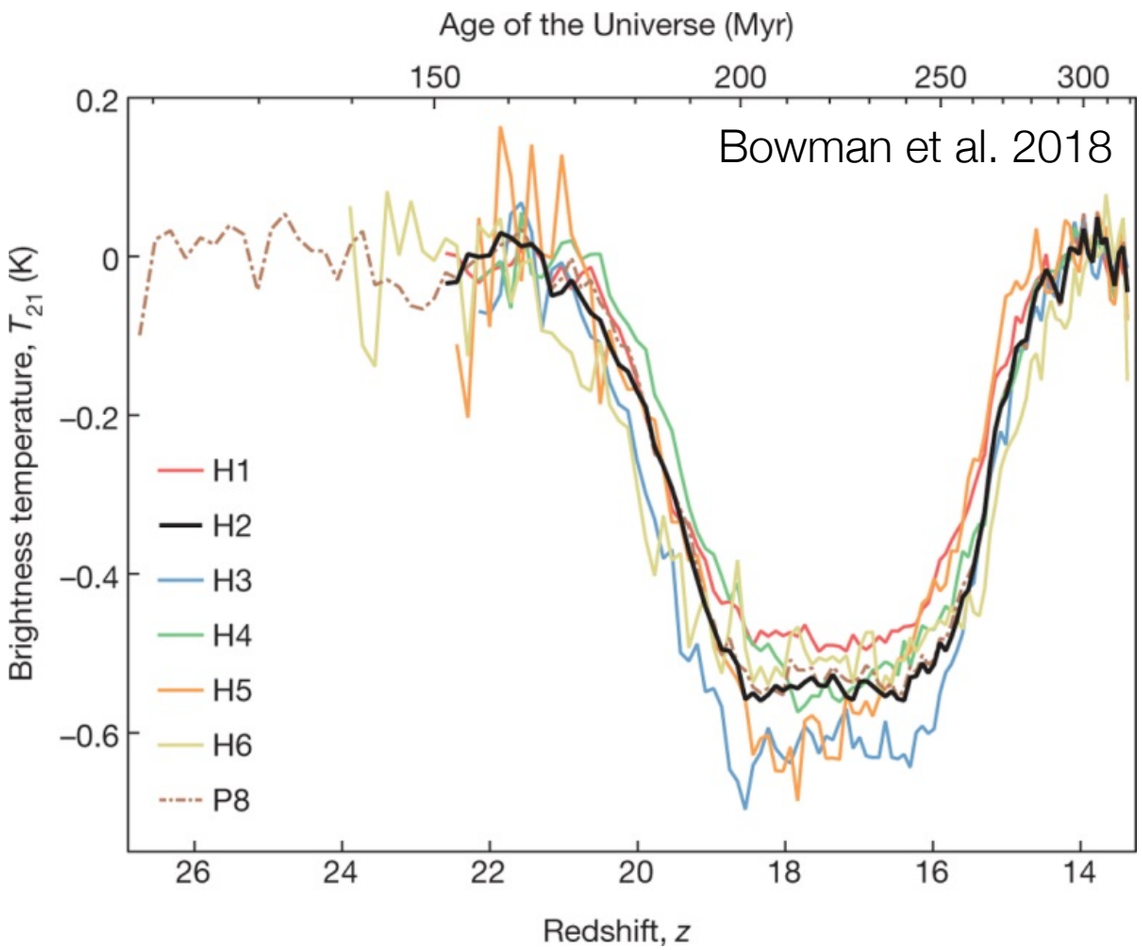
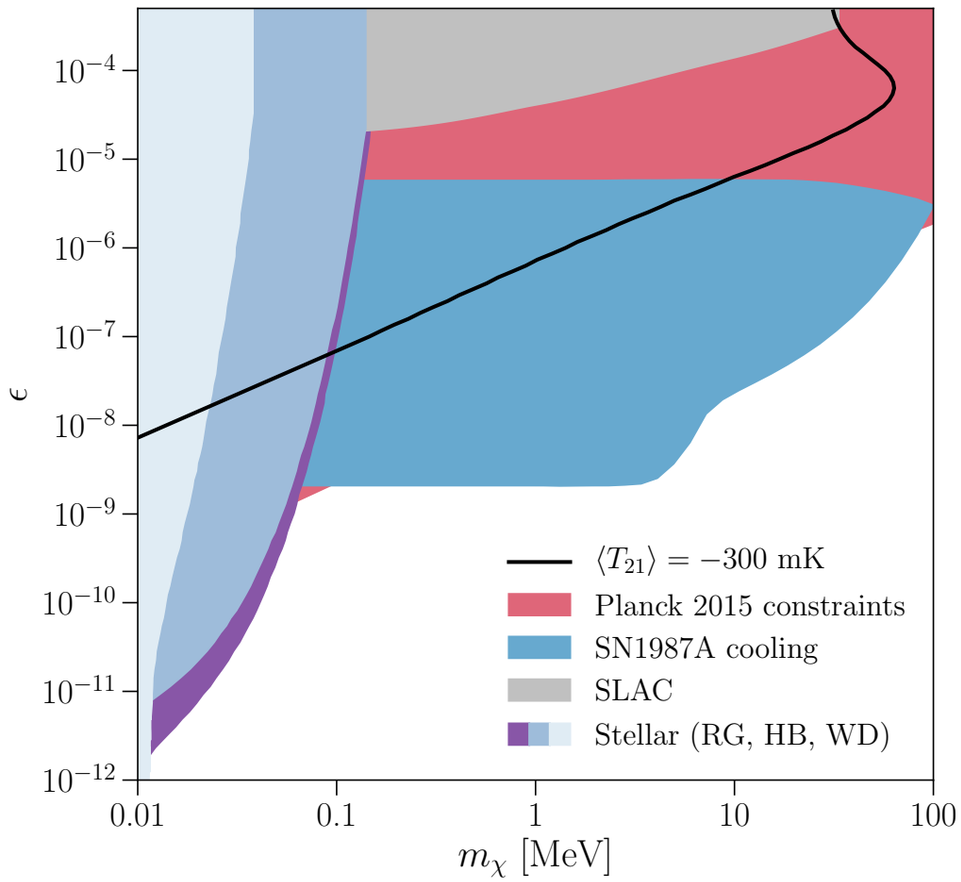
21-cm cosmology and connections to dark sectors

Jordan Mirocha (McGill)



Kovetz et al. 2018

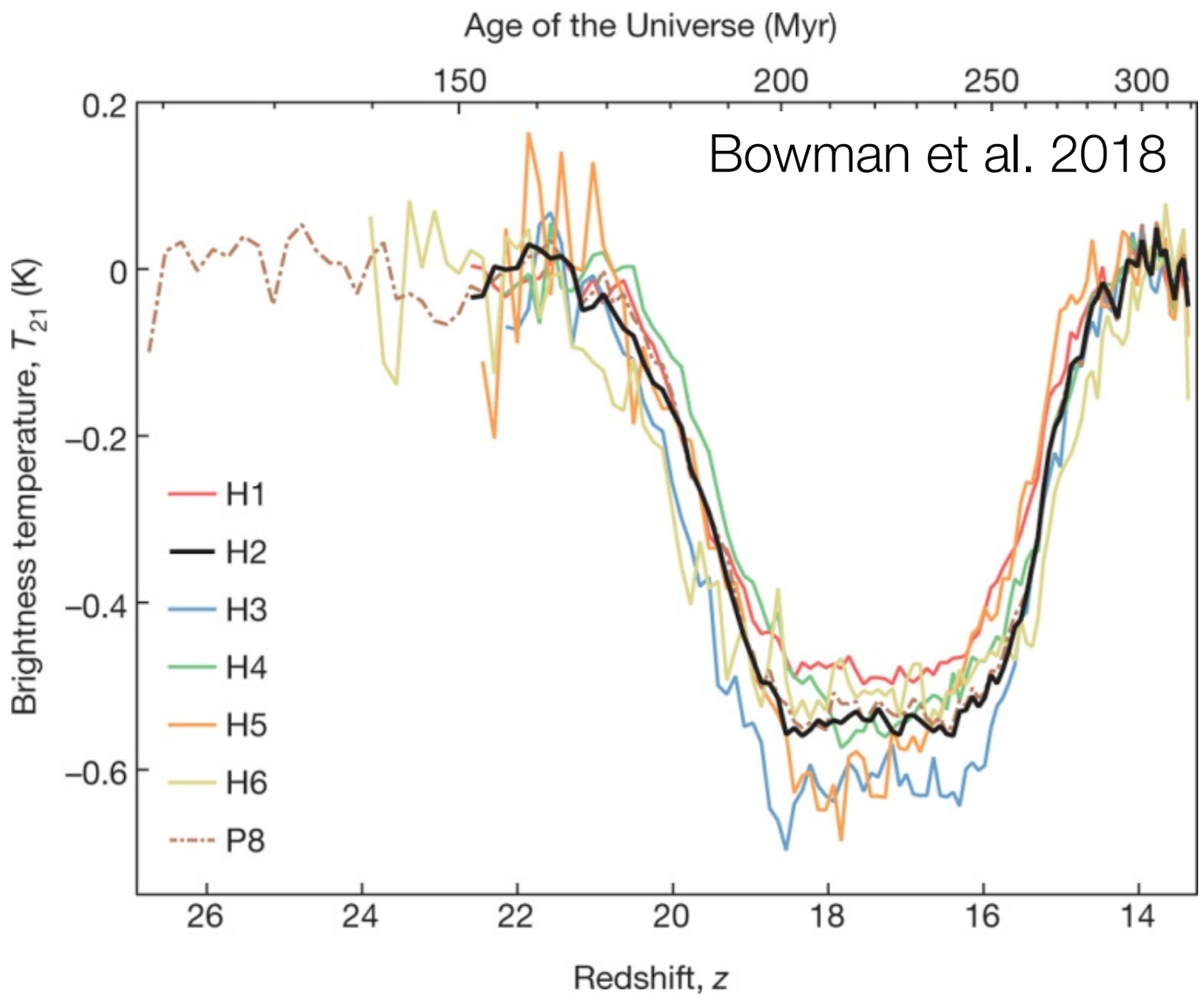


Outline

I. What is the global 21-cm signal? What is weird about the EDGES signal?

II. What are the leading ideas for the anomalous depth of the EDGES signal?

III. What does the EDGES signal tell us about galaxy formation? (*How does our ignorance about galaxy formation limit DM inference?)*



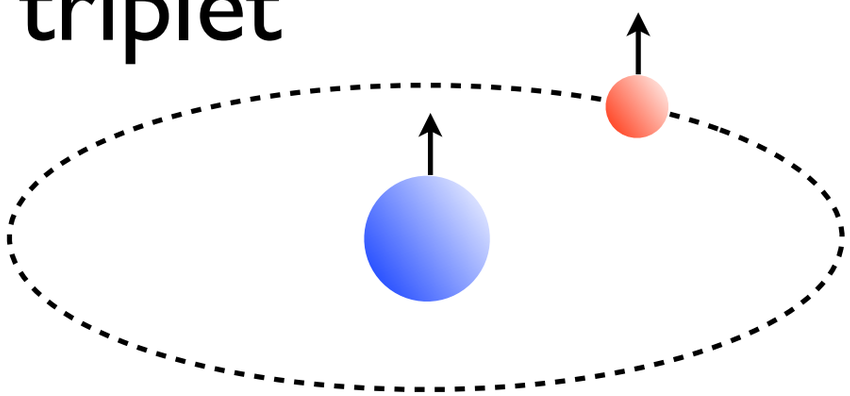
Part I:

The Global 21-cm Signal*

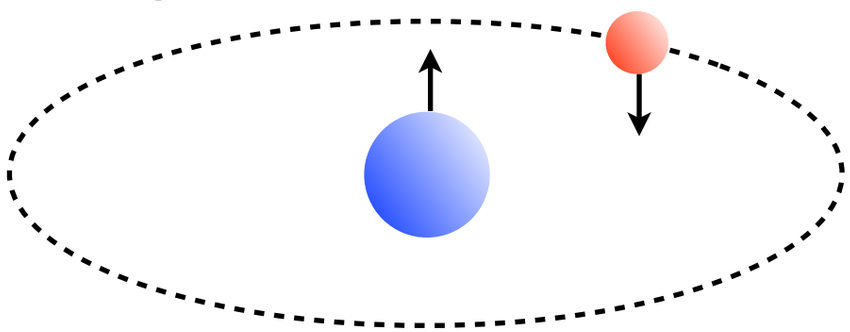
*Madau et al. (1997), Shaver et al. (1999)

21-cm Physics

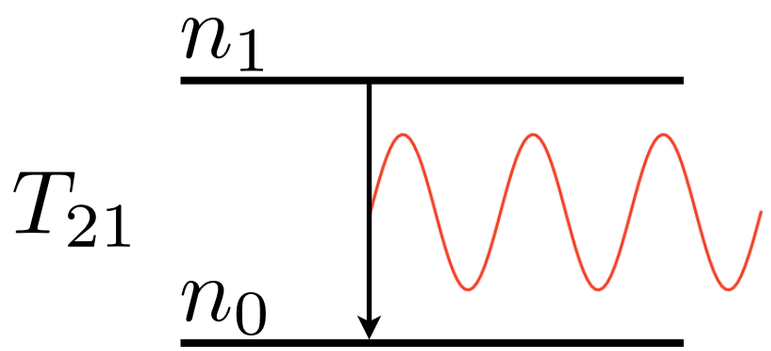
triplet



singlet



Ground-state hyper-fine splitting

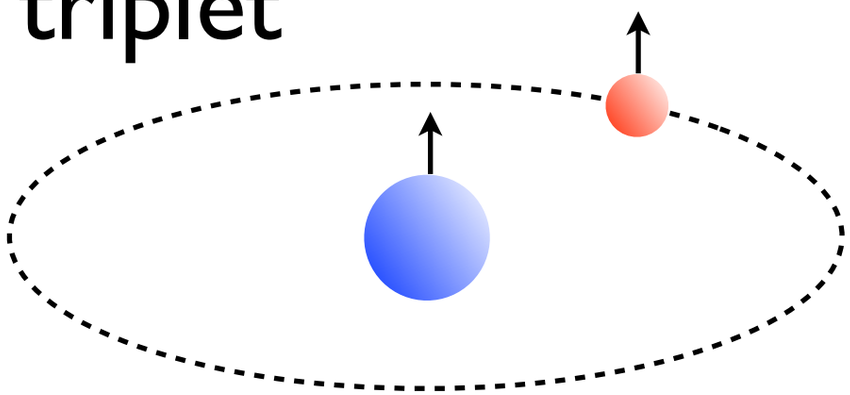


$\lambda = 21$ cm

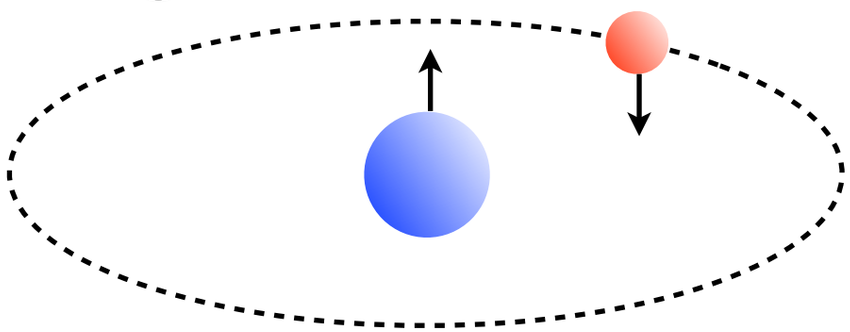
$$\frac{n_1}{n_0} = \frac{g_1}{g_0} \exp\left[T_{21}/T_S\right]$$

21-cm Physics

triplet



singlet



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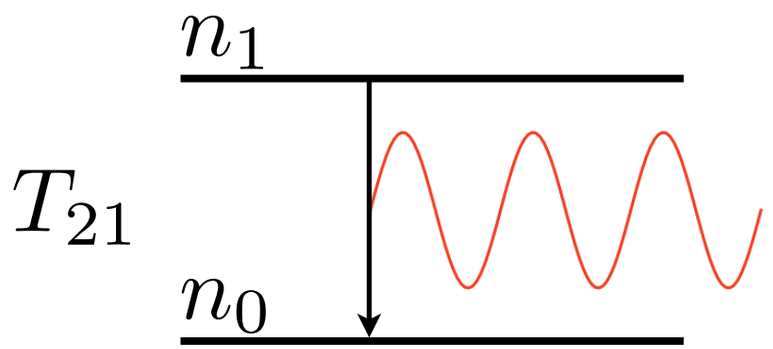


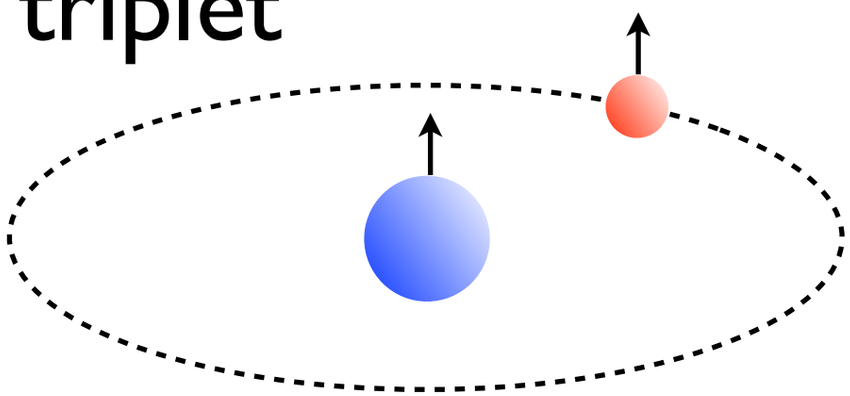
$\lambda = 21$ cm

$$\frac{n_1}{n_0} = \frac{g_1}{g_0} \exp\left[T_{21}/T_S\right]$$

$$T_S = T_S(n_{\rm H}, n_e, T_K, T_\gamma, J_\alpha)$$

21-cm Physics

triplet



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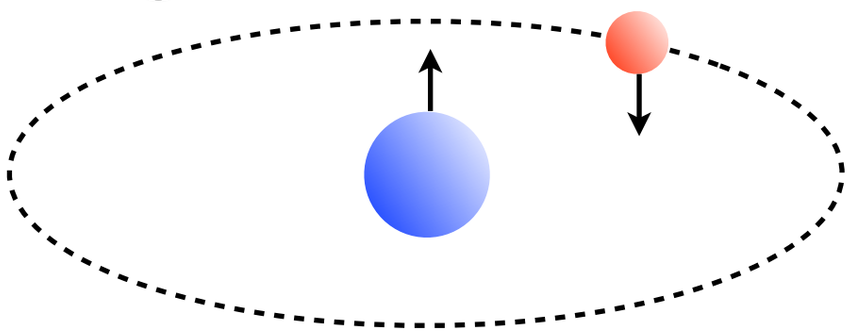
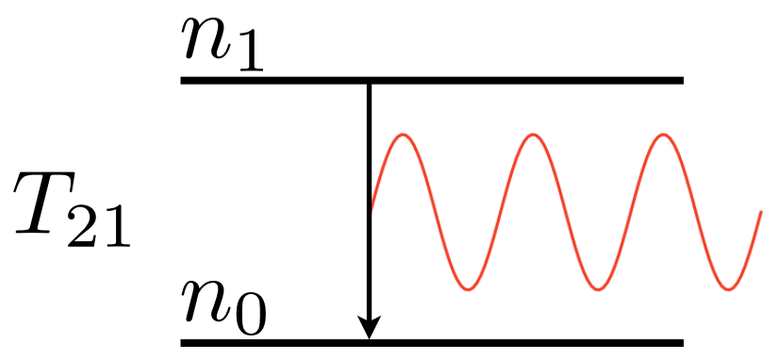


Ground-state hyper-fine splitting



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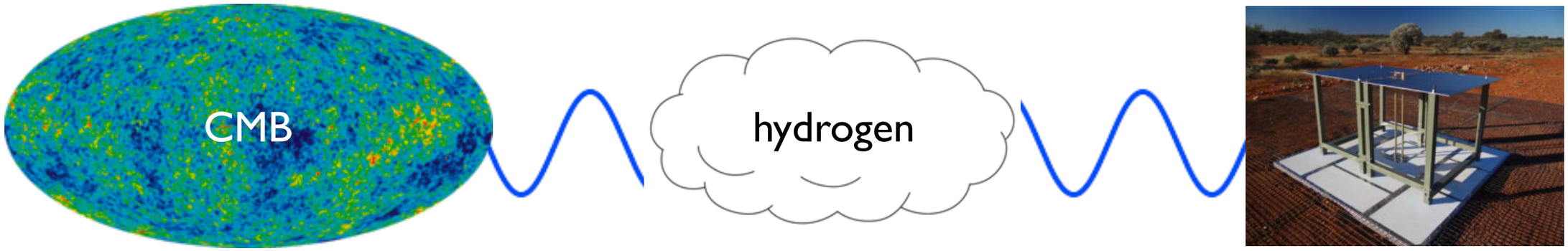
...?

21-cm Physics

T_γ T_S δT_b



Adapted from J. Pritchard

e.g., EDGES

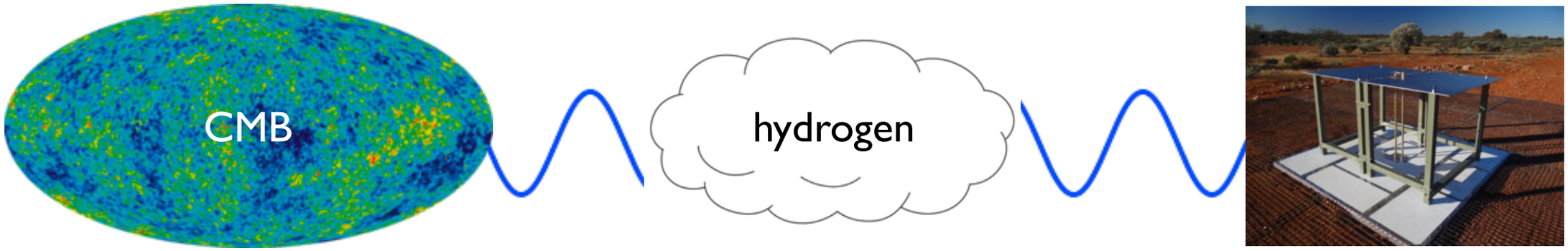
"Differential brightness temperature":

$$\delta T_b \simeq 27\, \overline{x}_{\mathrm{H\ I}} (1+\delta) \left(\frac{1+z}{10}\right)^{1/2} \left(1 - \frac{T_{\mathrm{CMB}}}{T_{\mathrm{S}}}\right)\ \mathrm{mK}$$

e.g., Furlanetto (2006)

21-cm Physics

T_γ T_S δT_b



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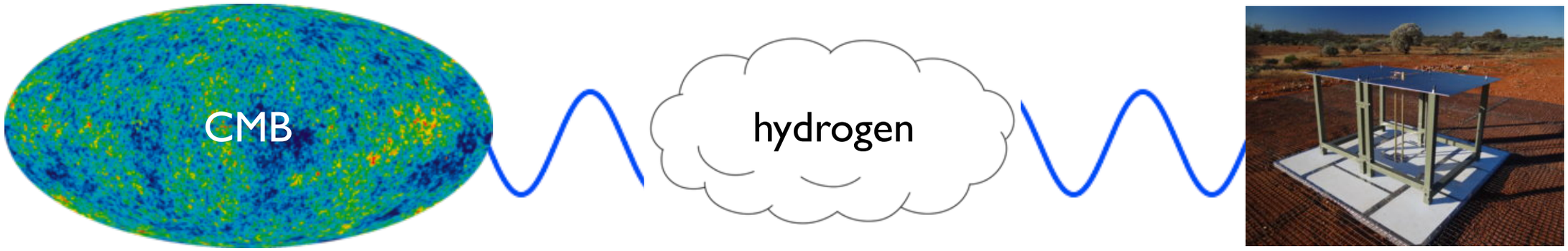

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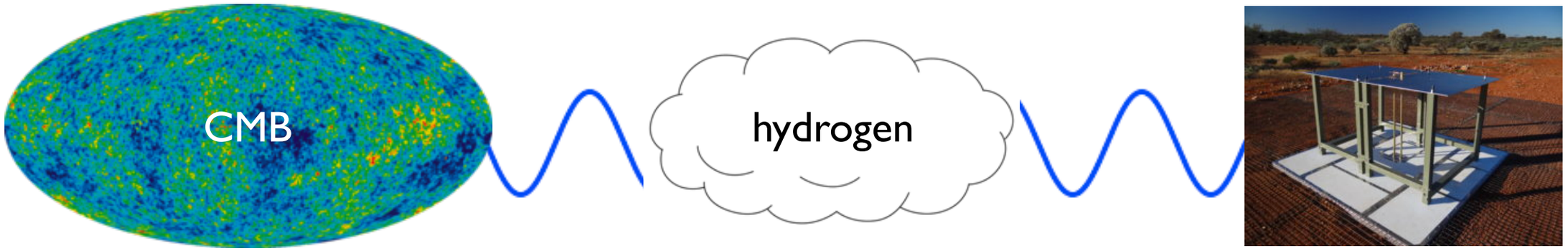
0

for global signal

e.g., Furlanetto (2006)

21-cm Physics

T_γ T_S δT_b



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21-cm Physics

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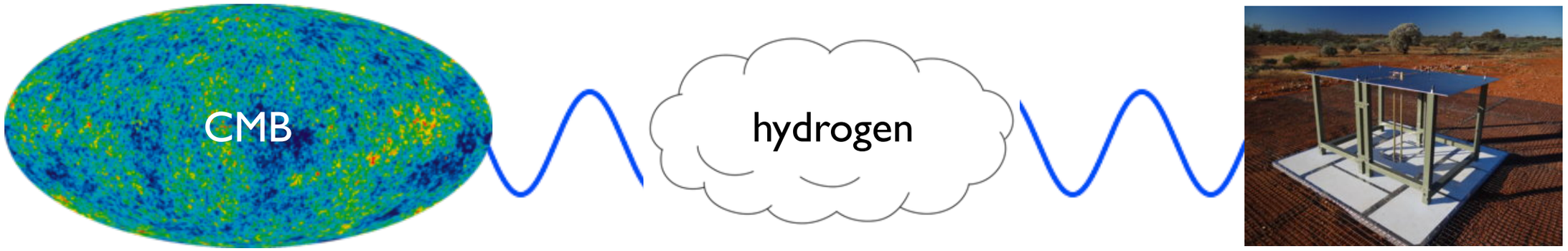


Adapted from J. Pritchard

e.g., EDGES

"Differential brightness temperature":

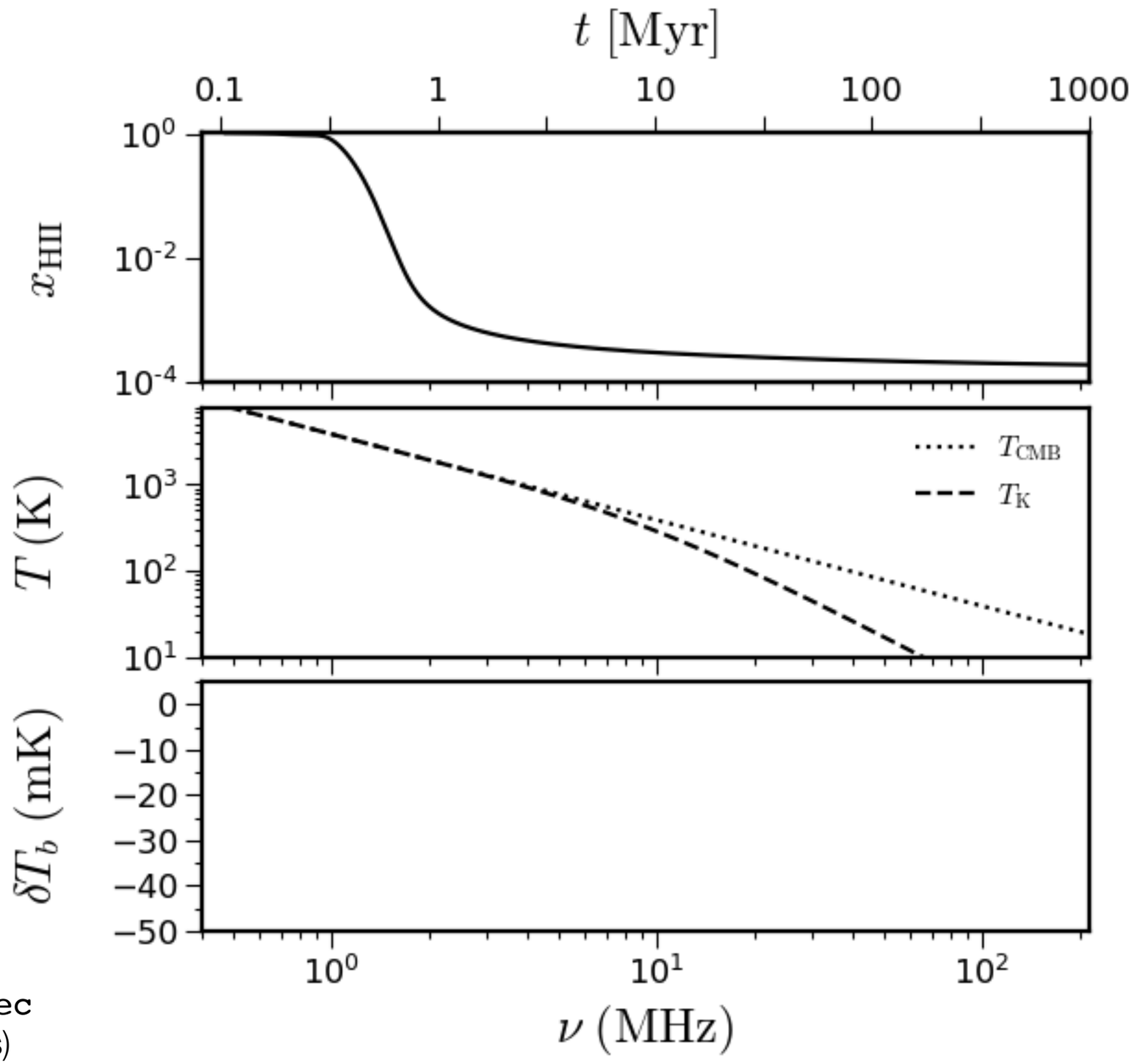
$$\delta T_b \simeq 27 \overline{x}_{\rm H\ I}(1+\delta)\left(\frac{1+z}{10}\right)^{1/2}\left(1-\frac{T_{\rm CMB}}{T_{\rm S}}\right)\ {\rm mK}$$

$\delta \to 0$ for global signal

$T_{\rm CMB} \to T_R$

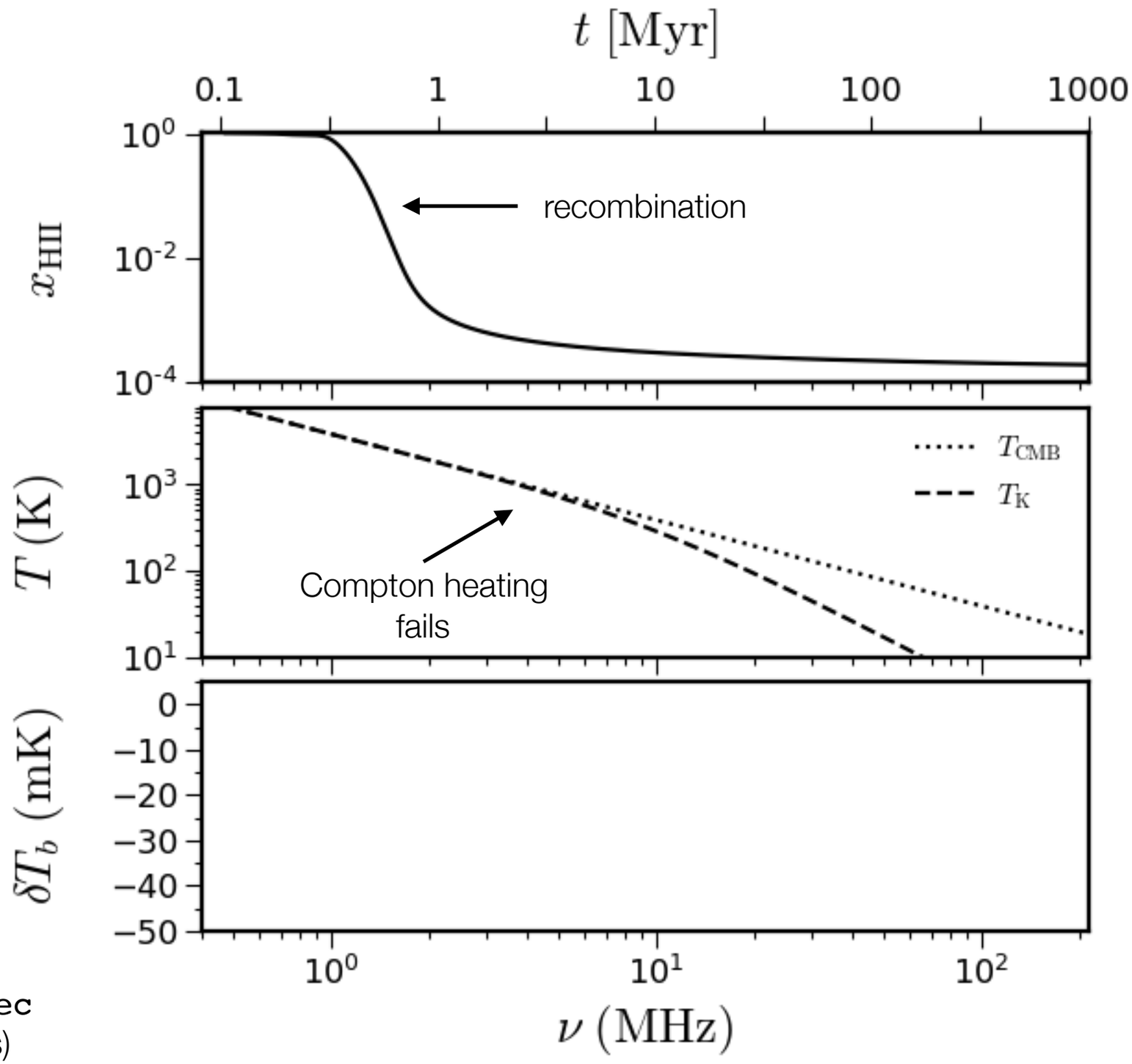
e.g., Furlanetto (2006)

Expectations w/o Astrophysics



Made w/ **`CosmoRec`**
(Chluba & Thomas)

Expectations w/o Astrophysics



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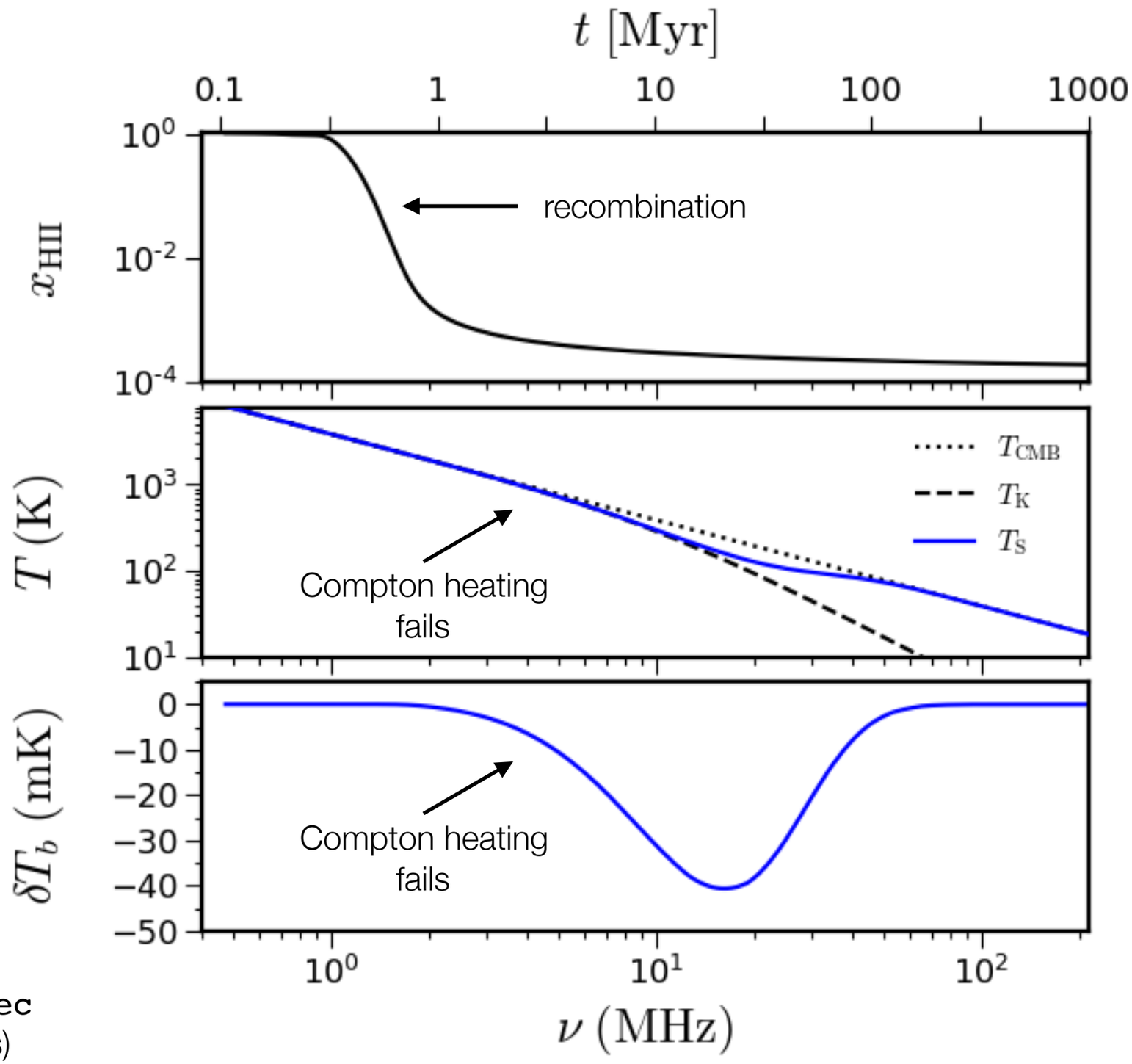

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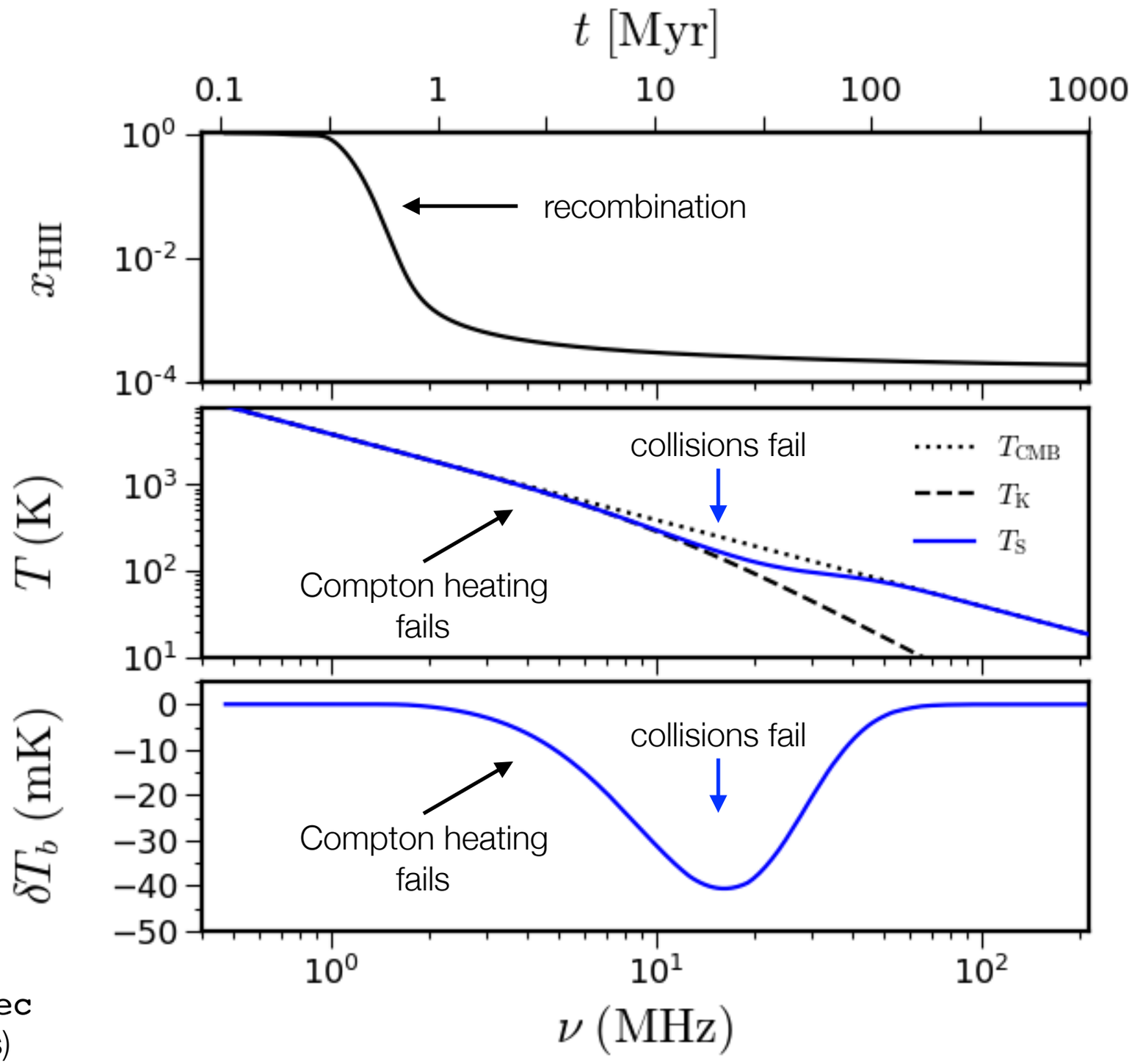
Expectations w/o Astrophysics



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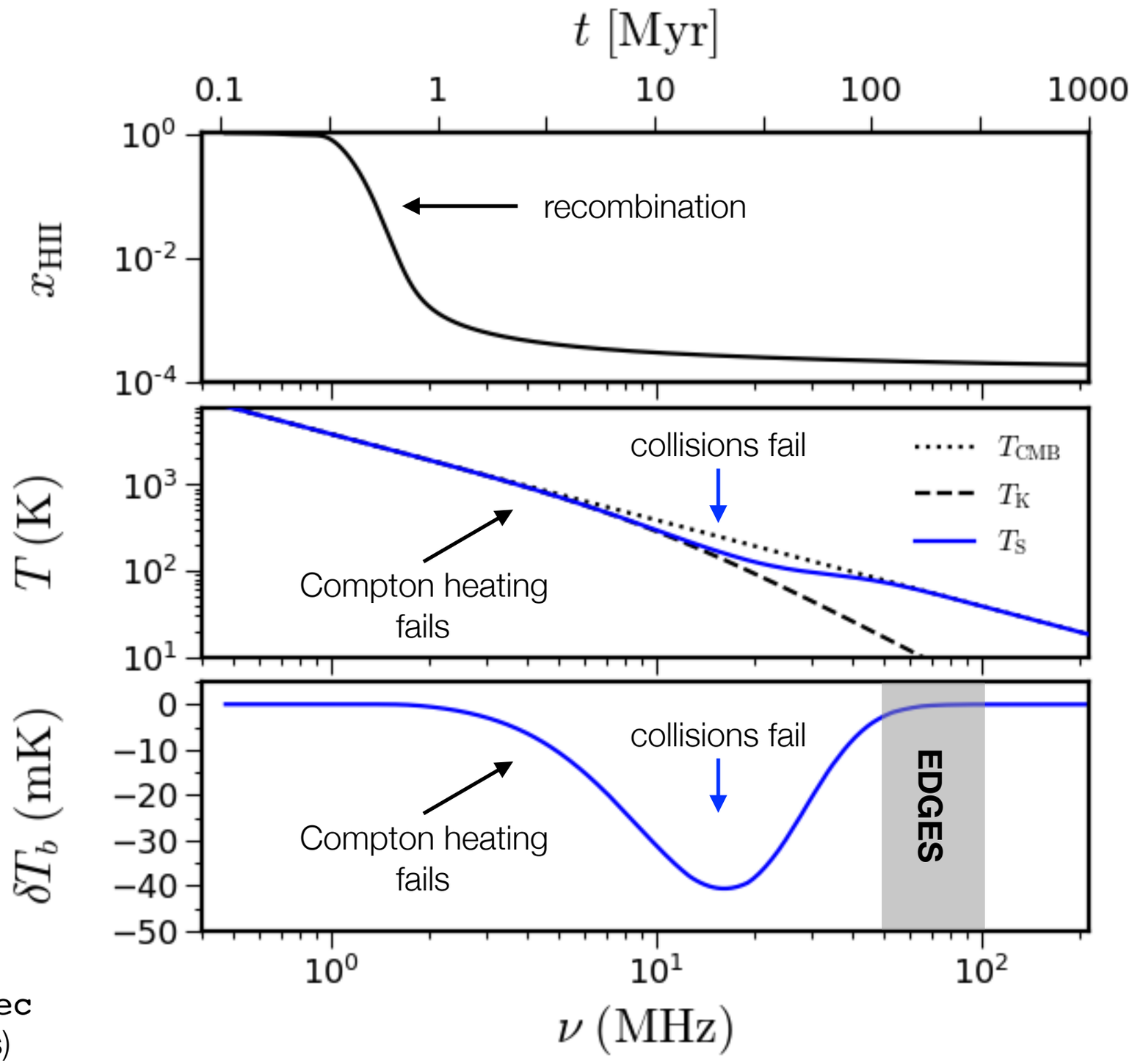
Expectations w/o Astrophysics

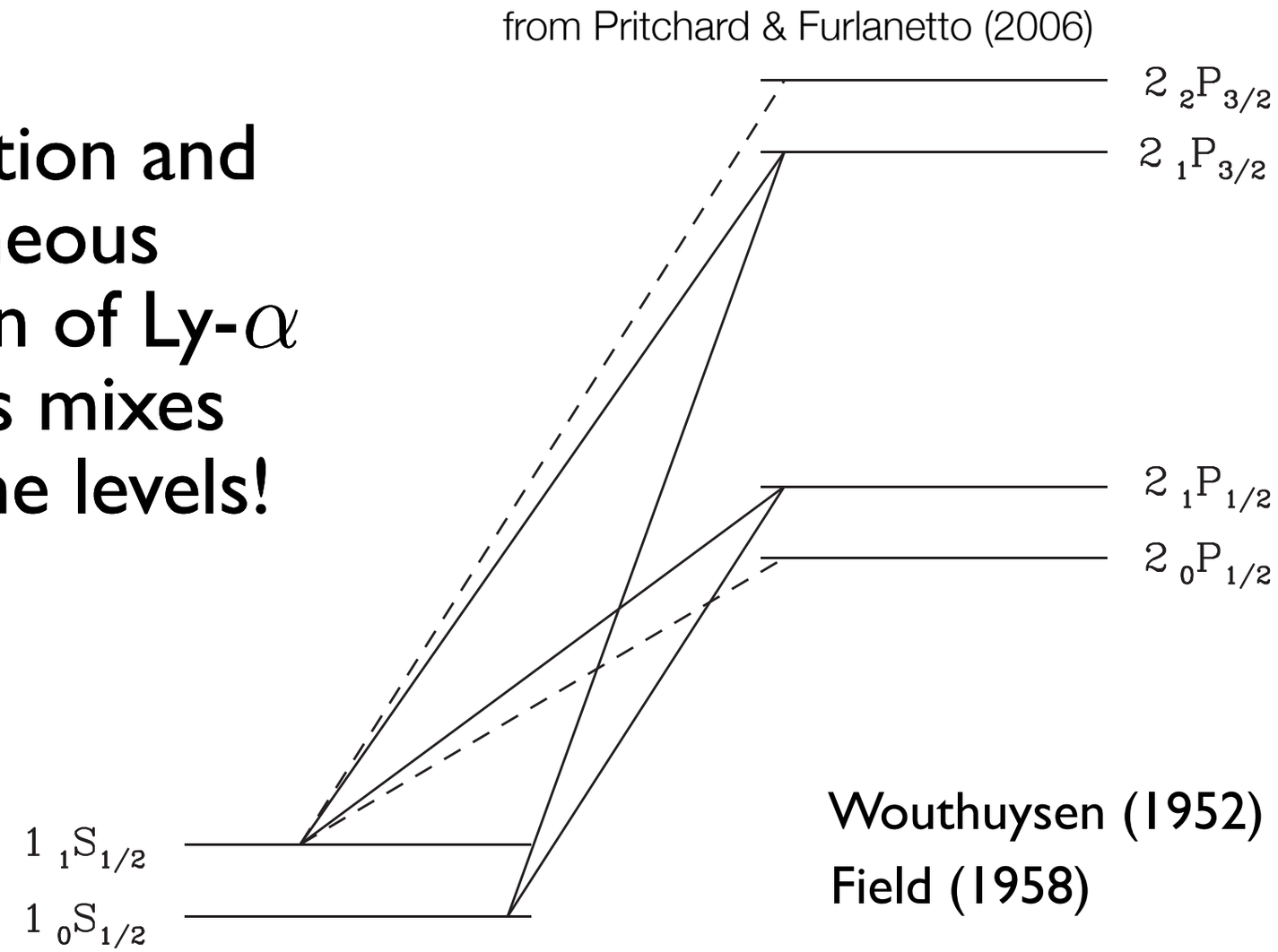


Made w/ **`CosmoRec`**
(Chluba & Thomas)

So why is there a signal beyond ~30 MHz?

Wouthuysen*-Field Effect

Absorption and spontaneous emission of Ly-α photons mixes hyperfine levels!

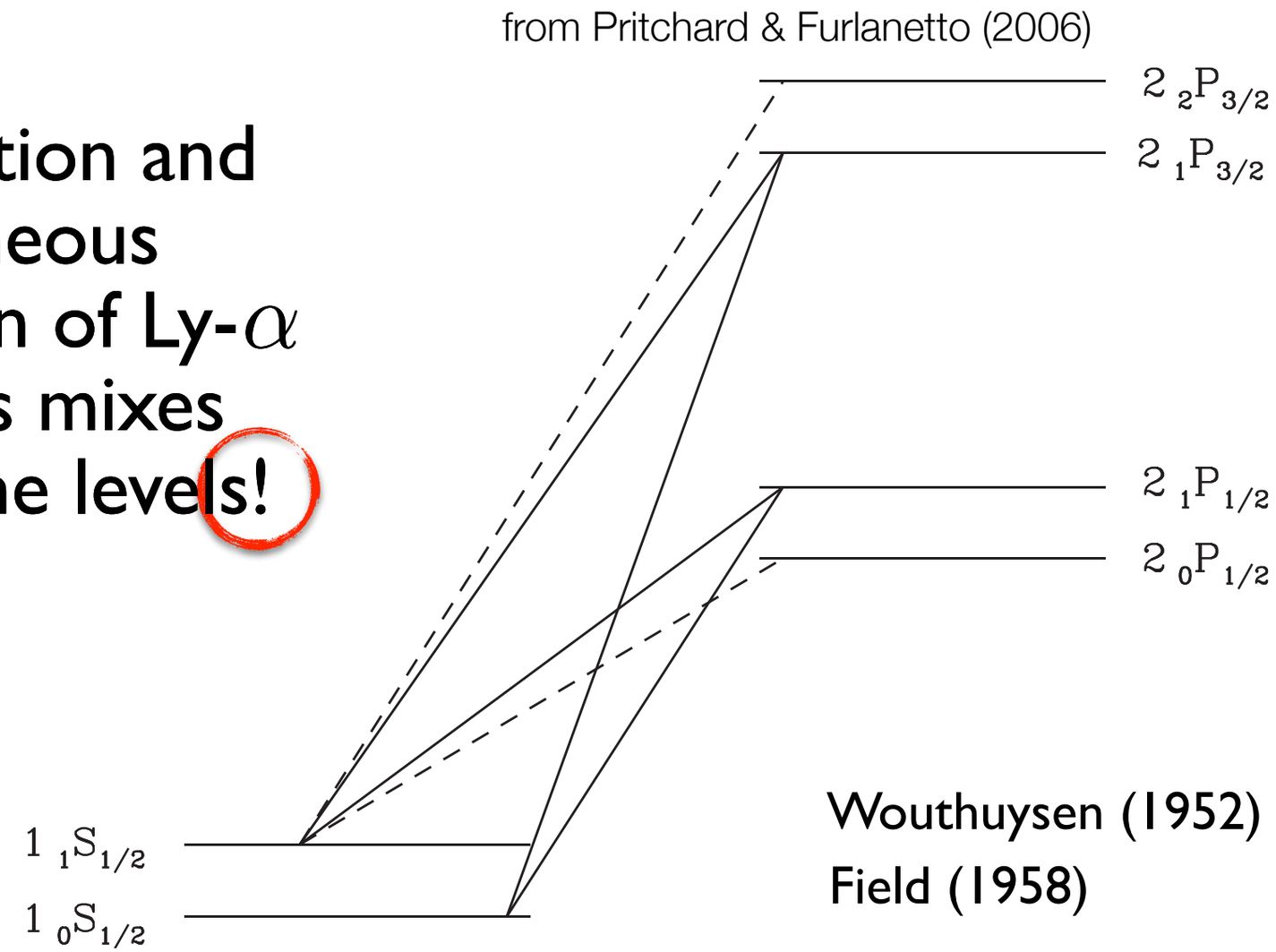


Wouthuysen (1952)
Field (1958)

*vowt-how-sen

Wouthuysen*-Field Effect

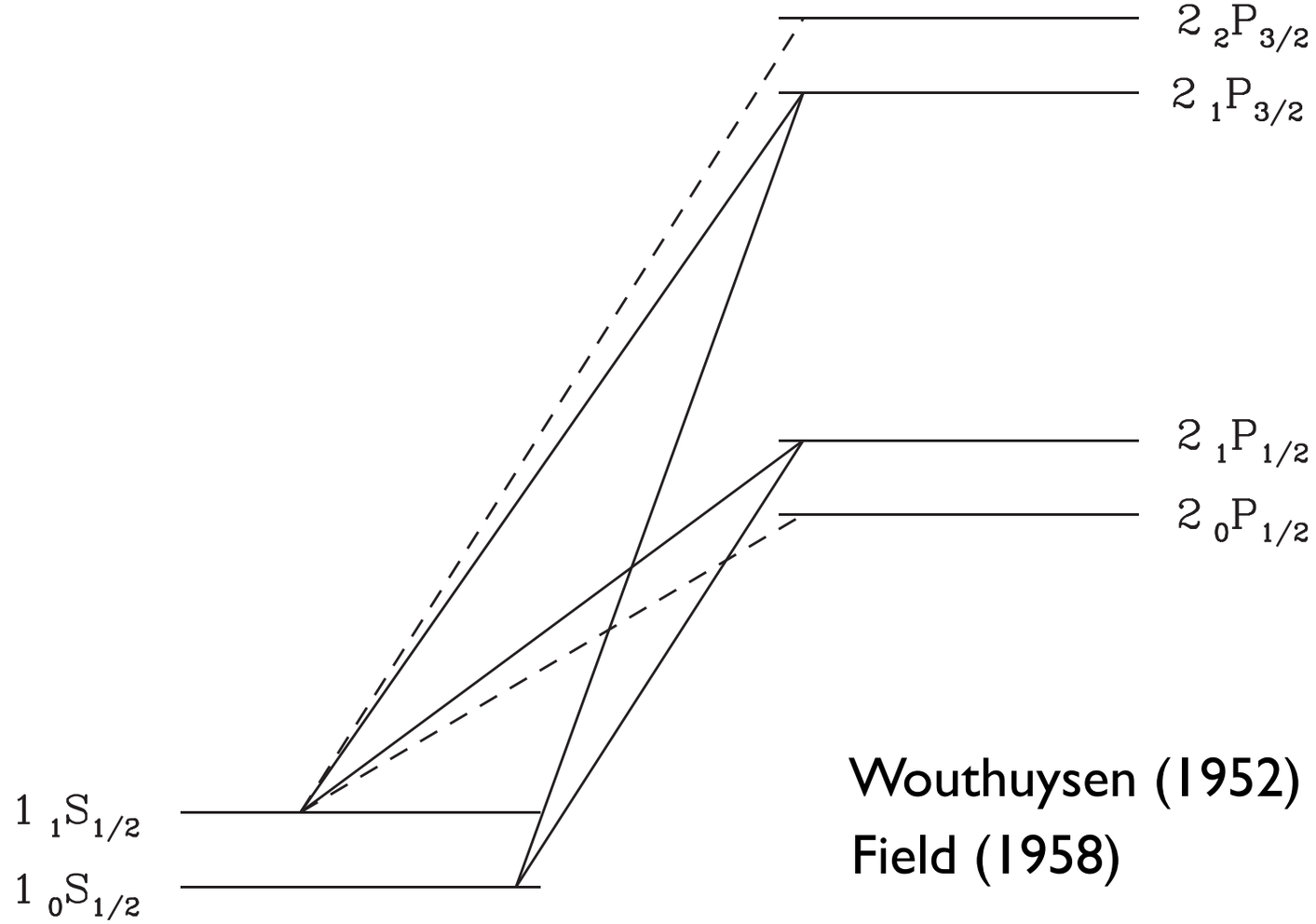
Absorption and spontaneous emission of Ly-α photons mixes hyperfine levels!



*vowt-how-sen

Wouthuysen*-Field Effect

from Pritchard & Furlanetto (2006)

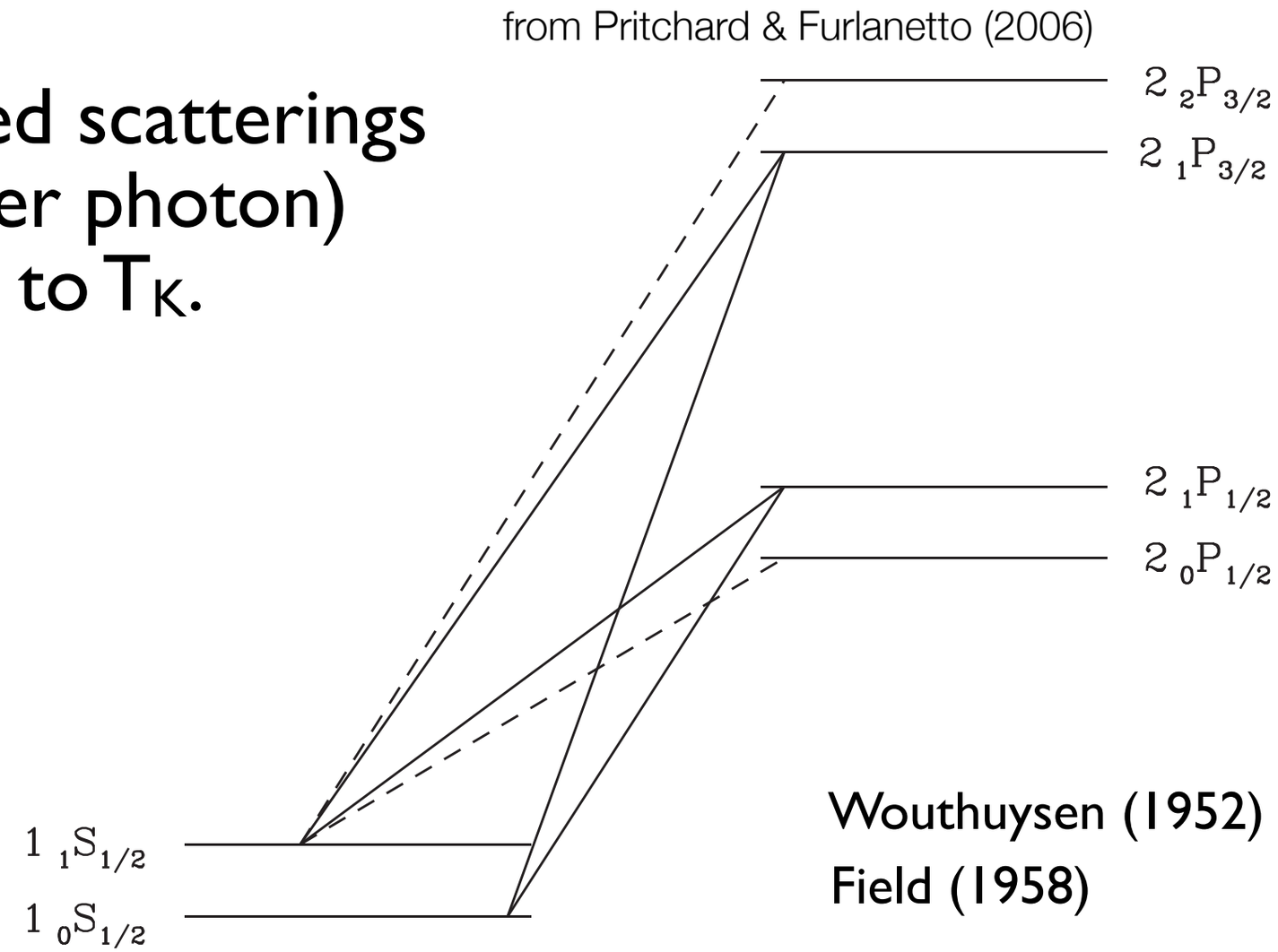


Wouthuysen (1952)
Field (1958)

*vowt-how-sen

Wouthuysen*-Field Effect

Repeated scatterings (~10^6 per photon) drive T_S to T_K.



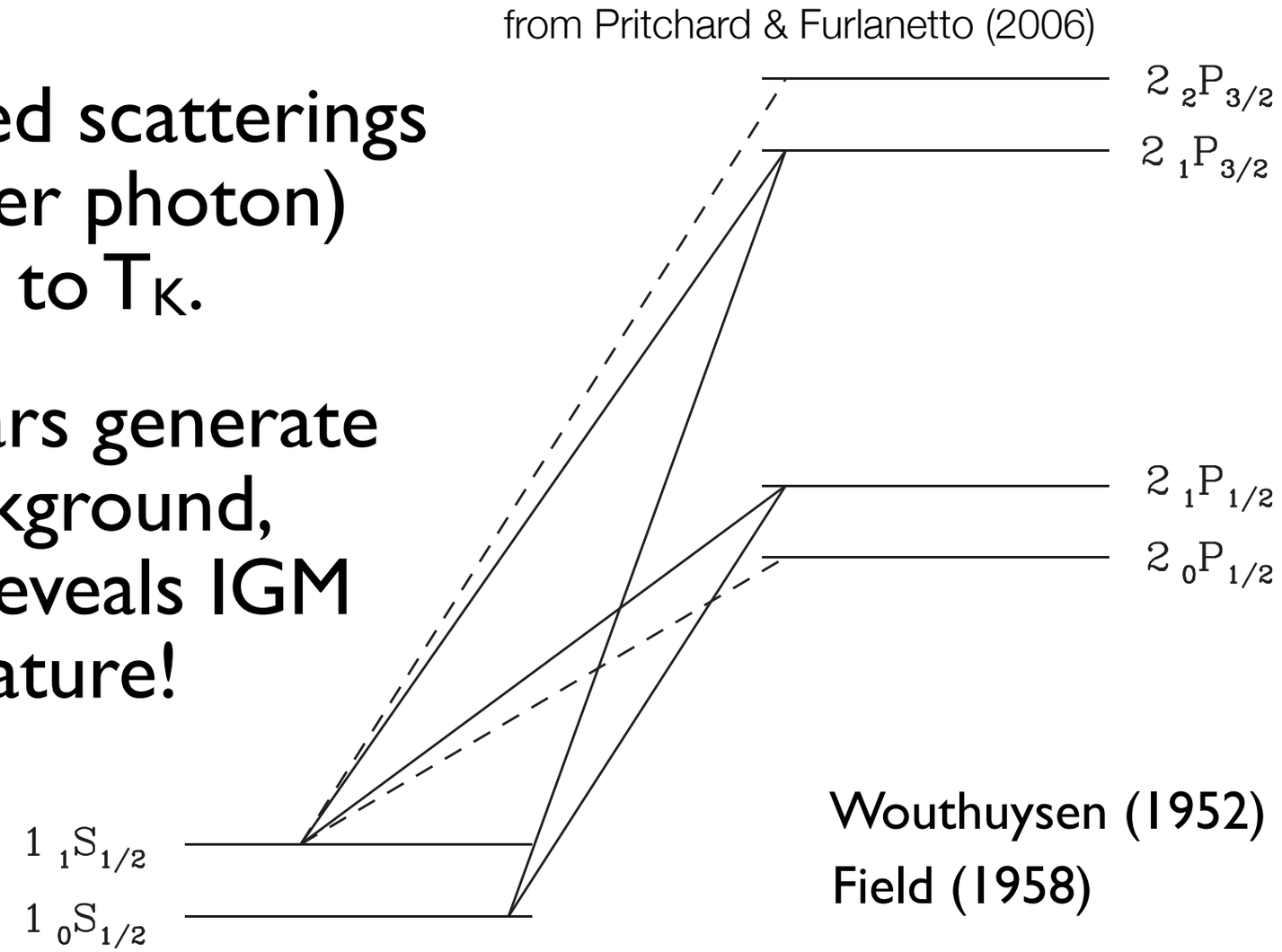
*vowt-how-sen

Wouthuysen*-Field Effect

Repeated scatterings (~10^6 per photon) drive T_S to T_K.

First stars generate UV background, which reveals IGM temperature!

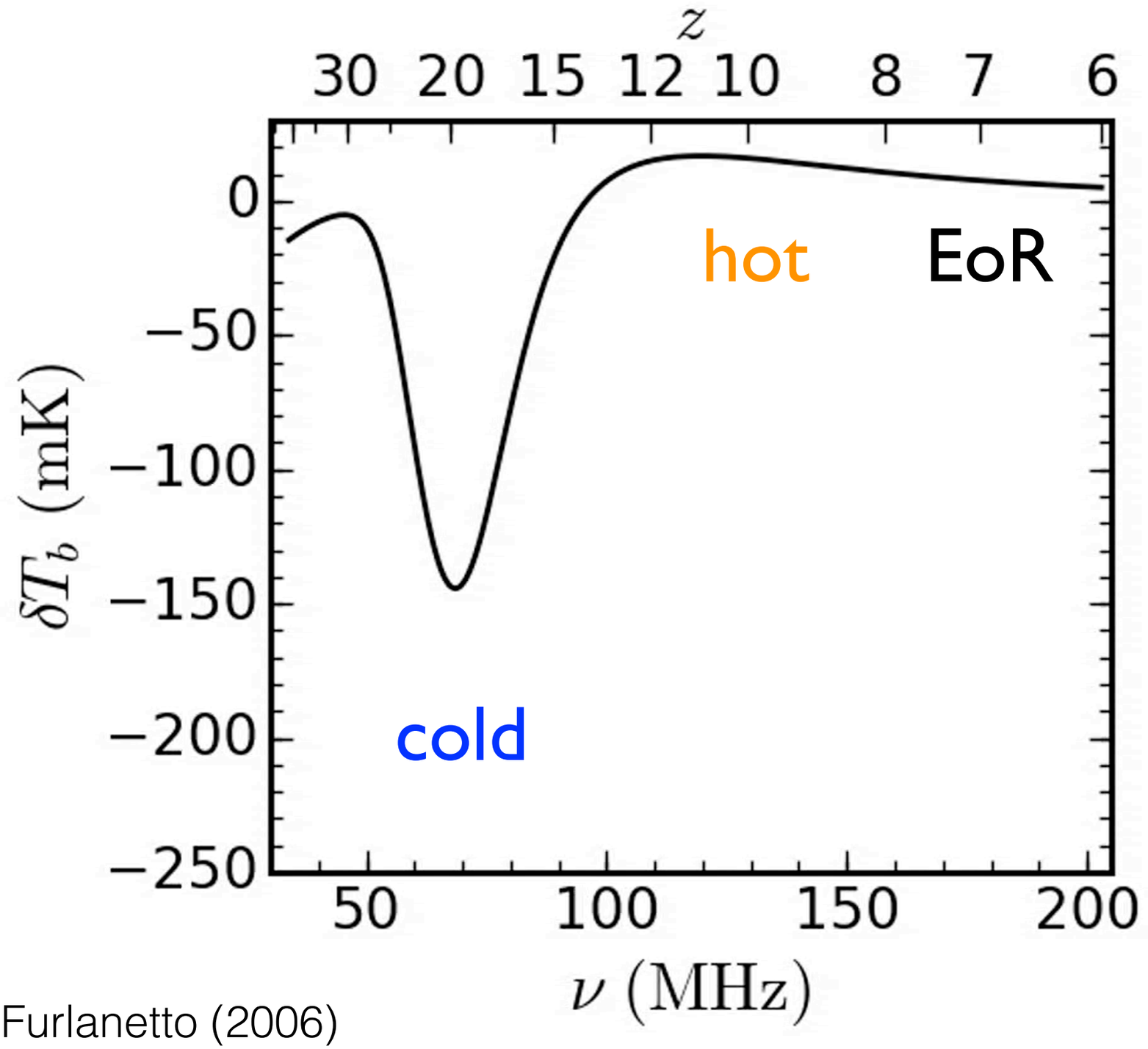
from Pritchard & Furlanetto (2006)



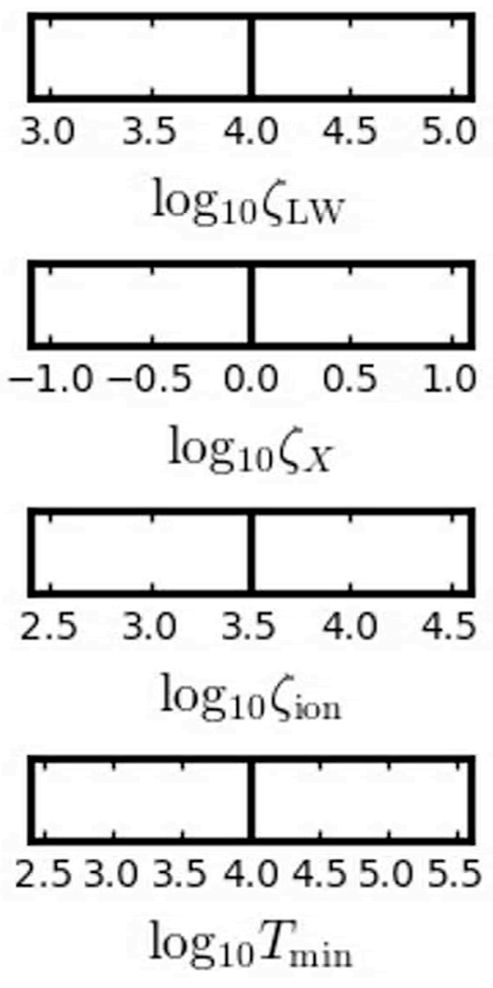
Wouthuysen (1952)
Field (1958)

*vowt-how-sen

The Global 21-cm Signal



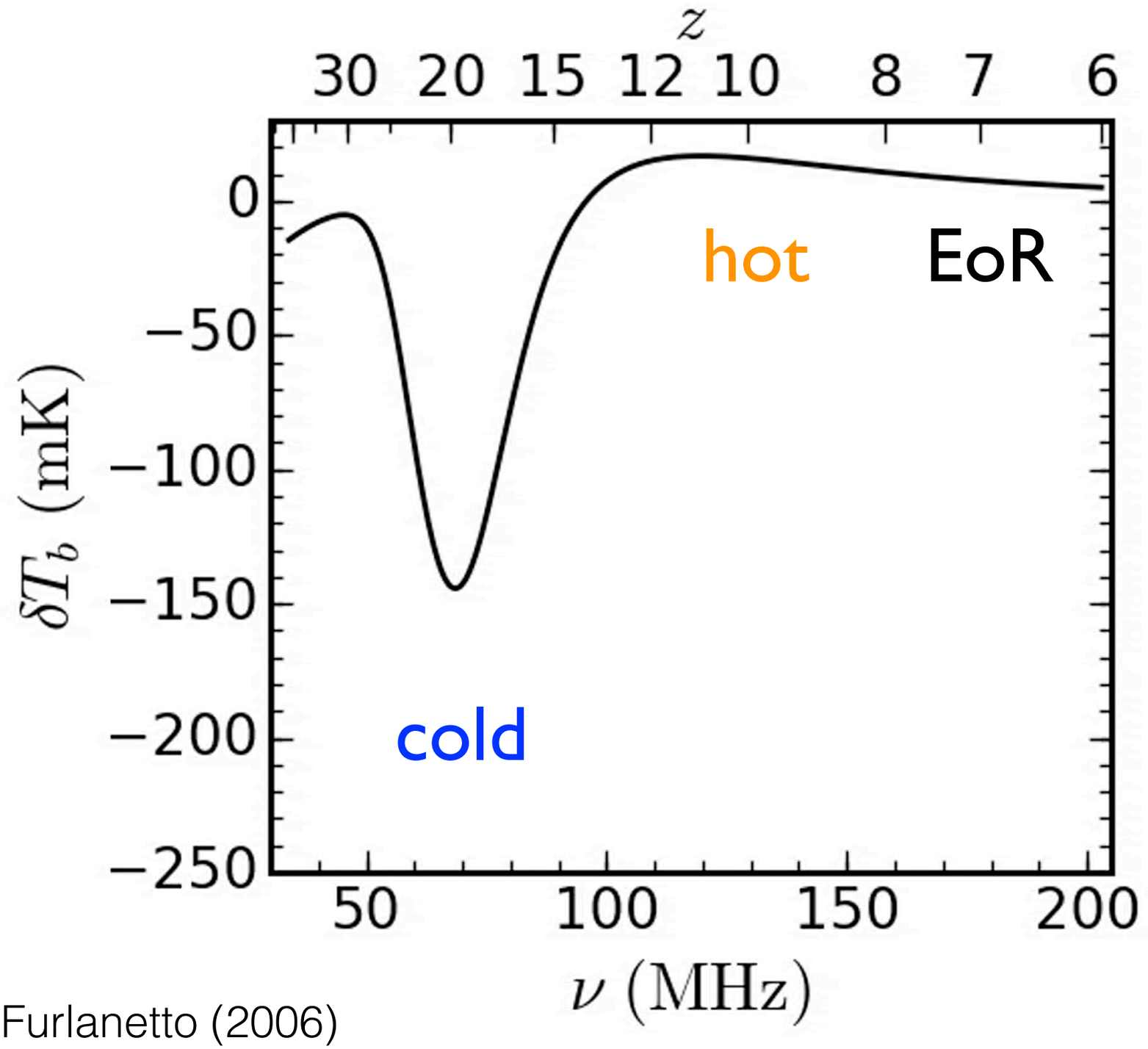
$$\mathrm{SFRD} \propto f_* \frac{df_{\mathrm{coll}}}{dt}$$



$$\zeta_i = f_* N_i f_{\mathrm{esc},i}$$

e.g., Furlanetto (2006)

The Global 21-cm Signal



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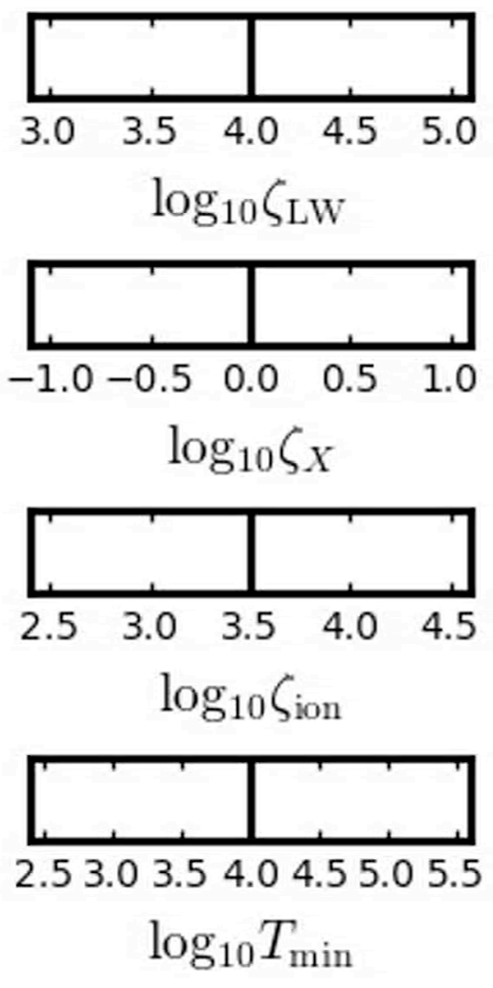

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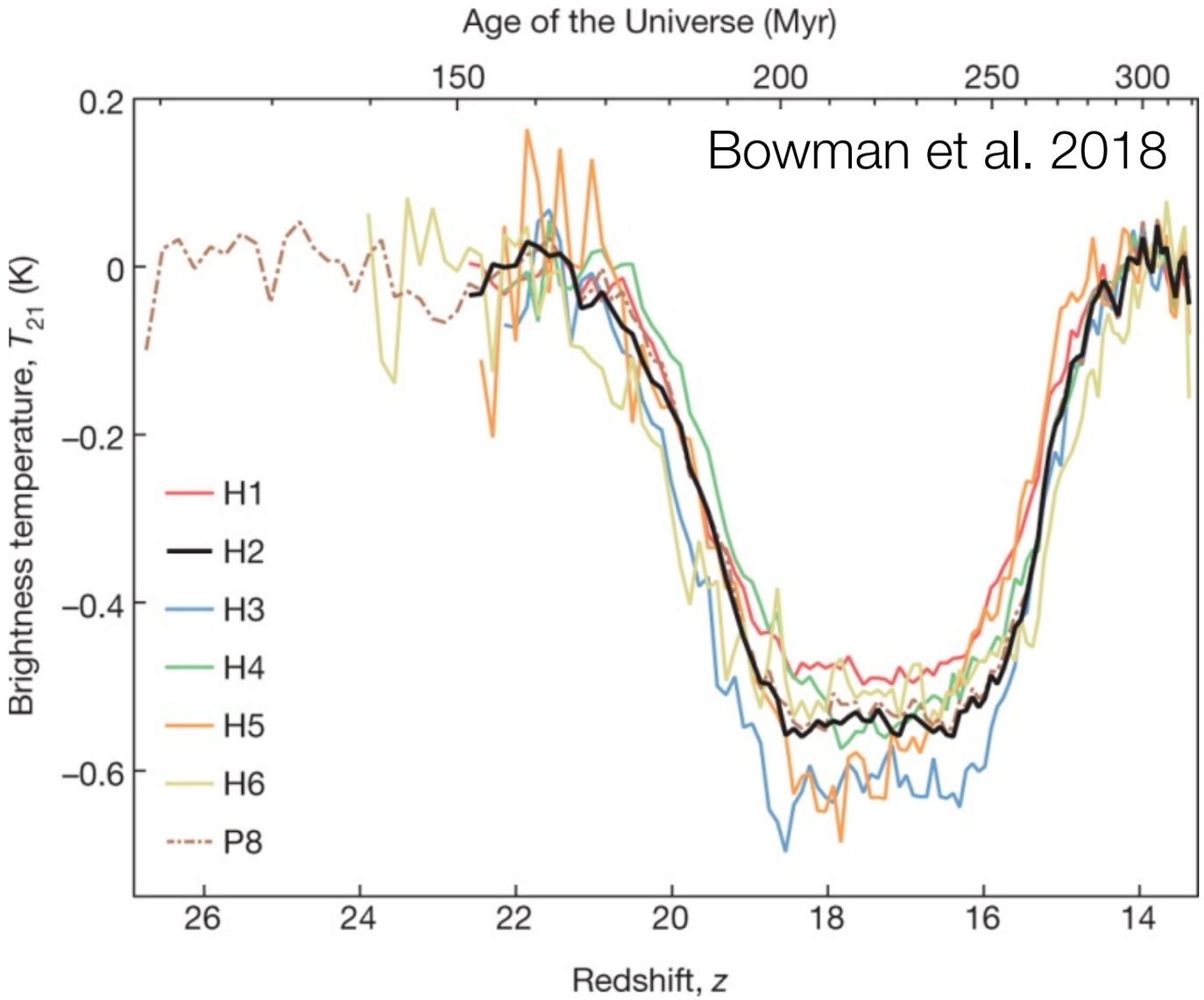
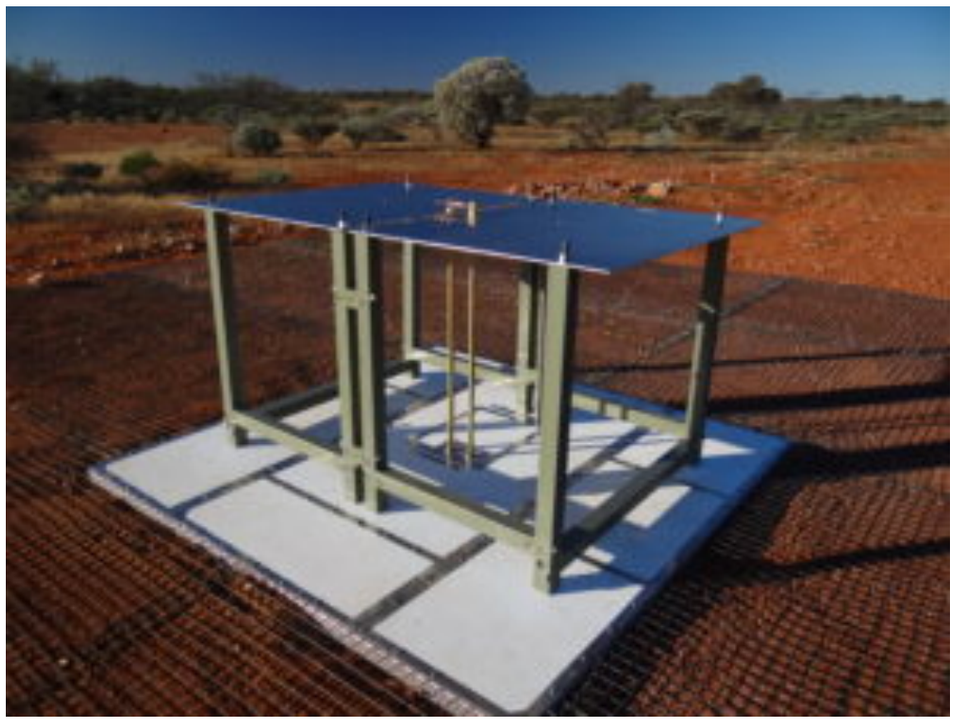
Enter: EDGES



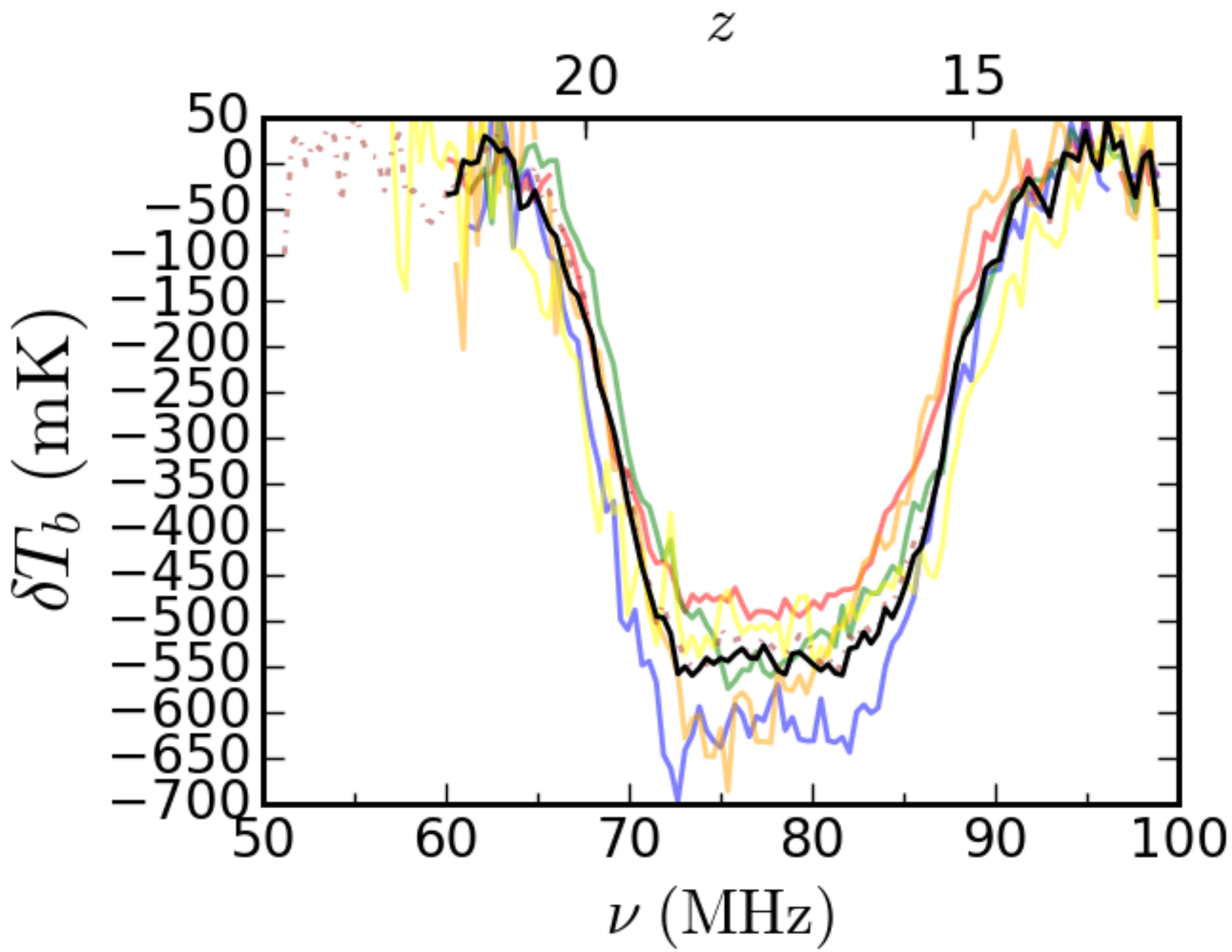
Published in Nature, March 1, 2018

Observing site:
Murchison Radio Observatory (W. Australia)



See also, e.g., Bowman & Rogers (2010), Monsalve et al. (2017)

EDGES: Key Features



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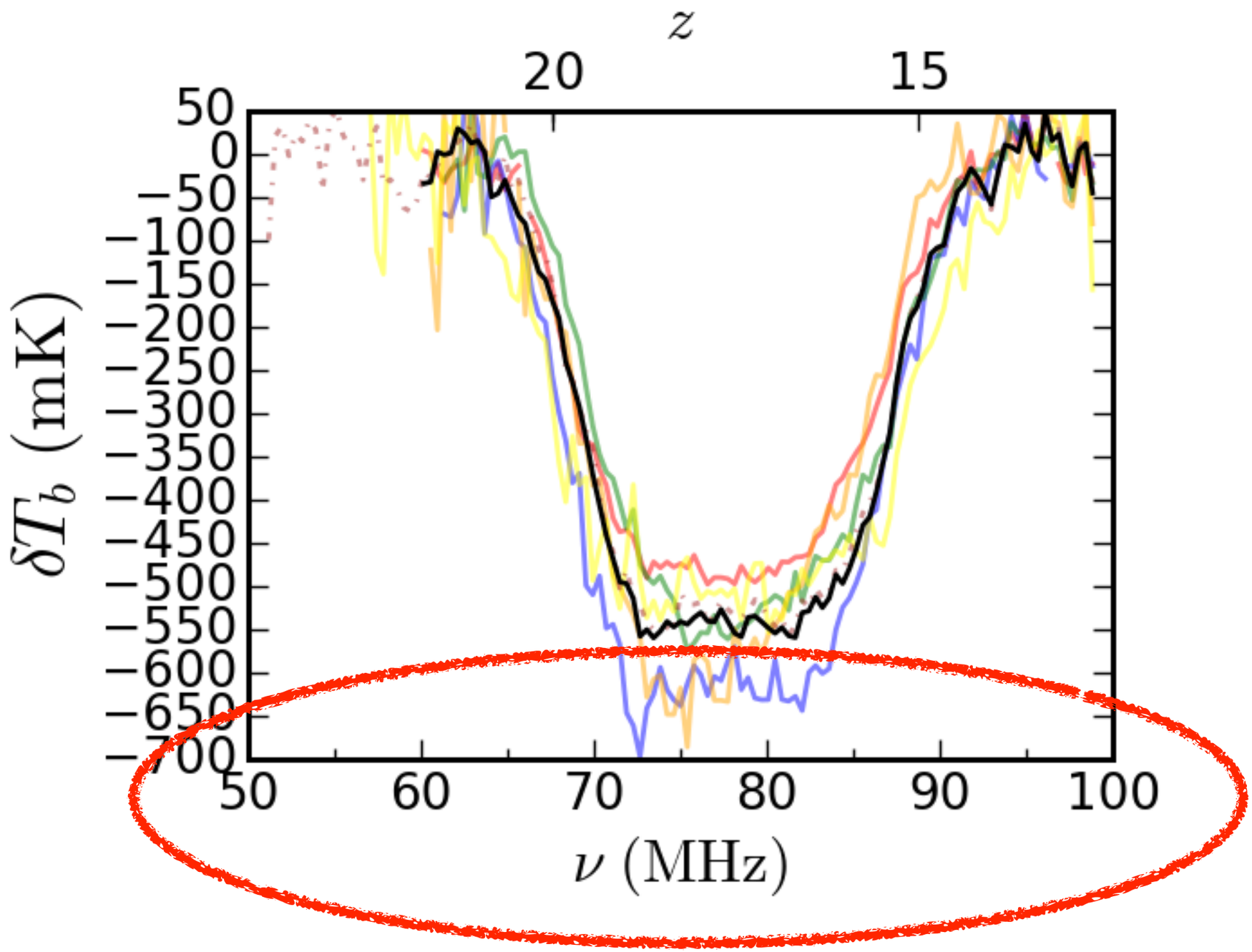

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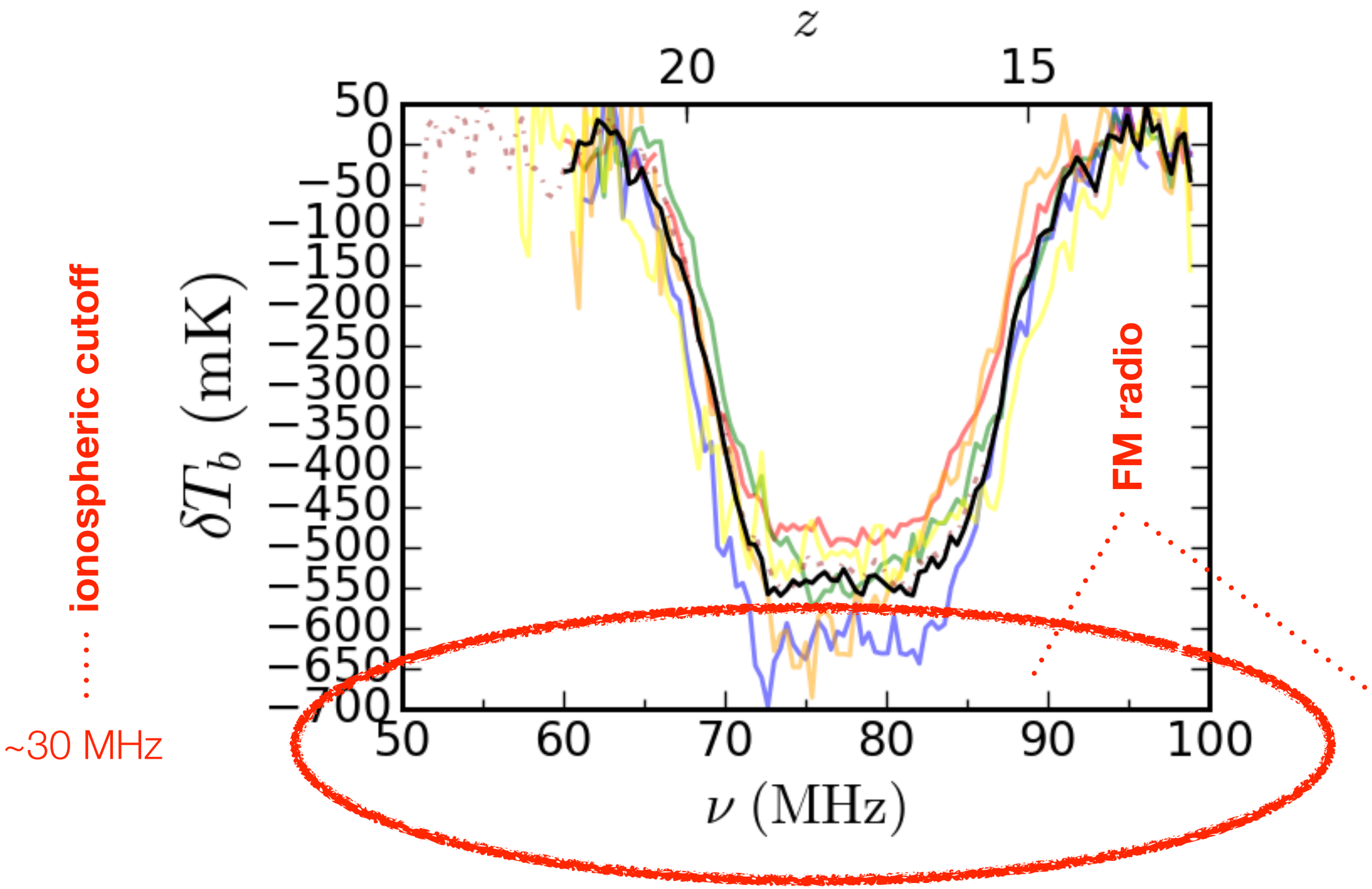

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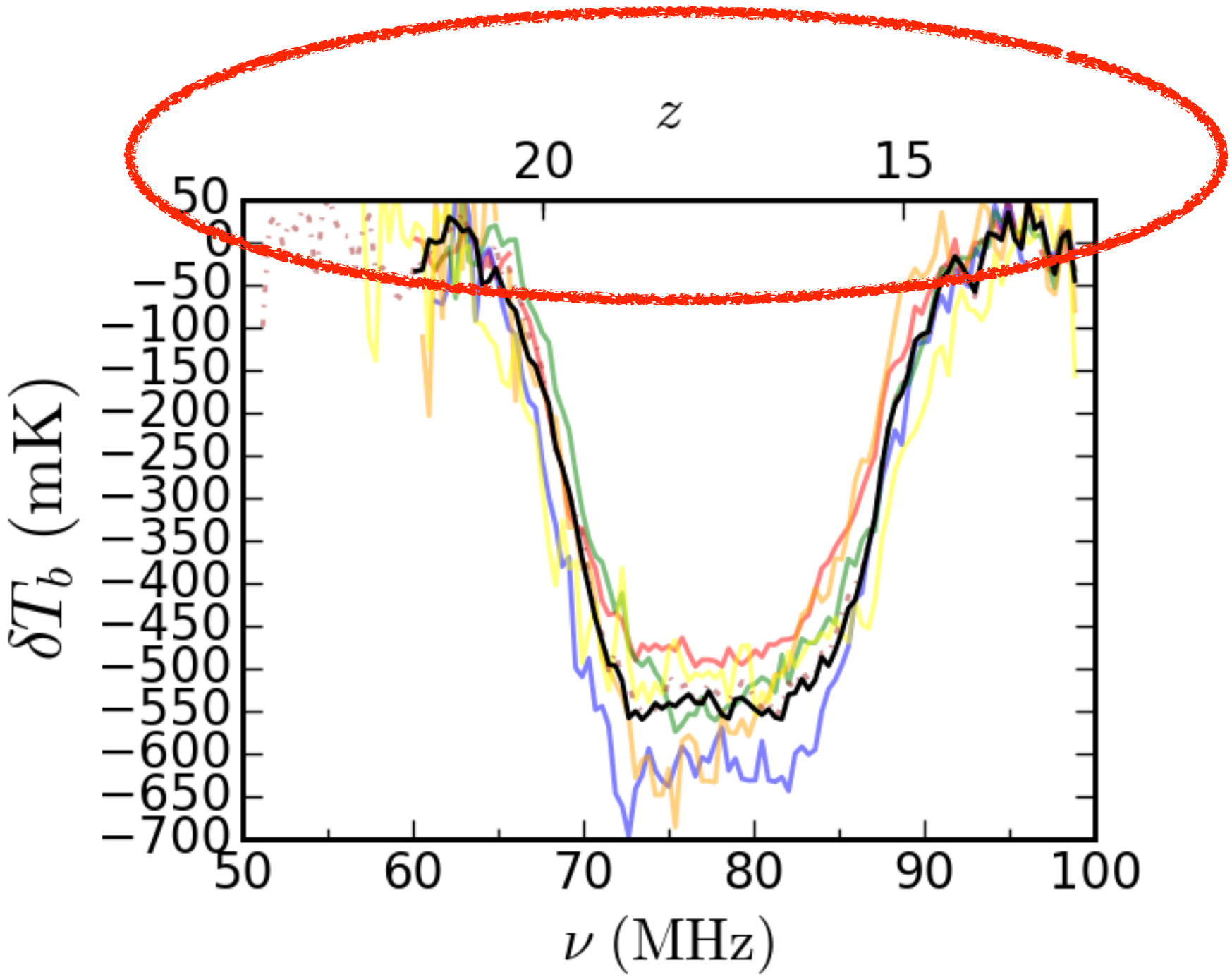

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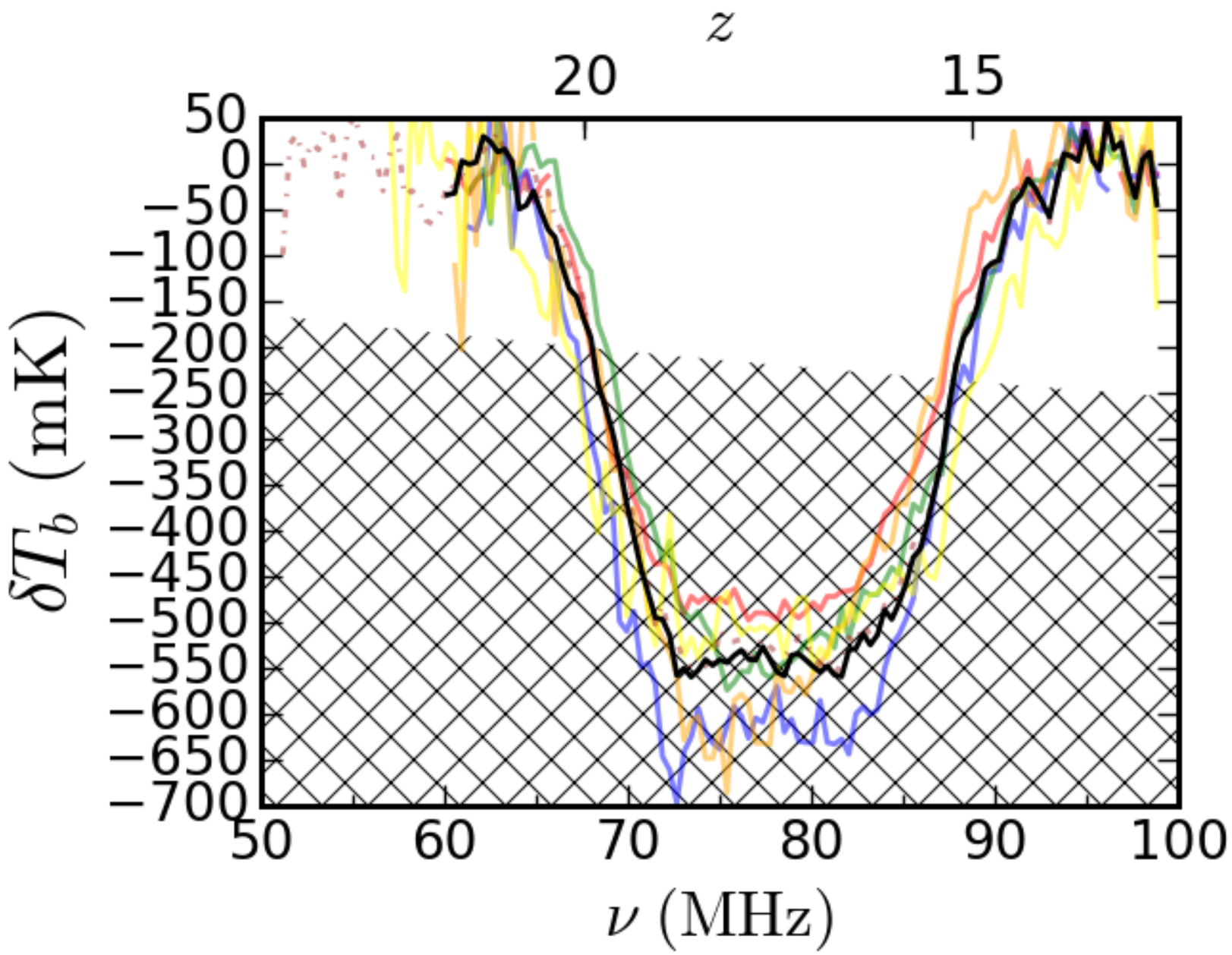
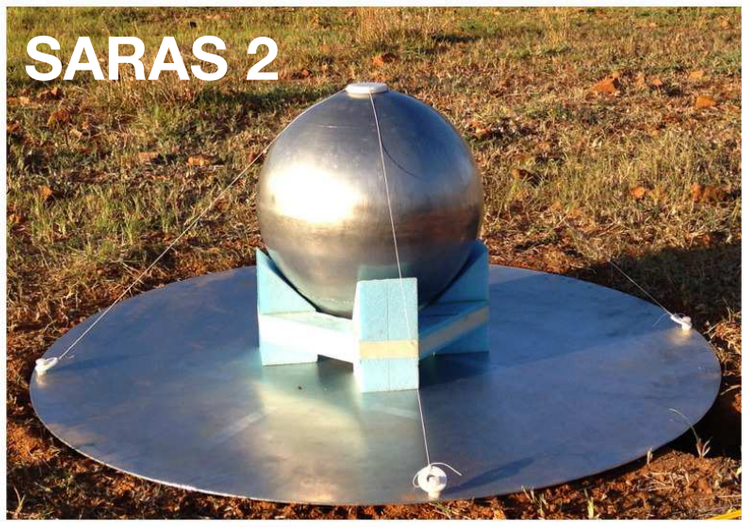


Requires temperatures colder than those predicted in ~adiabatically cooling IGM

Independent Work in Progress



Part II:

Explanations for the anomalous EDGES amplitude

Initial Considerations

$$\delta T_b \simeq 27\, \overline{x}_{\mathrm{H\ I}}(1+\delta) \left(\frac{\Omega_{b,0}h^2}{0.023}\right) \left(\frac{0.15}{\Omega_{m,0}h^2}\frac{1+z}{10}\right)^{1/2} \left(1-\frac{T_{\mathrm{R}}}{T_{\mathrm{S}}}\right)\ \mathrm{mK}$$

Q. How to amplify signal by a factor of 2-3?

Initial Considerations

$$\delta T_b \simeq 27\, \overline{x}_{\mathrm{H\ I}} (1+\delta) \left(\frac{\Omega_{b,0} h^2}{0.023}\right) \left(\frac{0.15}{\Omega_{m,0} h^2} \frac{1+z}{10}\right)^{1/2} \left(1 - \frac{T_{\mathrm{R}}}{T_{\mathrm{S}}}\right)\ \mathrm{mK}$$

Q. How to amplify signal by a factor of 2-3?

1. Decrease T_S via baryon-DM interactions.

- Barkana, Munoz & Loeb, Fialkov et al., Berlin et al., Slatyer & Wu, Kovetz+

Note: inclusion in these lists does not imply authors' endorsement of the solution!

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2. Increase T_R via DM decay or synchrotron from BHs, galaxies.
   - Feng & Holder, Ewall-Wice et al., Fraser et al., Mirocha & Furlanetto, Sharma

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2. Increase T_R via DM decay or synchrotron from BHs, galaxies.
   - Feng & Holder, Ewall-Wice et al., Fraser et al., Mirocha & Furlanetto, Sharma
3. Alter the cosmology.
   - McGaugh, Costa et al., Hill et al.

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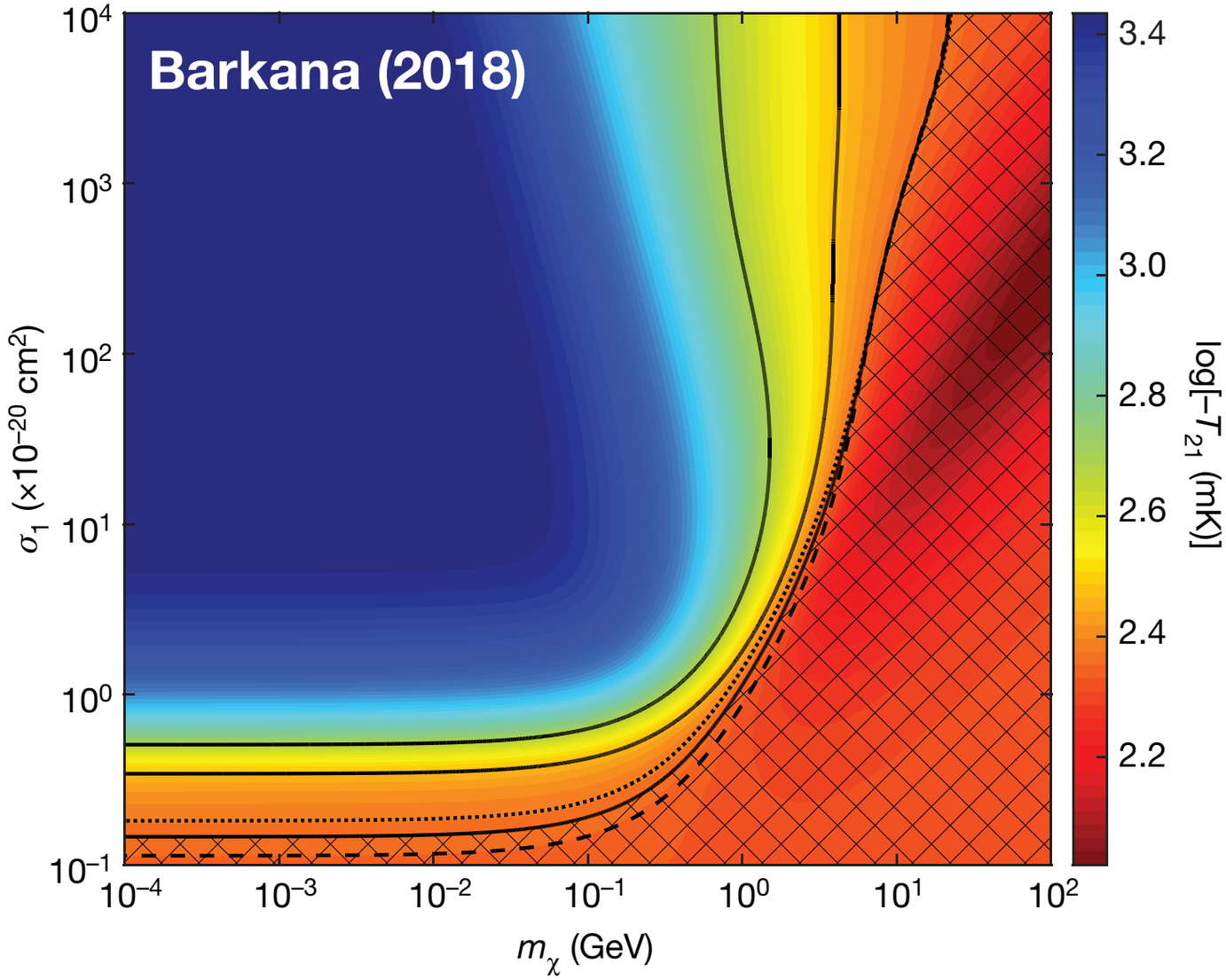
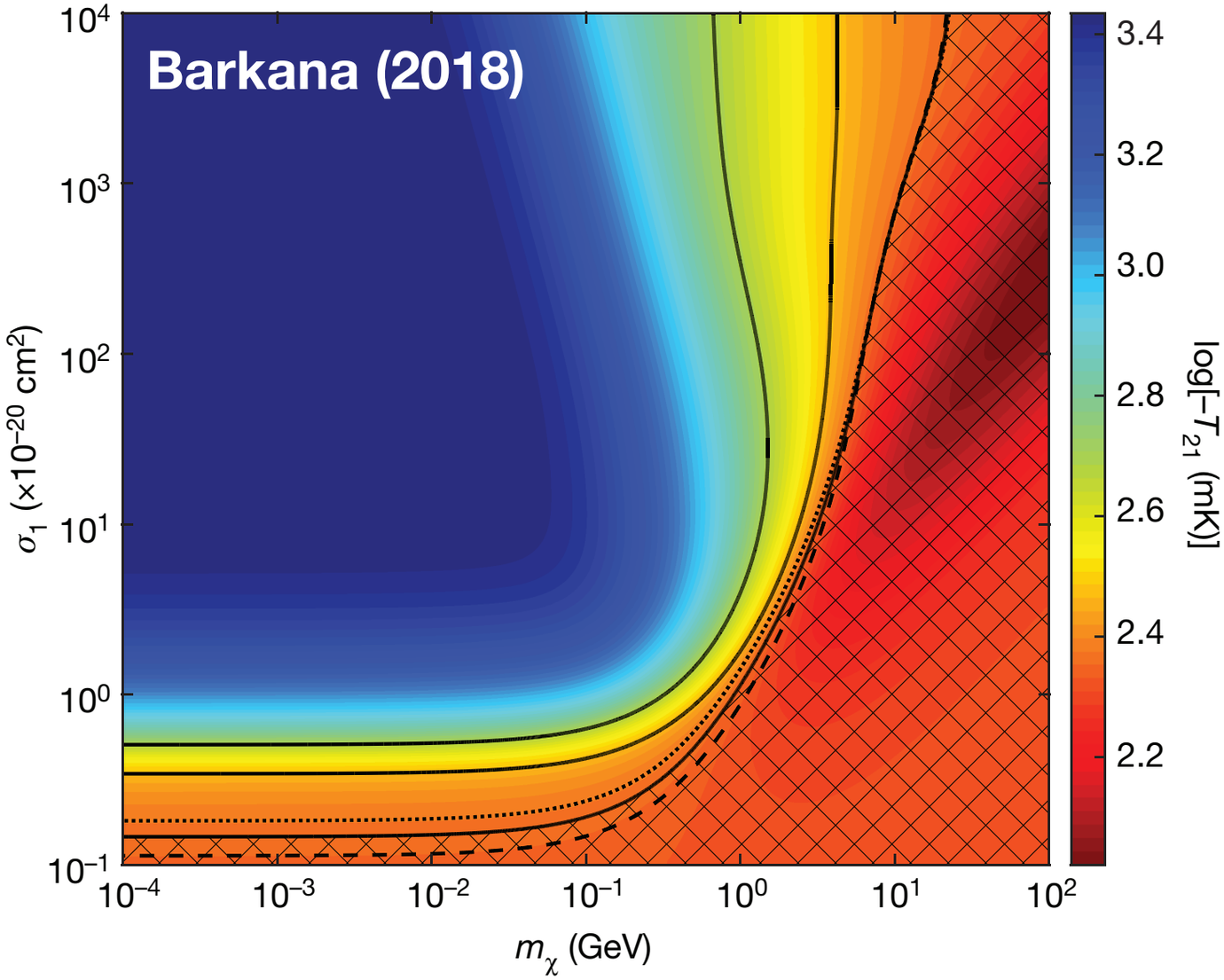
DM as a coolant



DM as a coolant

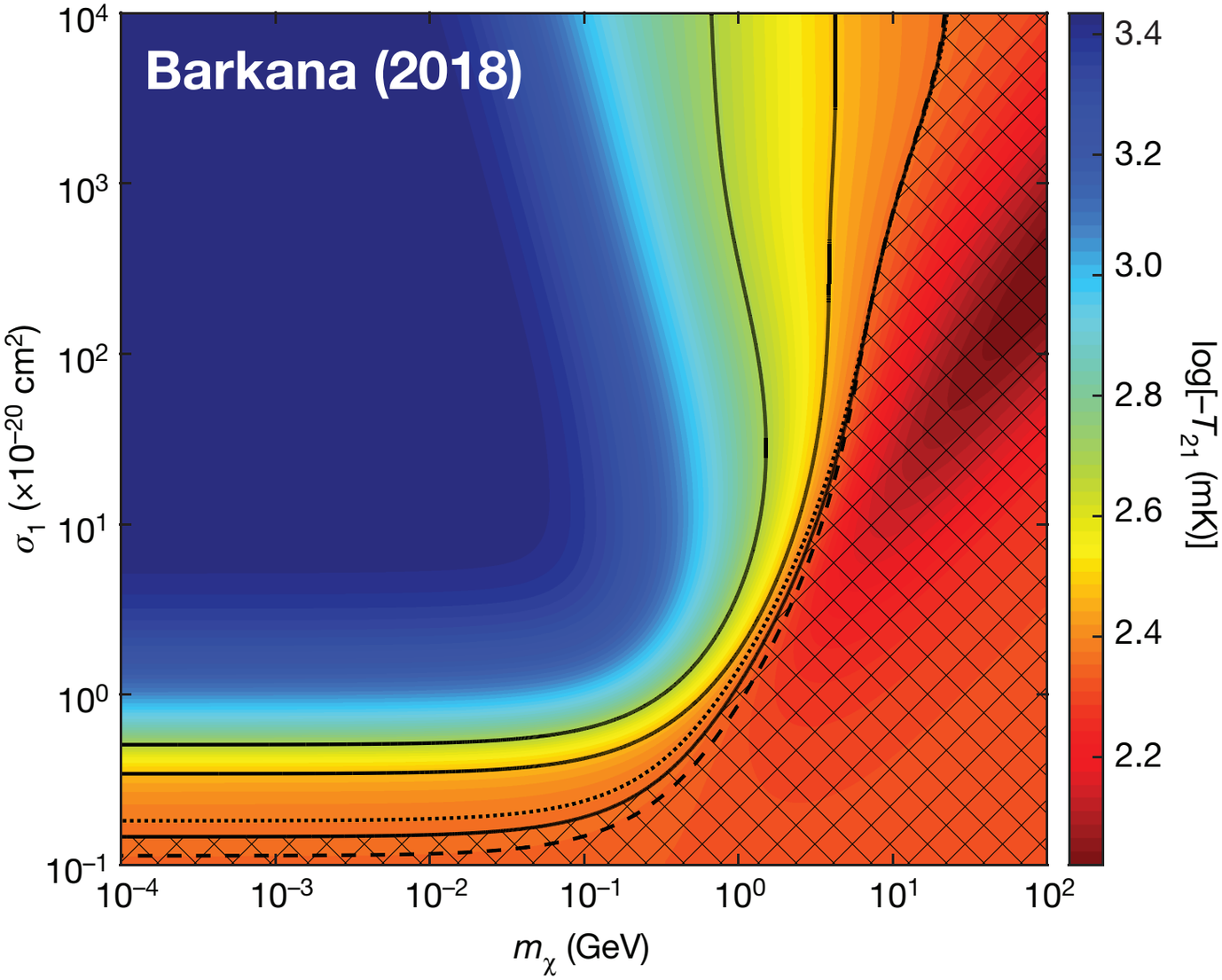
- Initial suggestion of milli-charged DM from Barkana (2018).



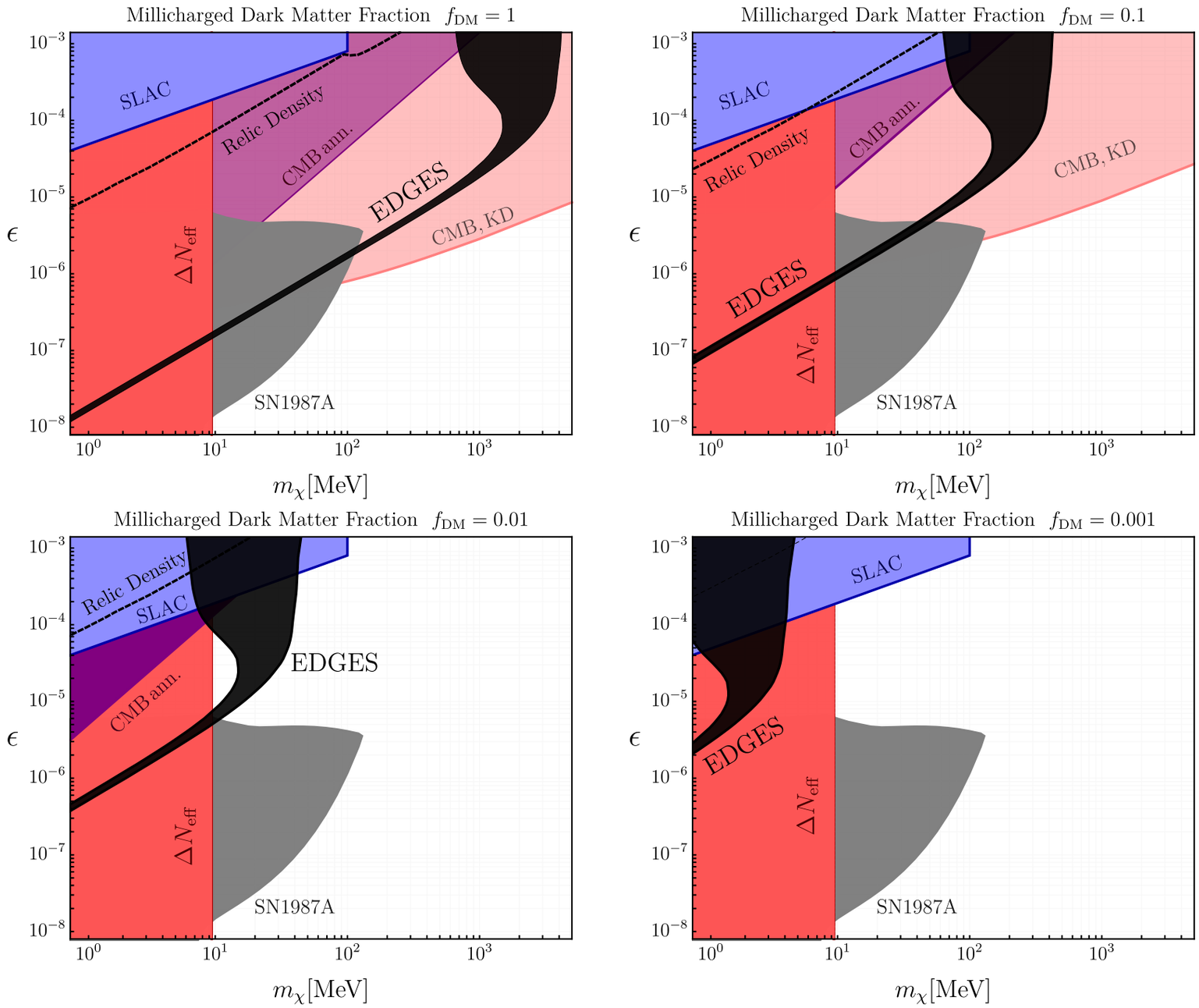
DM as a coolant

- Initial suggestion of milli-charged DM from Barkana (2018).

- Revision to $f_{DM} < 0.1$ by Munoz and Loeb based on galactic B-field arguments.



Further Revision of DM cooling



Berlin et al. (1803.02804), see also see also Boddy et al. (1808.00001), Kovetz et al. (1807.11482)

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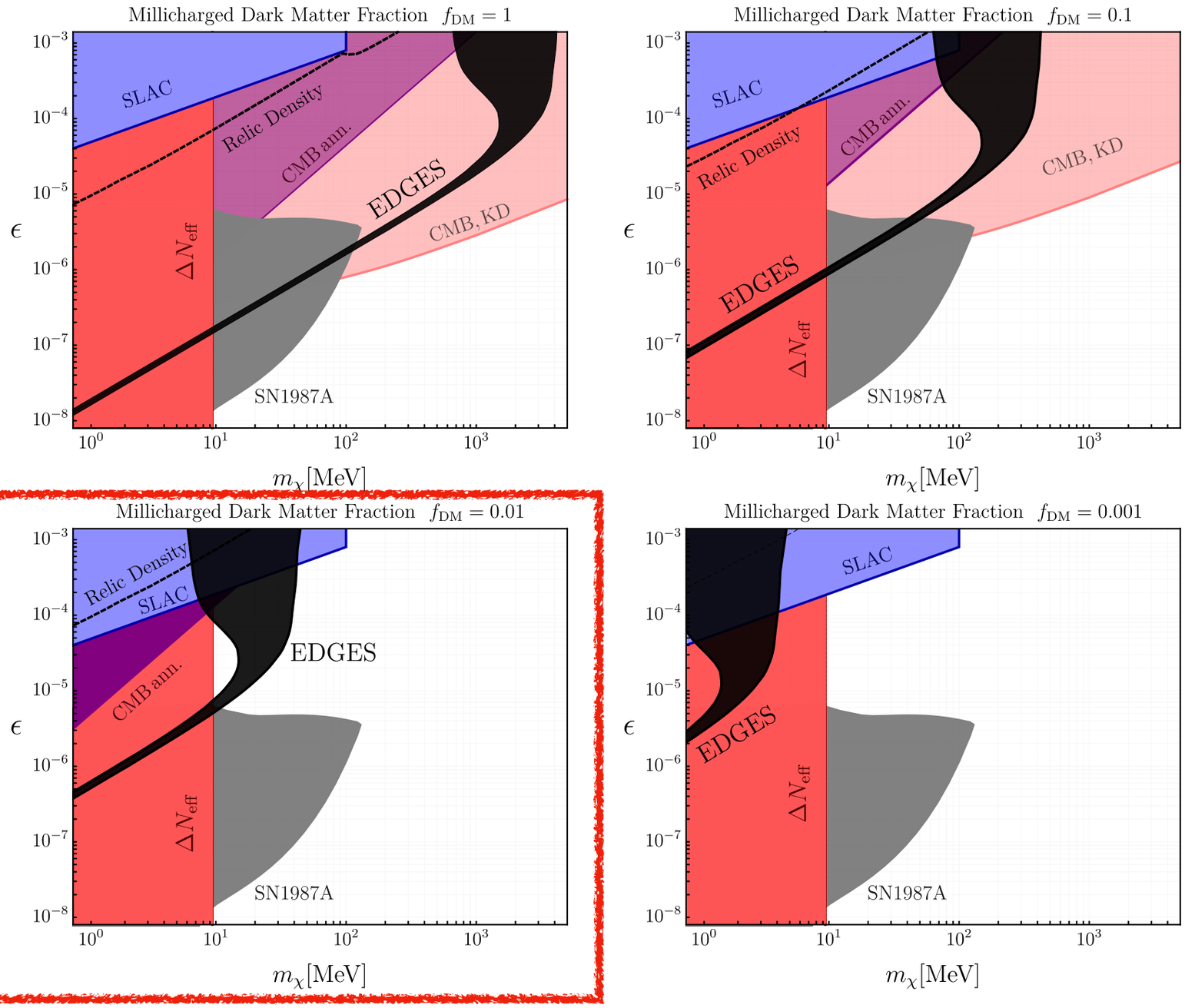
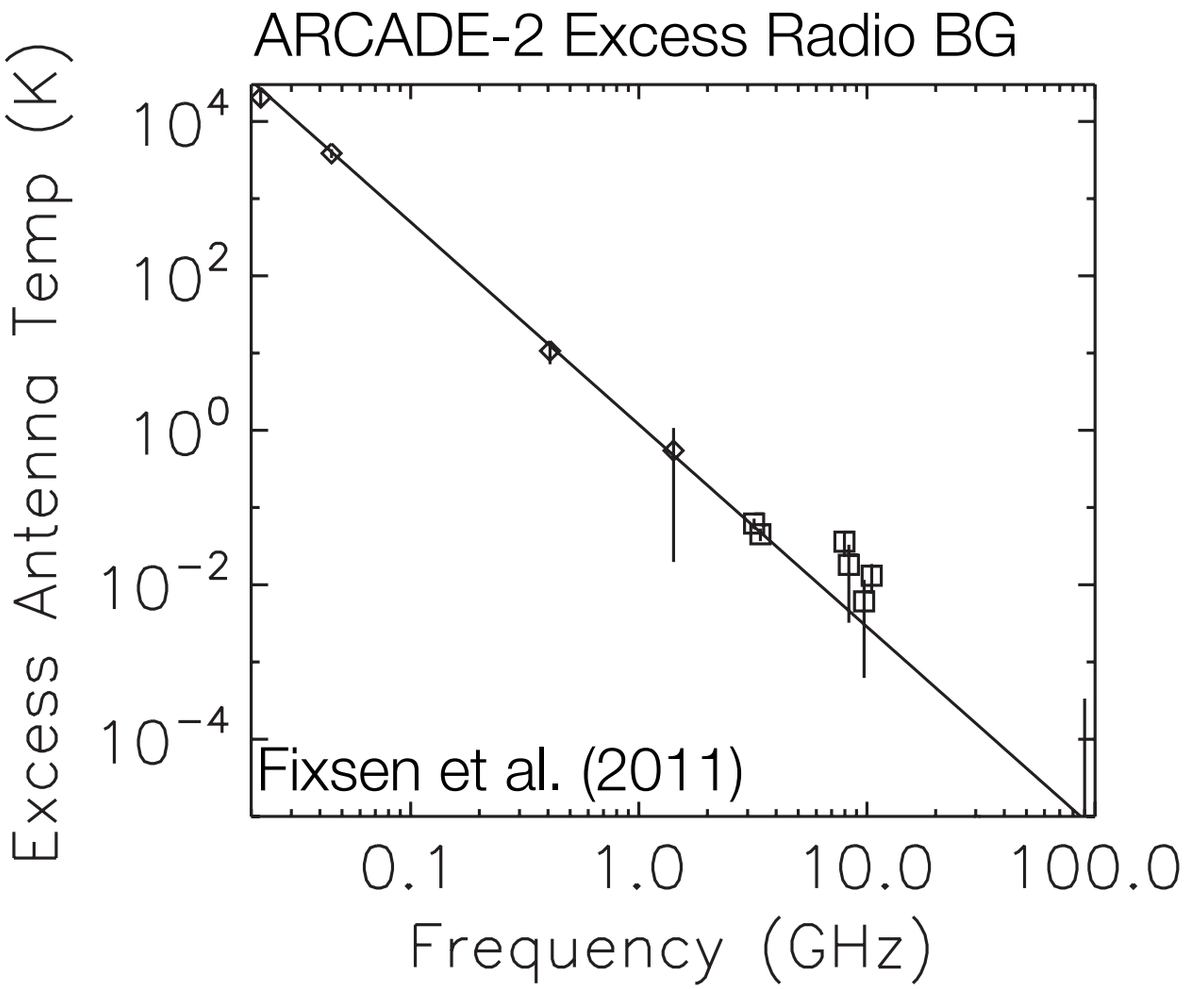


f_{DM} ~ 0.01

Berlin et al. (1803.02804), see also see also Boddy et al. (1808.00001), Kovetz et al. (1807.11482)

Alternative: non-CMB radio BG



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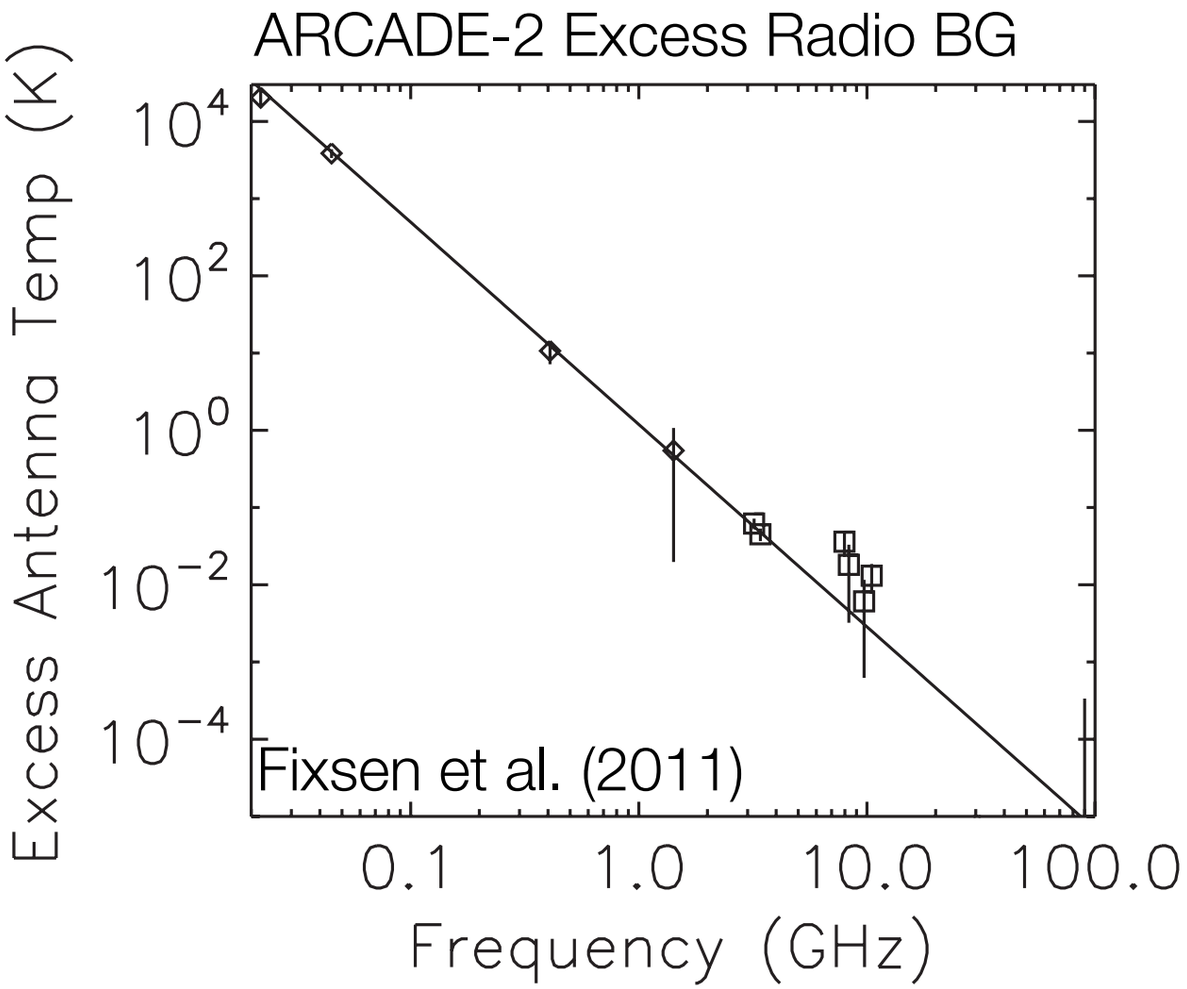

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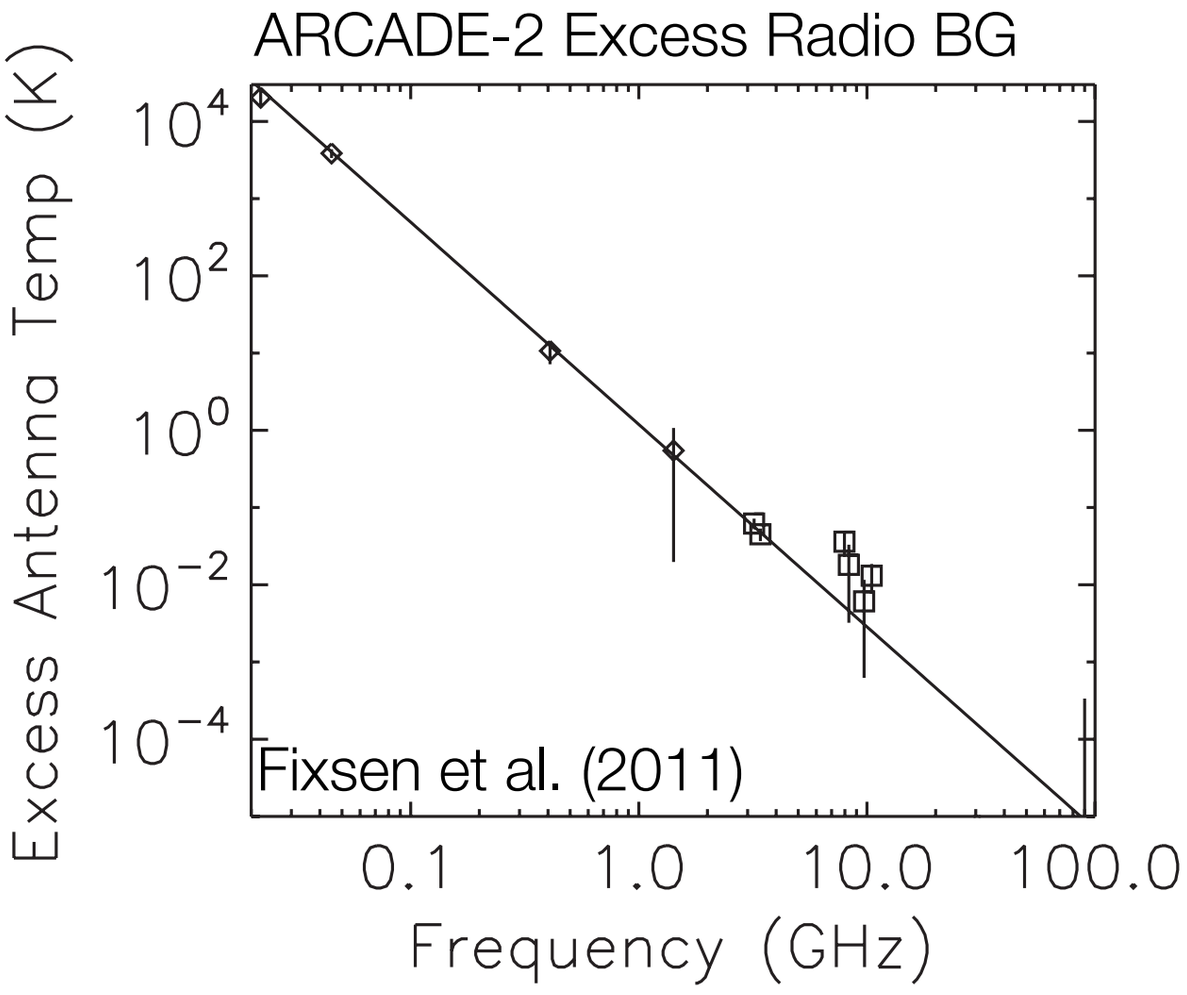

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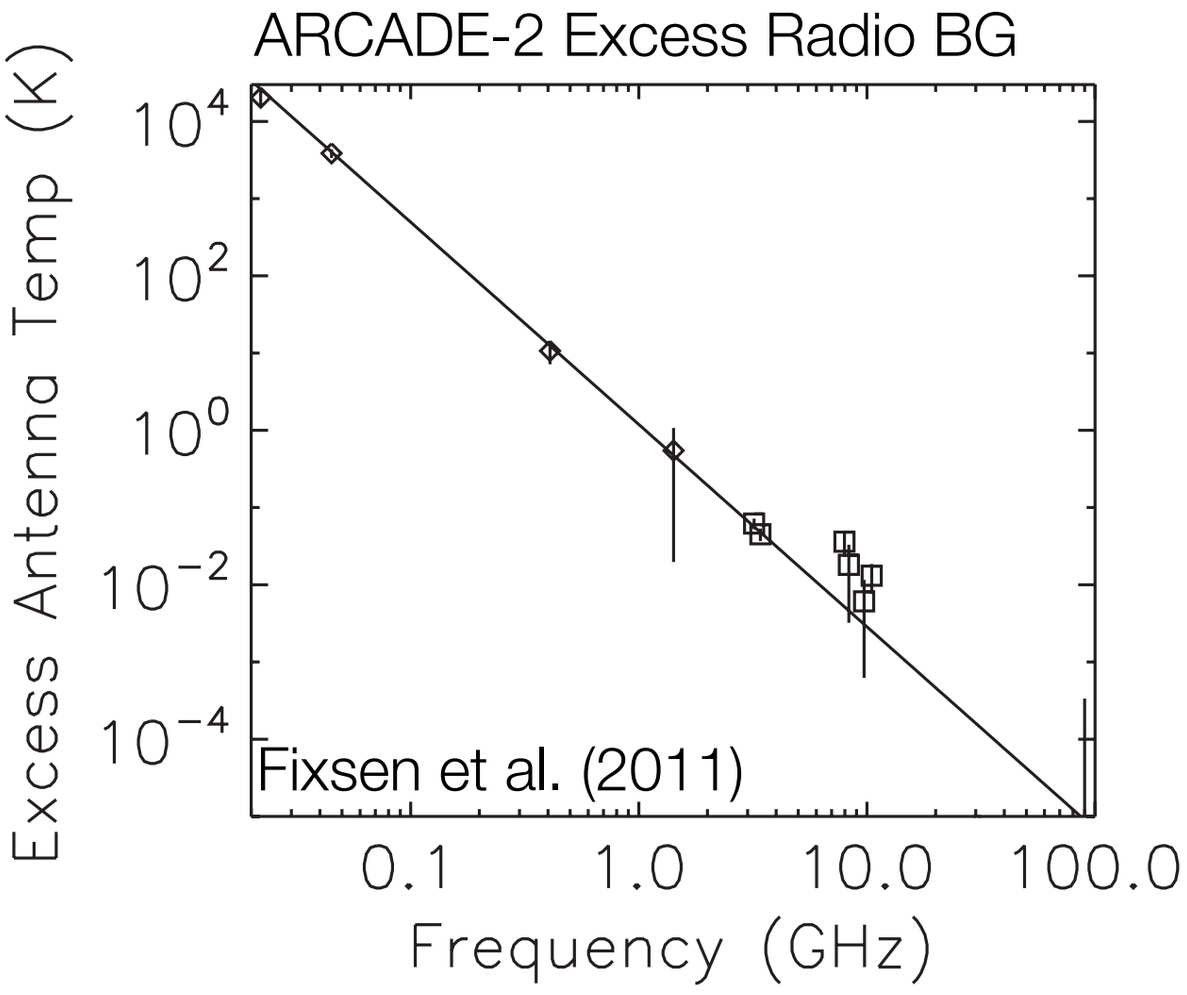

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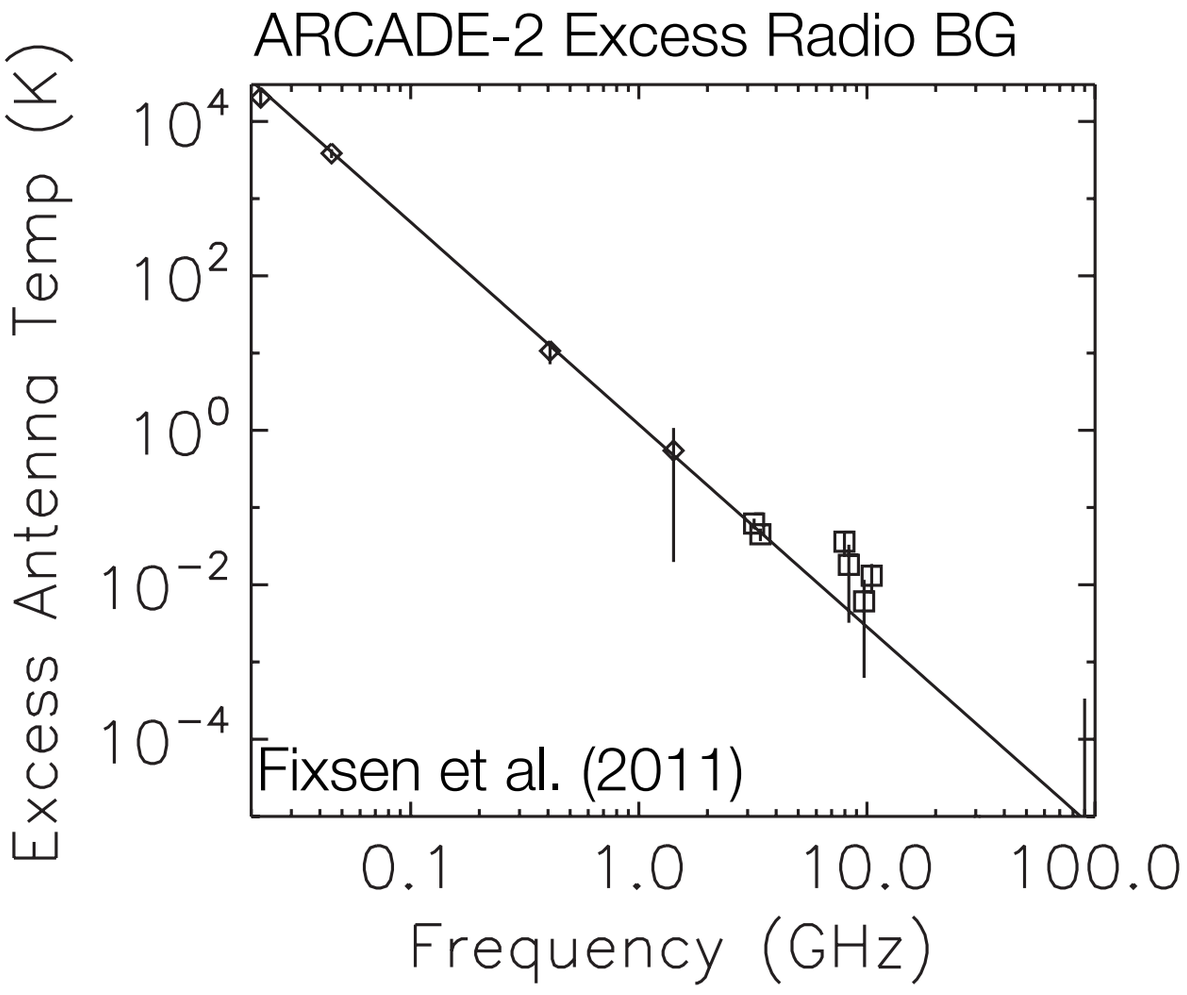

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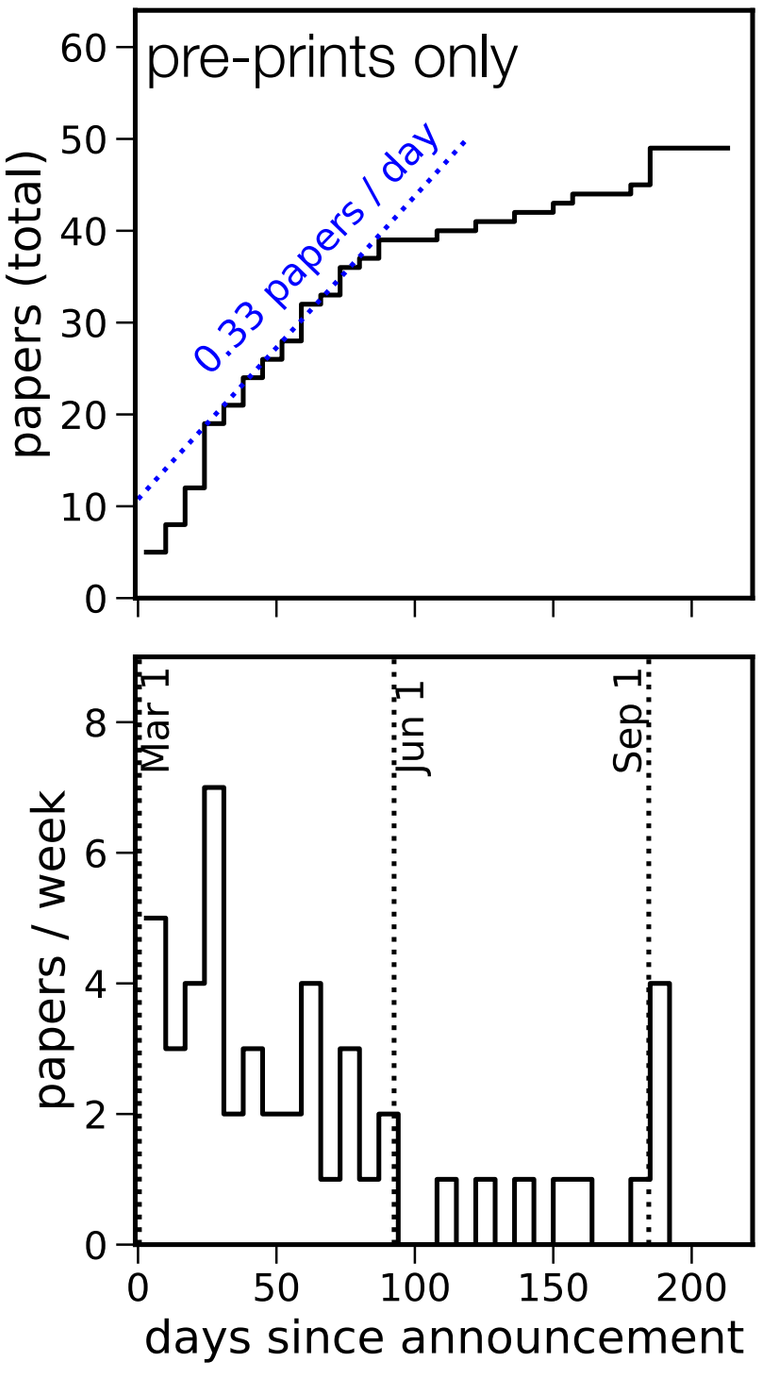
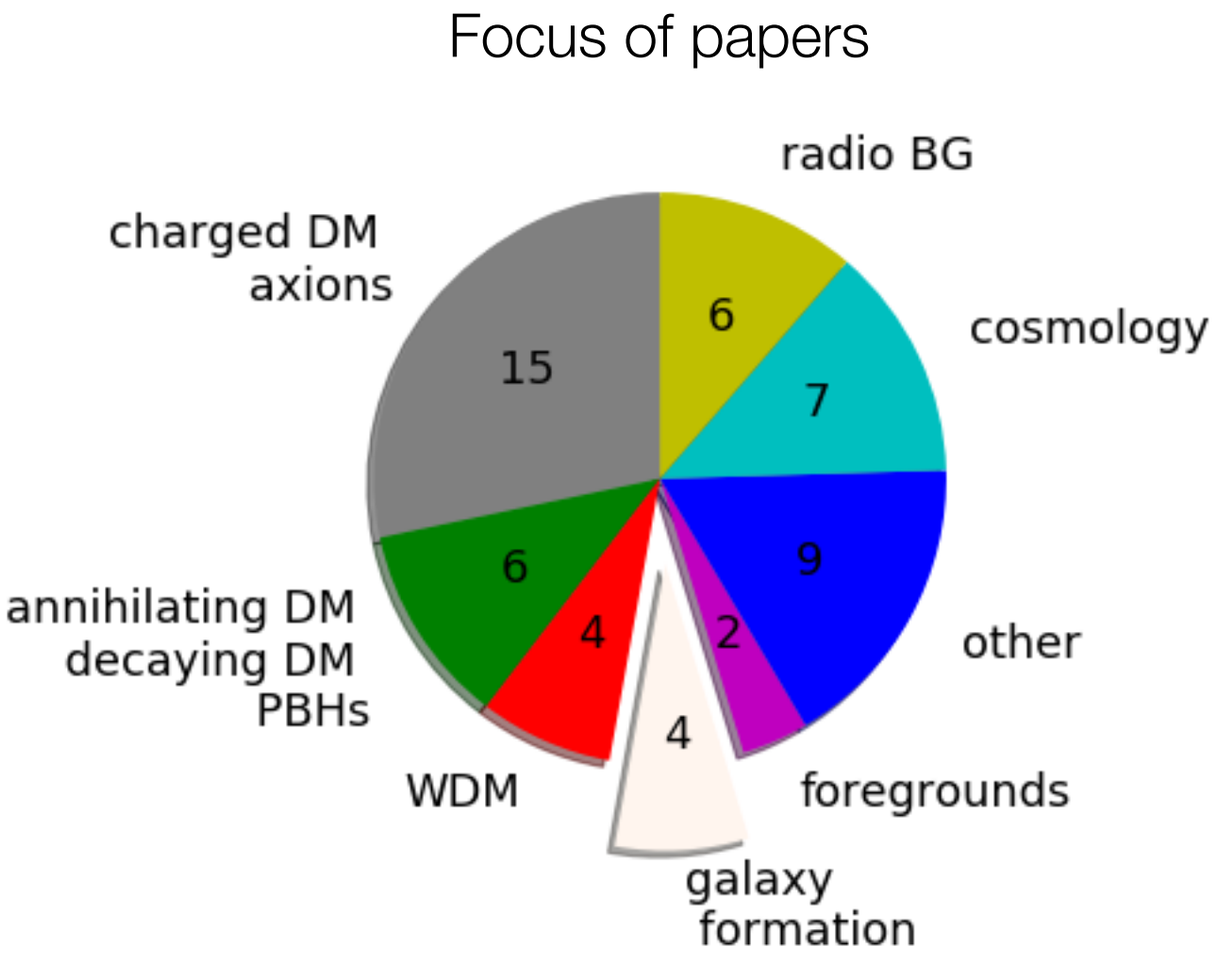
- If associated with star formation, require ~10^3x boost in low-frequency production efficiency per SFR (Mirocha & Furlanetto), even neglecting IC losses (Sharma 2018).

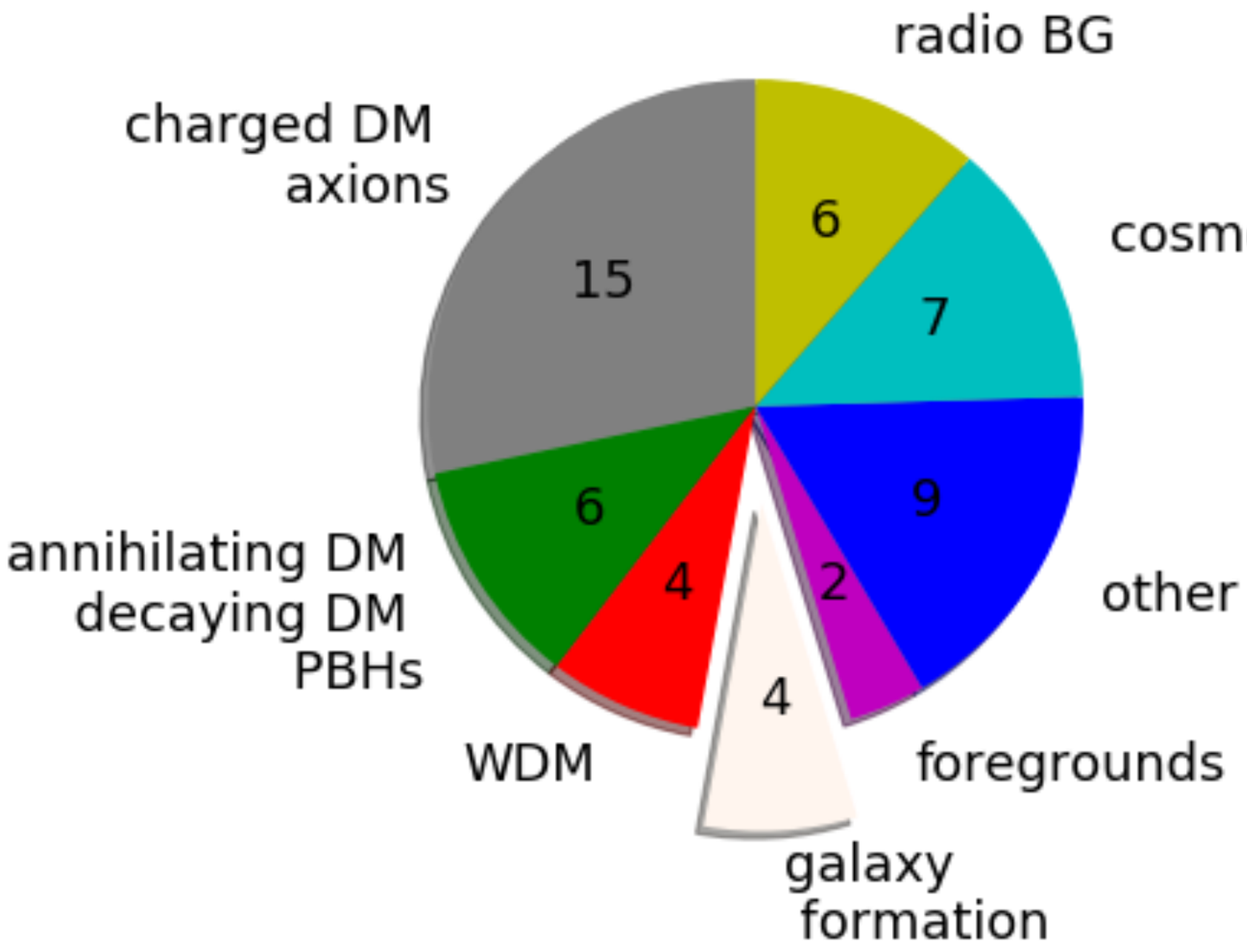
Responses to EDGES





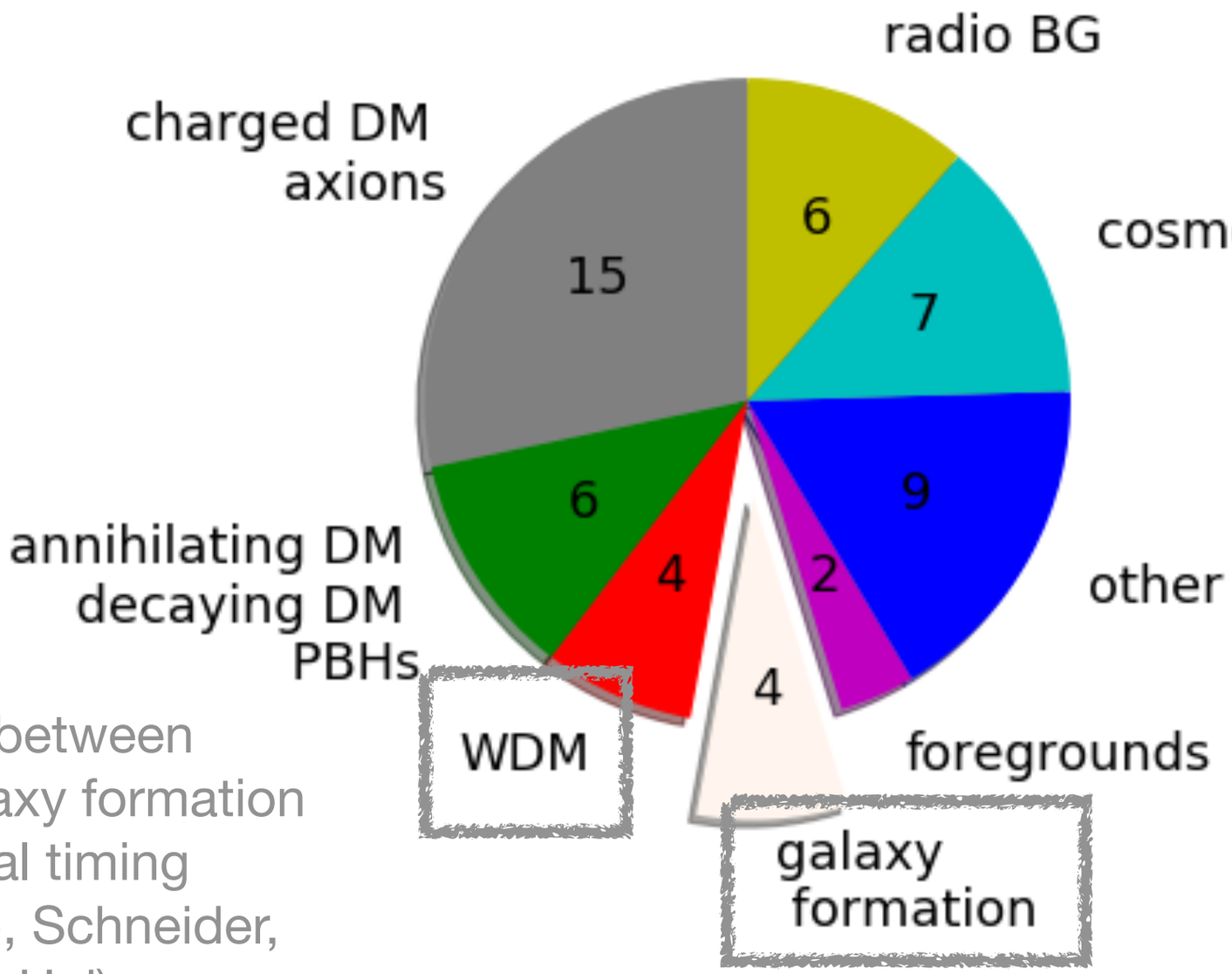
Includes explanations for signal amplitude and use of its timing to constrain WDM, galaxies.

Responses to EDGES



Hard to categorize papers: wedges are strongly linked!

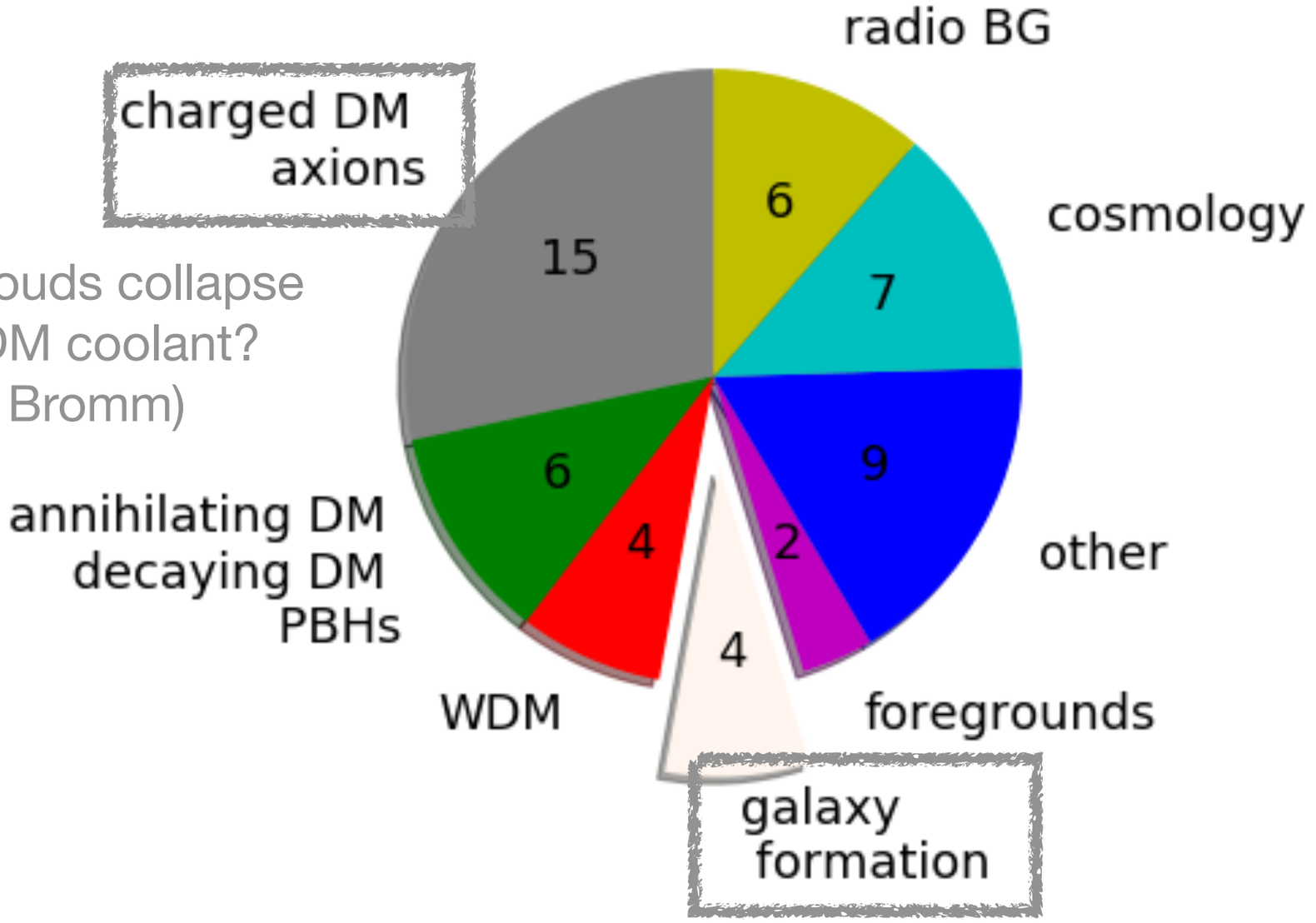
Responses to EDGES



Interplay between WDM and galaxy formation sets signal timing (Safarzadeh+, Schneider, Lidz & Hui)

Hard to categorize papers: wedges are strongly linked!

Responses to EDGES

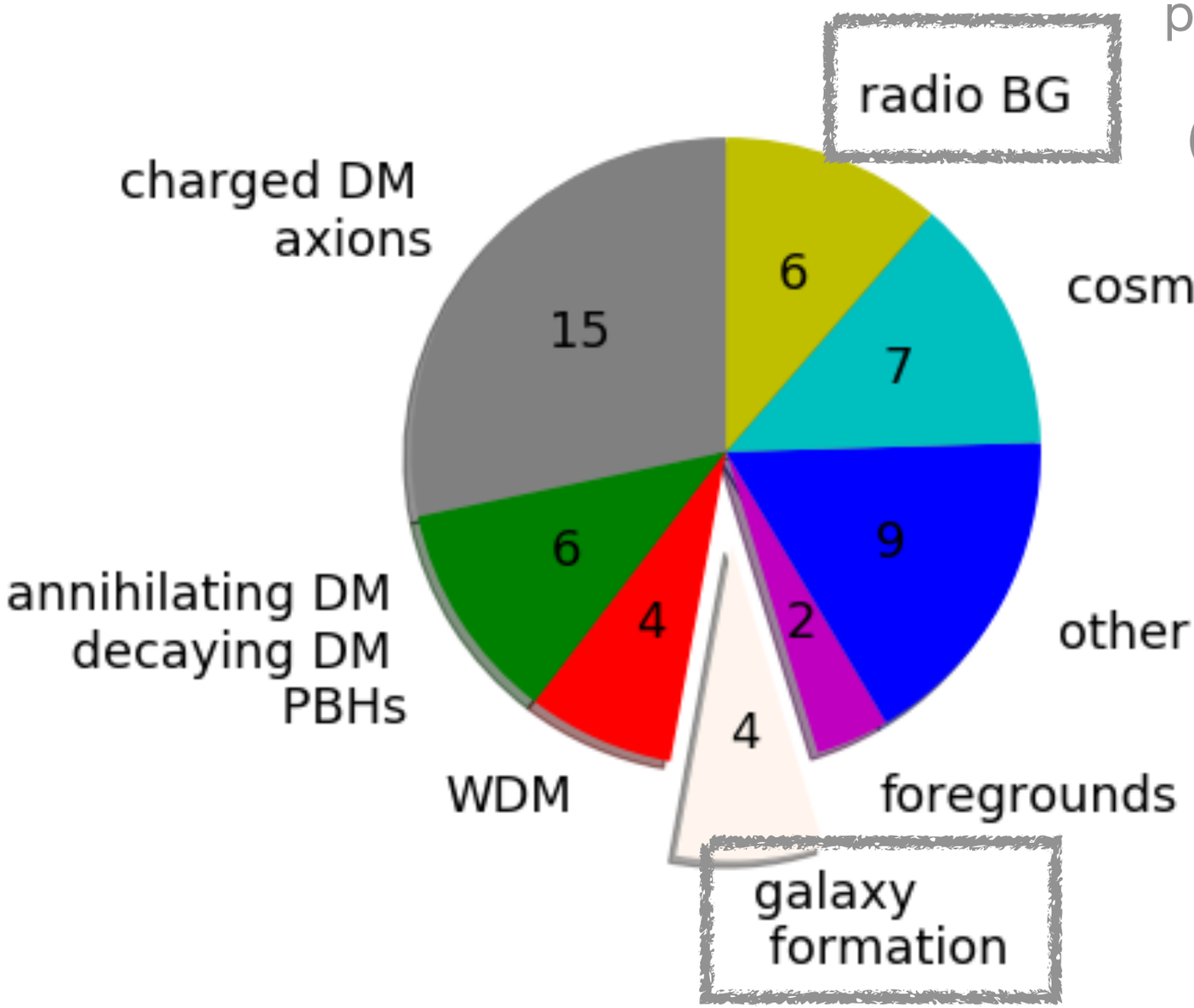


How do first clouds collapse with new b-DM coolant? (Hirano & Bromm)

Hard to categorize papers: wedges are strongly linked!

Responses to EDGES

Can galaxies or BHs produce the required radio background? (Ewall-Wice+, Mirocha & Furlanetto, Sharma)



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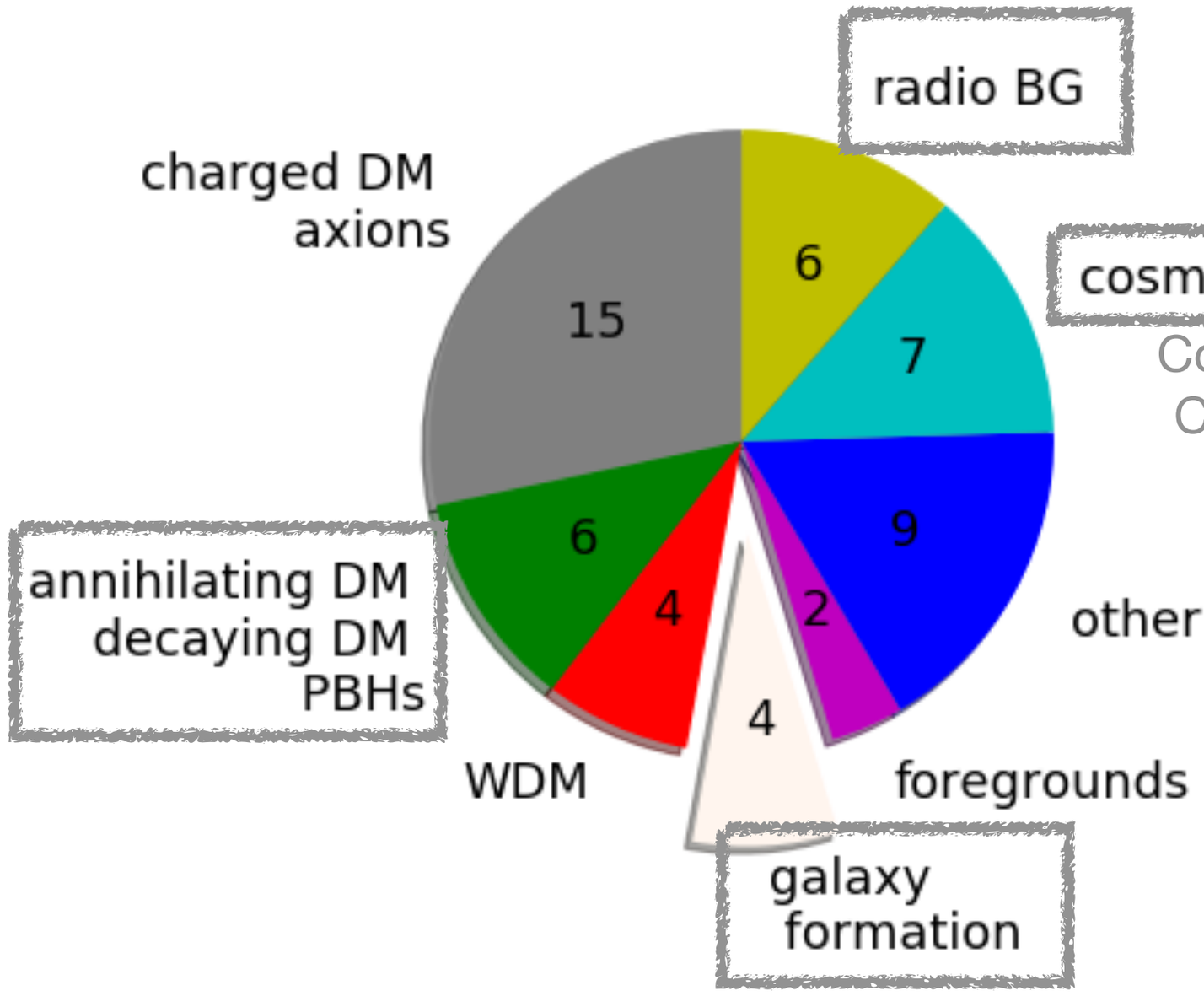
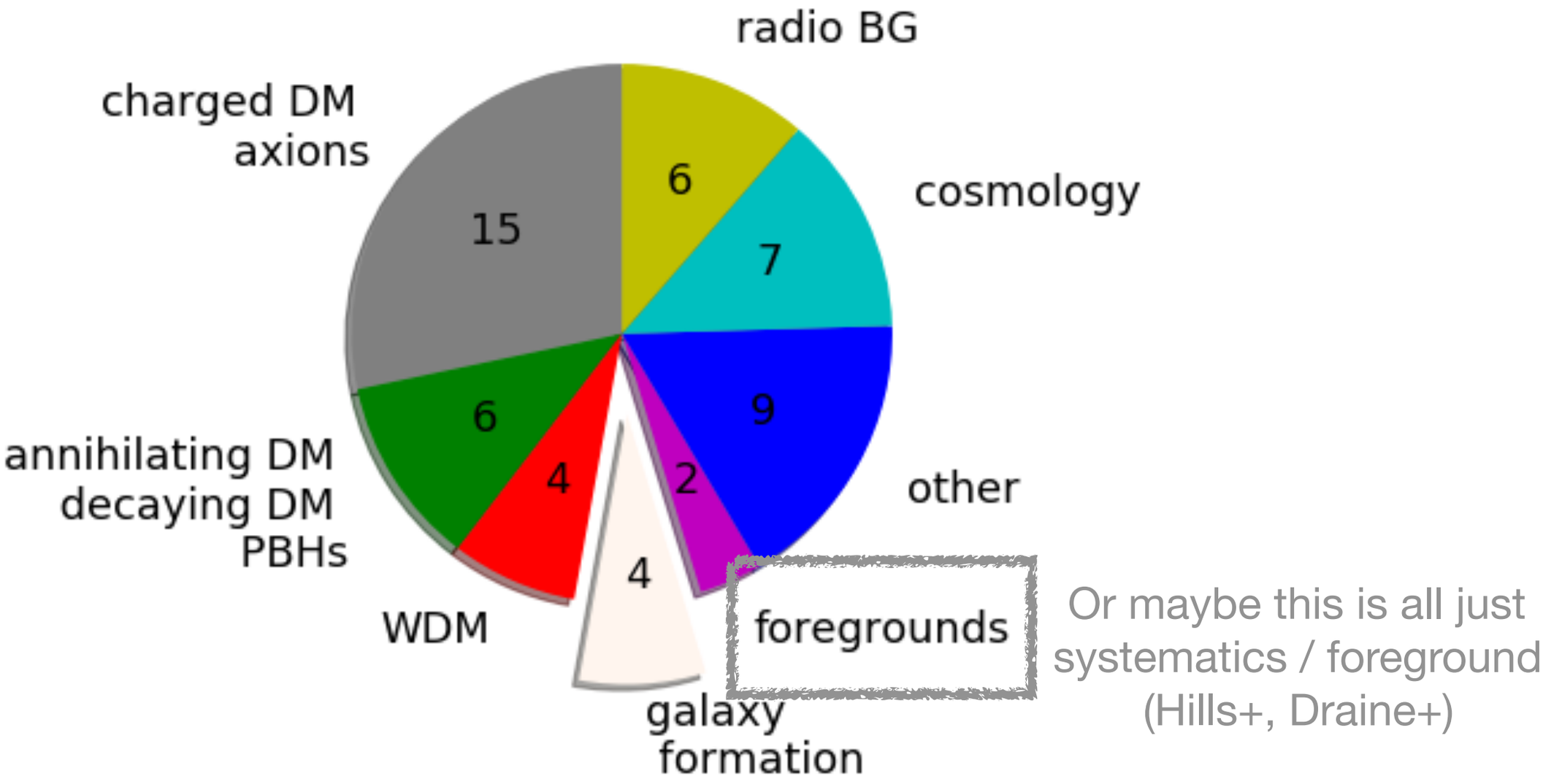


Could a decaying particle or CMB modification account for radio BG? (Fraser+, Pospelov+)

Hard to categorize papers: wedges are strongly linked!

Responses to EDGES



Or maybe this is all just systematics / foreground (Hills+, Draine+)

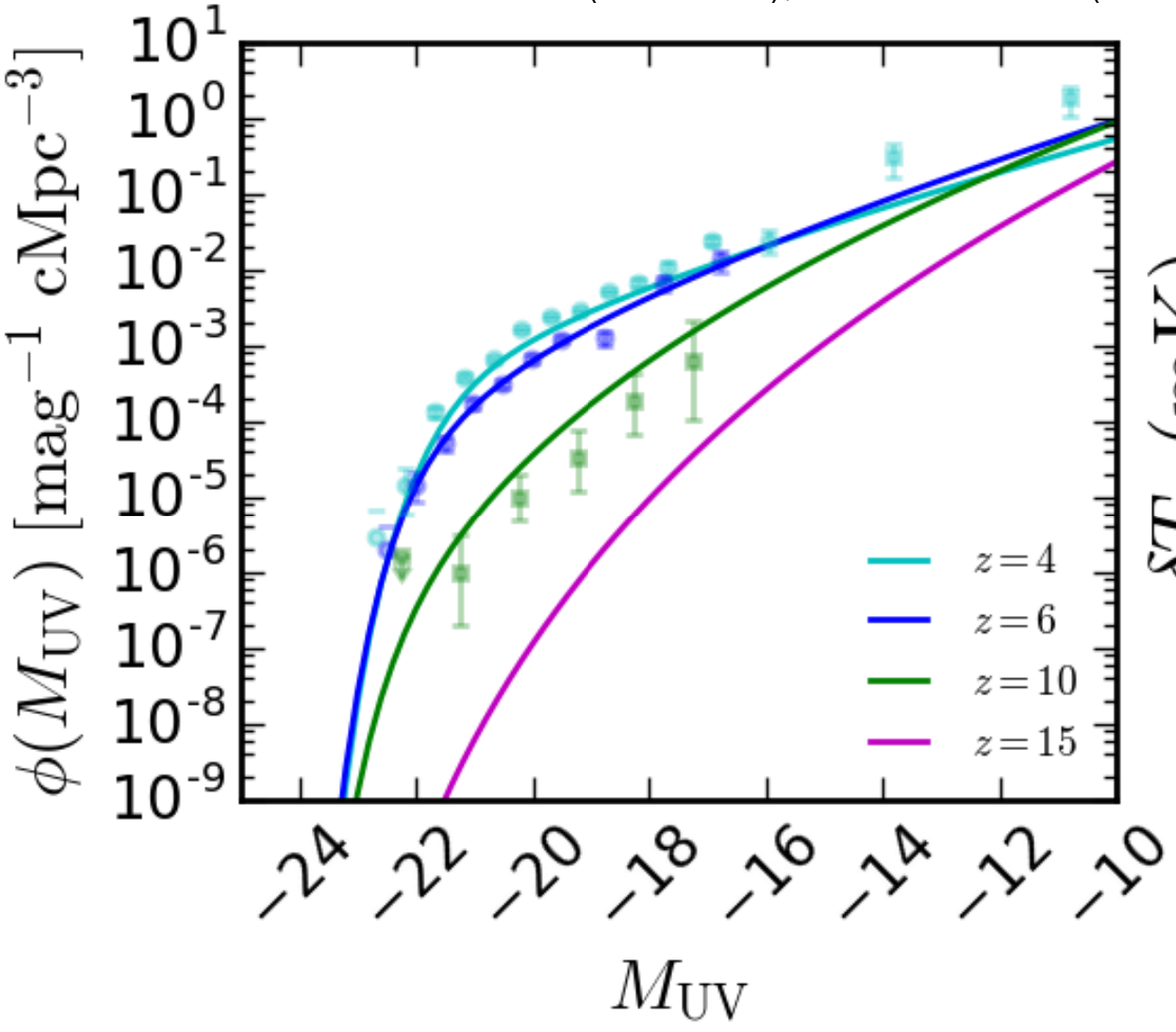
Hard to categorize papers: wedges are strongly linked!

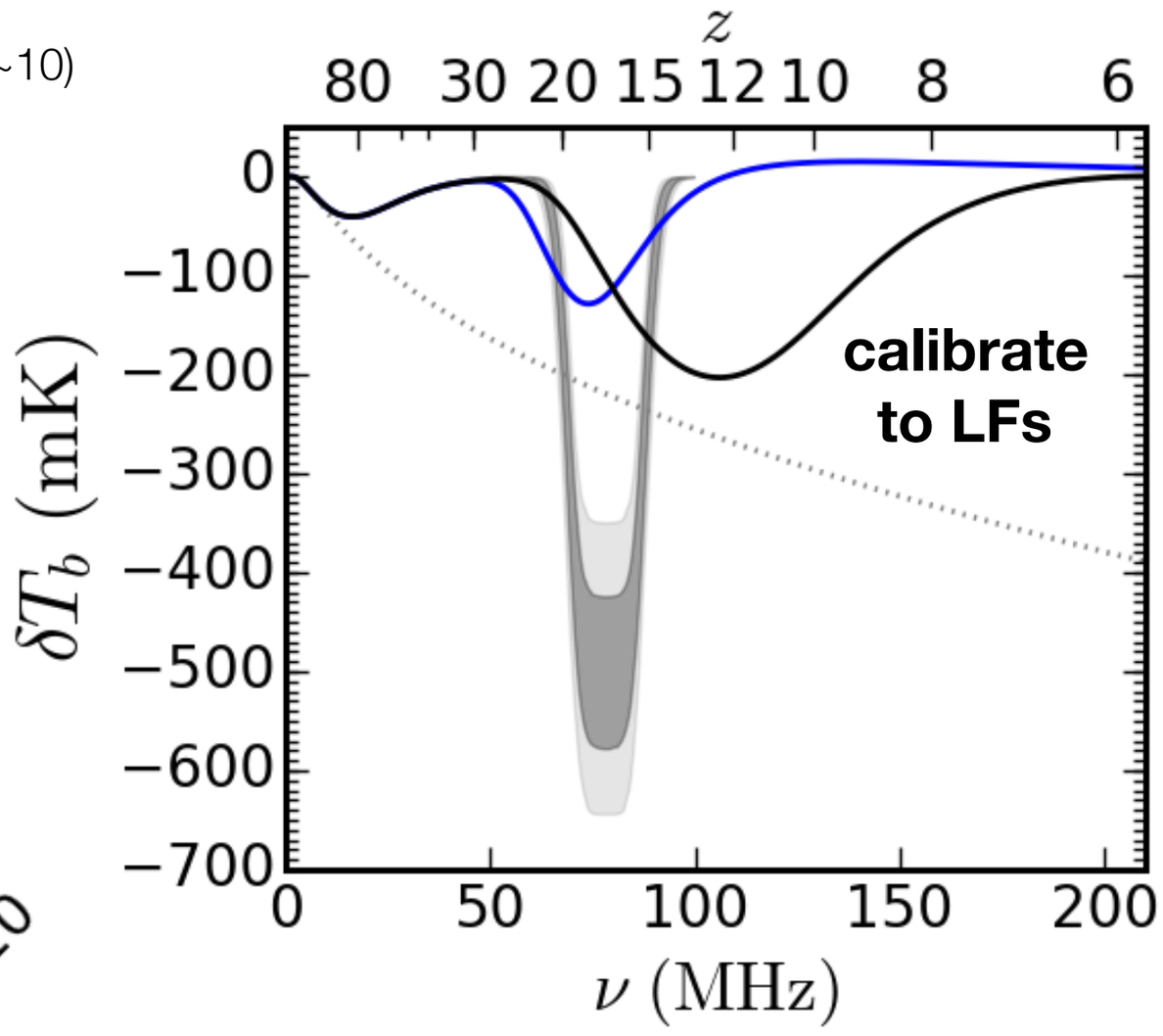
Part III:

New hints about galaxy formation as well?

EDGES in Context

High-z galaxy luminosity functions from
Bouwens+ 2015 ($4 < z < 8$), Oesch+ 2018 ($z \sim 10$)





Mirocha, Furlanetto, & Sun (2017)

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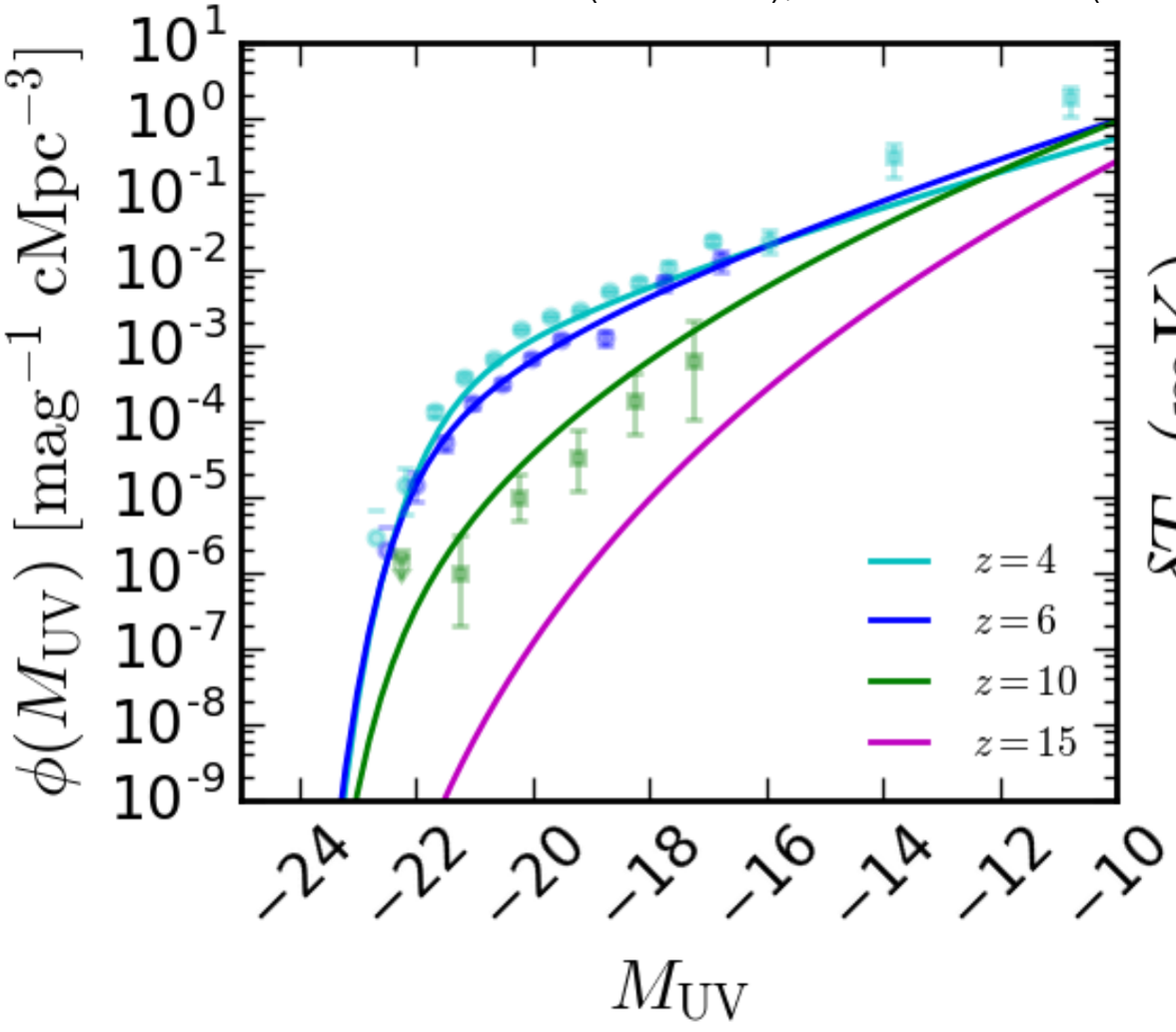

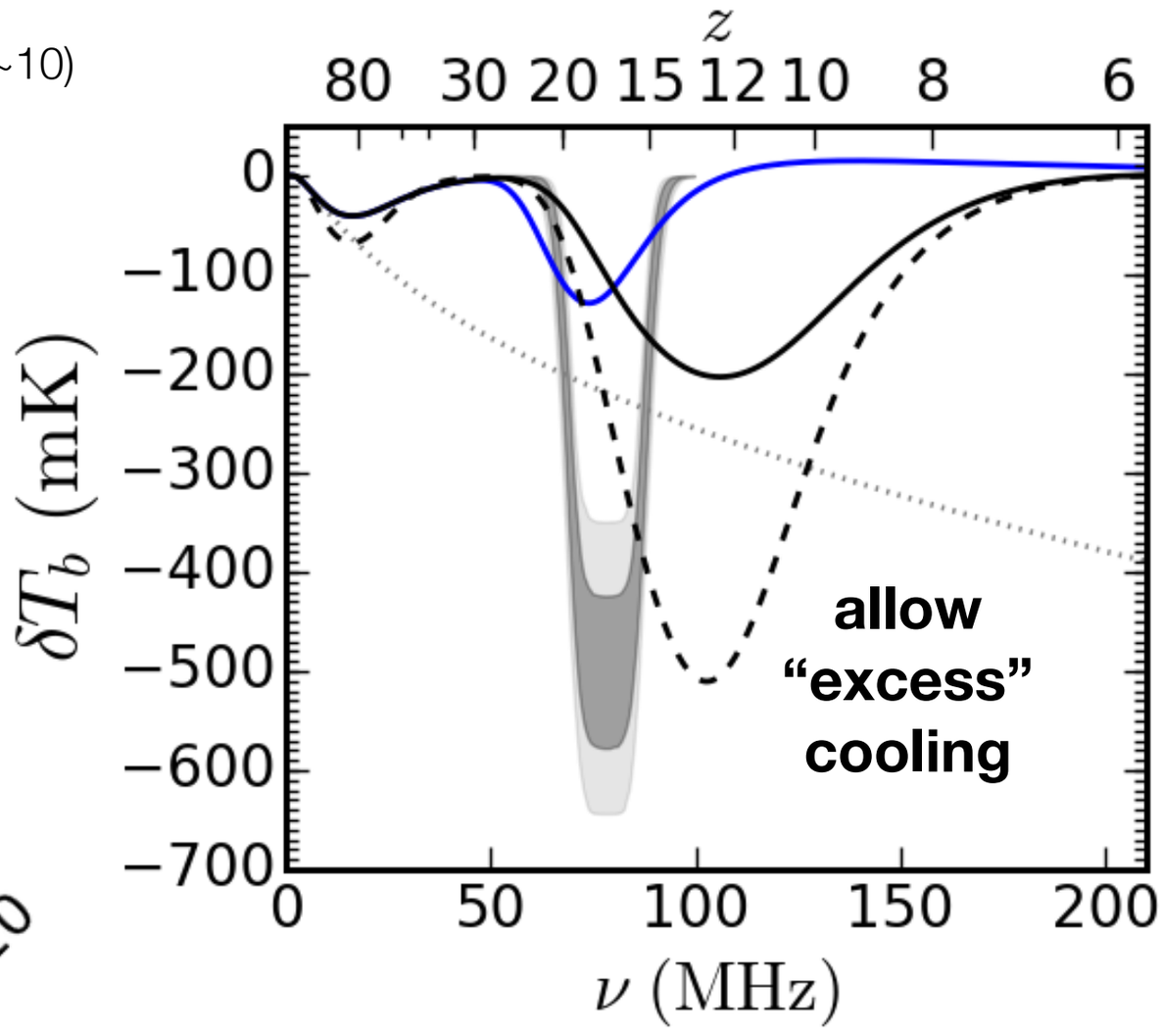

Mirocha & Furlanetto (2018), astro-ph/1803.03272

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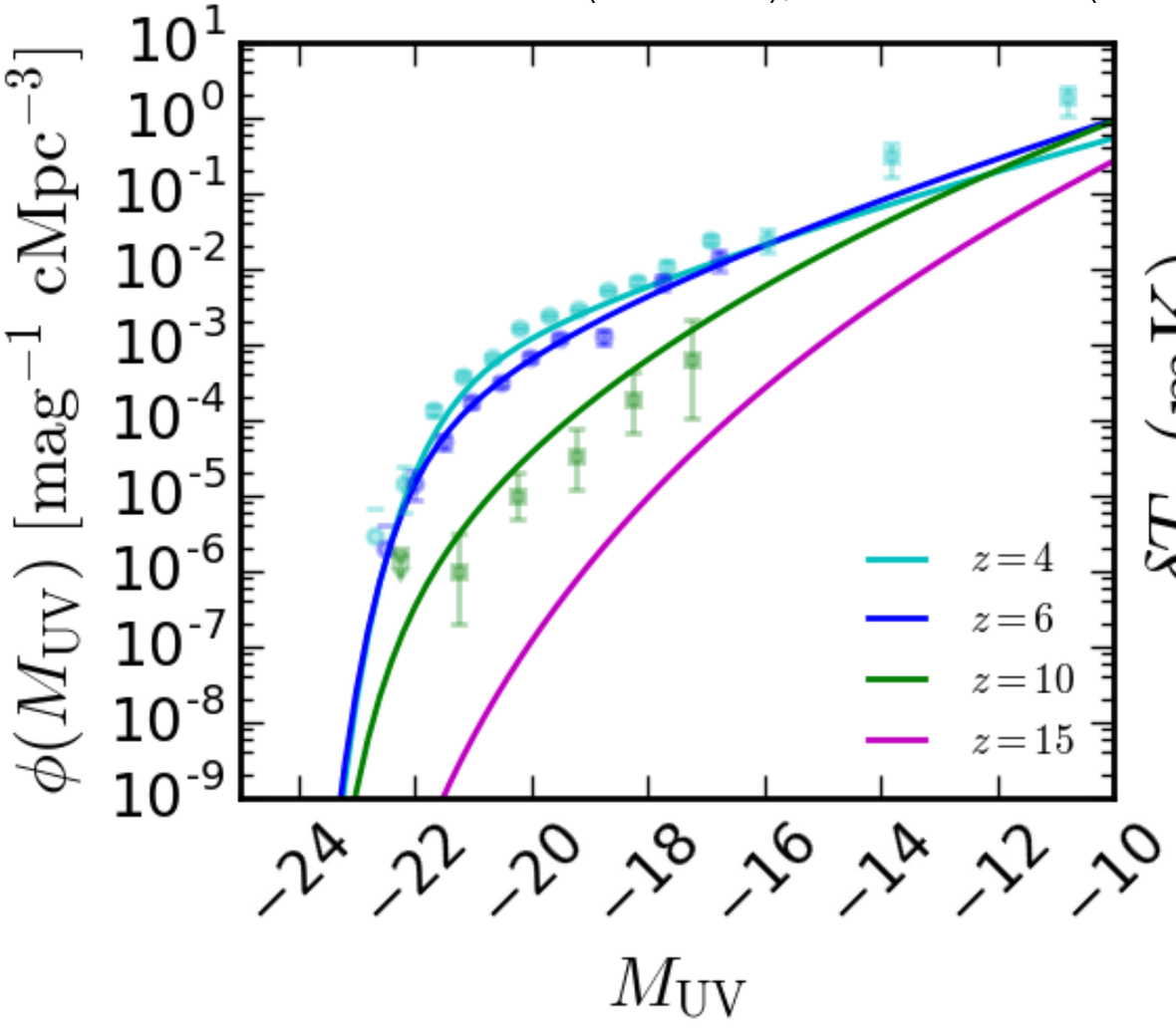
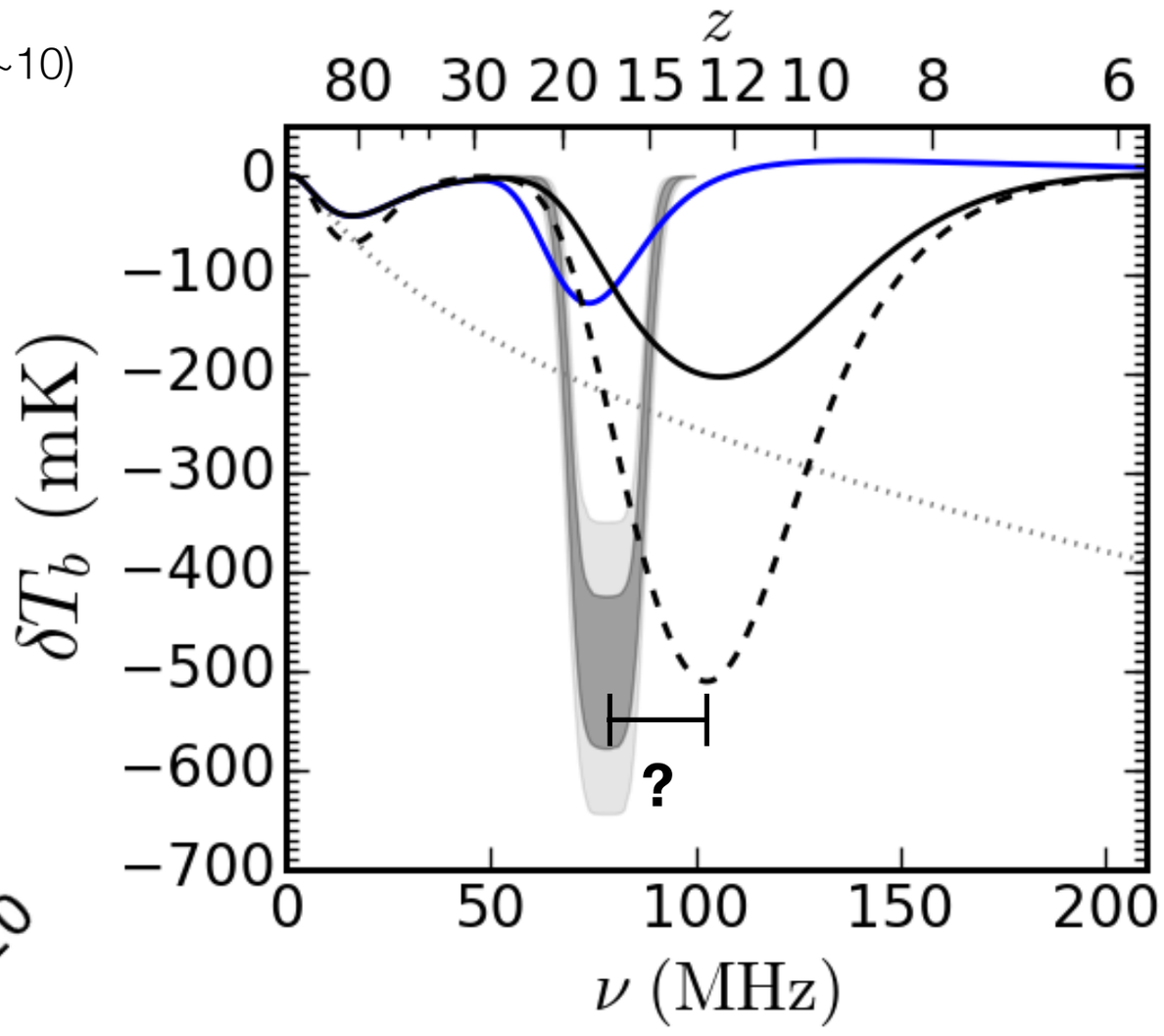
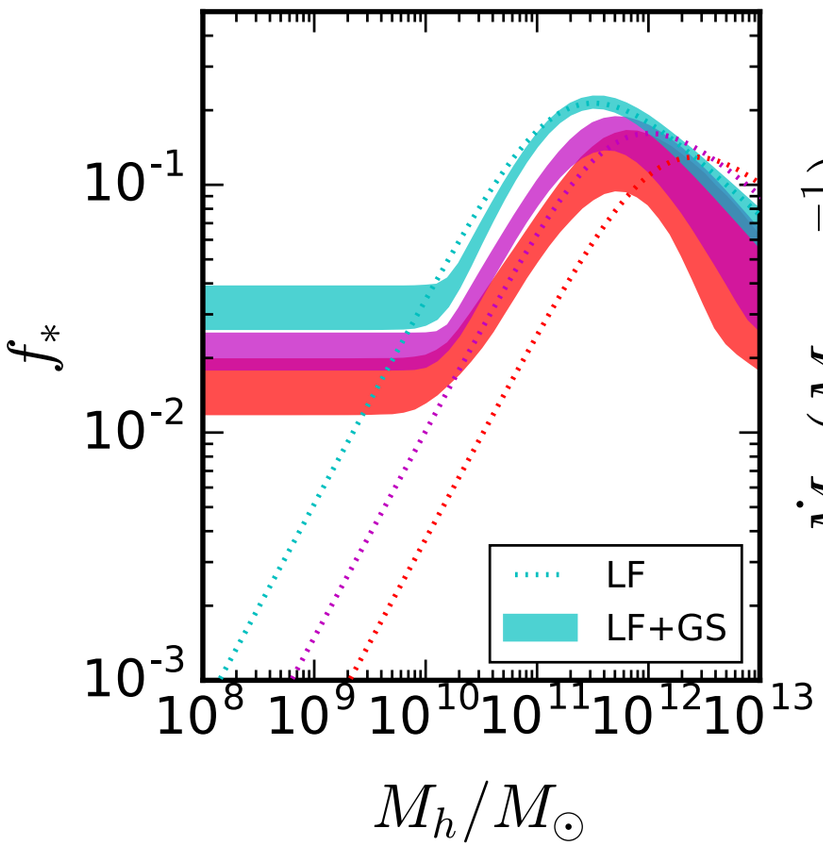


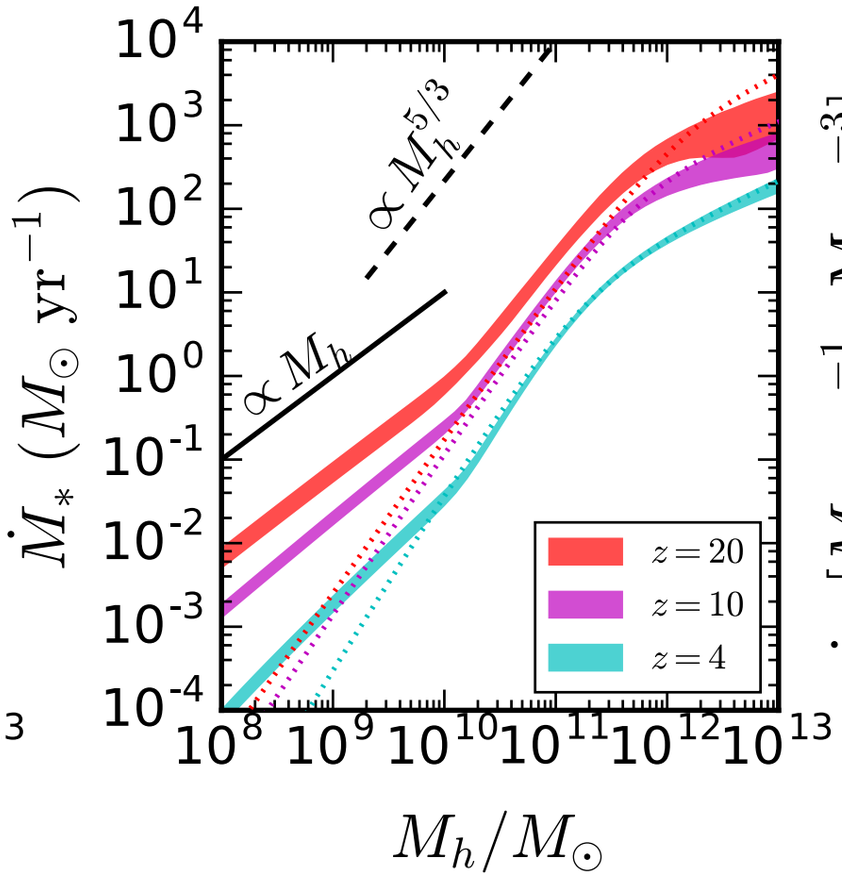


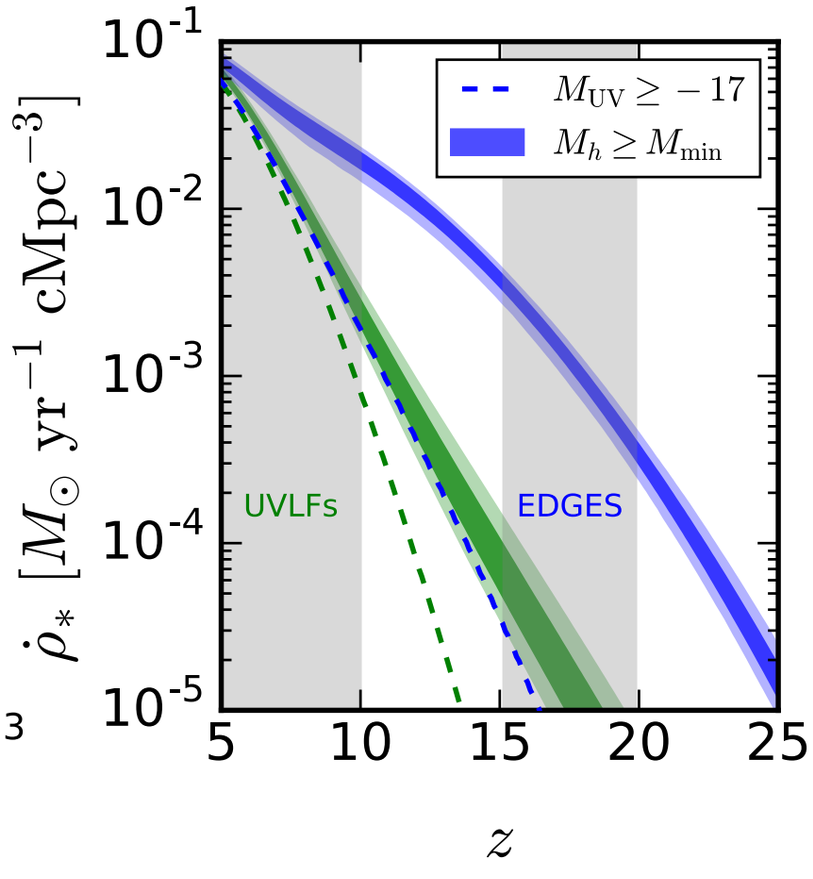
Mirocha & Furlanetto (2018), astro-ph/1803.03272

Engineering a Solution

Q. What must SFE be to fit EDGES signal?







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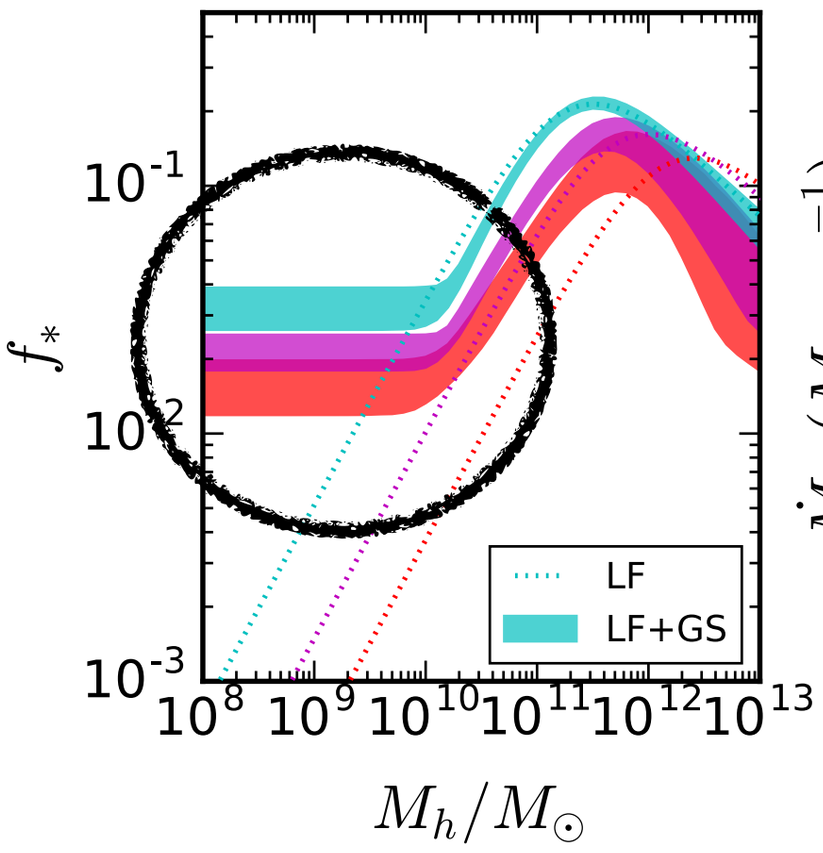

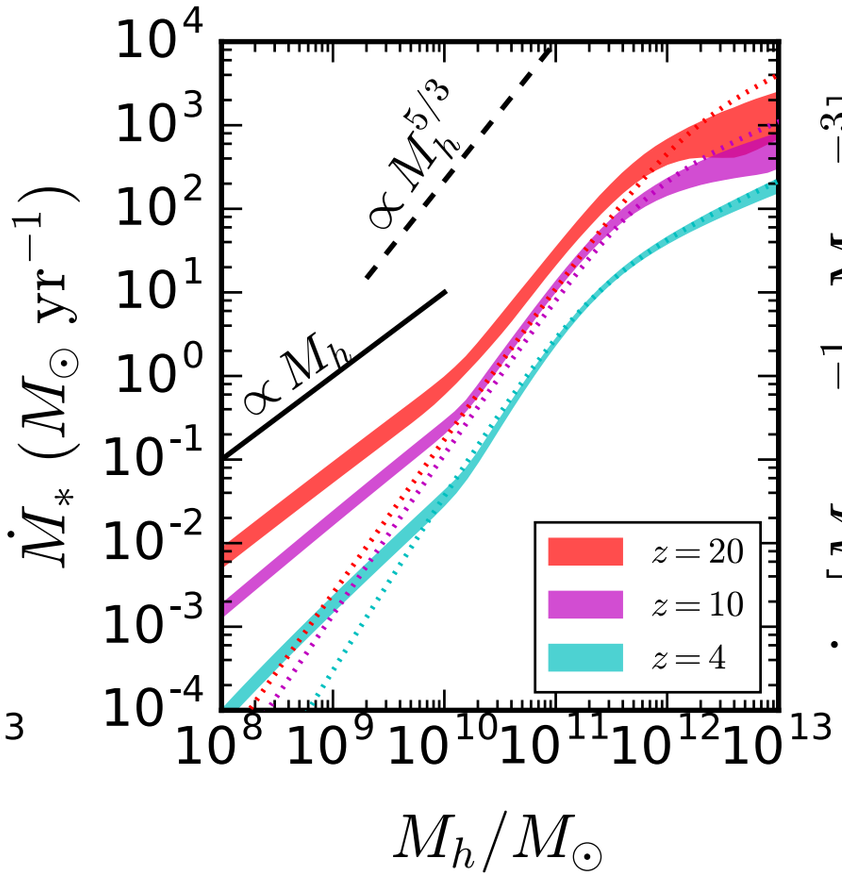

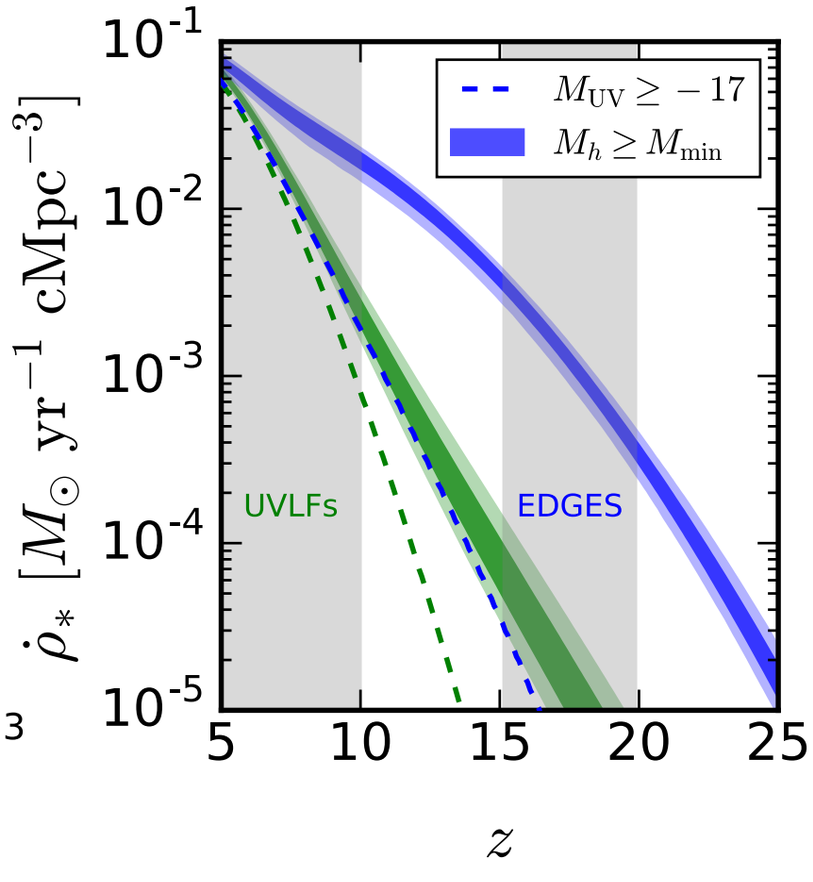

***Implies boost in number counts in future JWST UDF.**

Mirocha & Furlanetto (2018), astro-ph/1803.03272

Shape Problems

- Fit UVLF and EDGES simultaneously, vary SFE parameters, L_X-SFR relation. Limit to atomic cooling halos.

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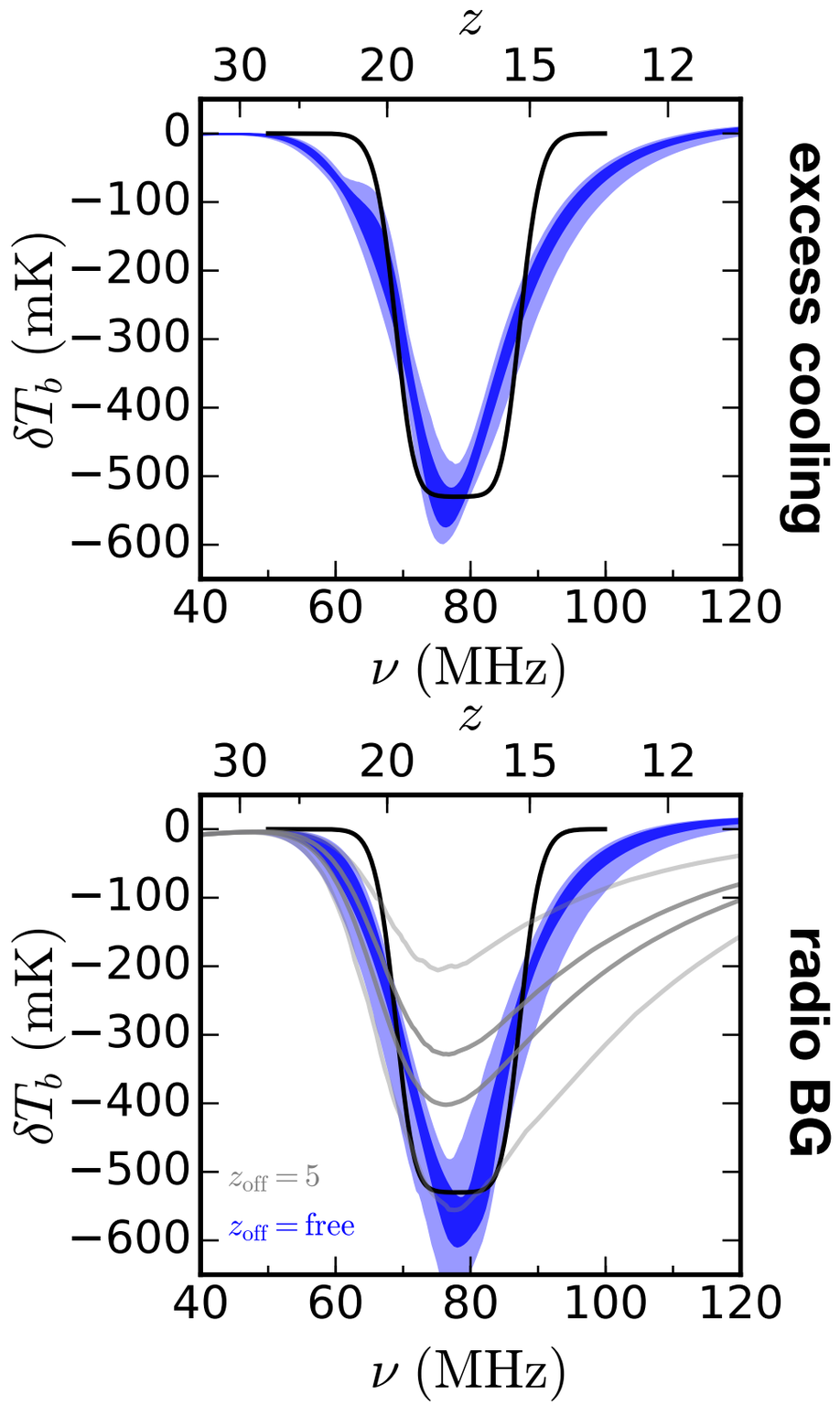
- Generate radio background assuming L_R ~ f_R x SFR.



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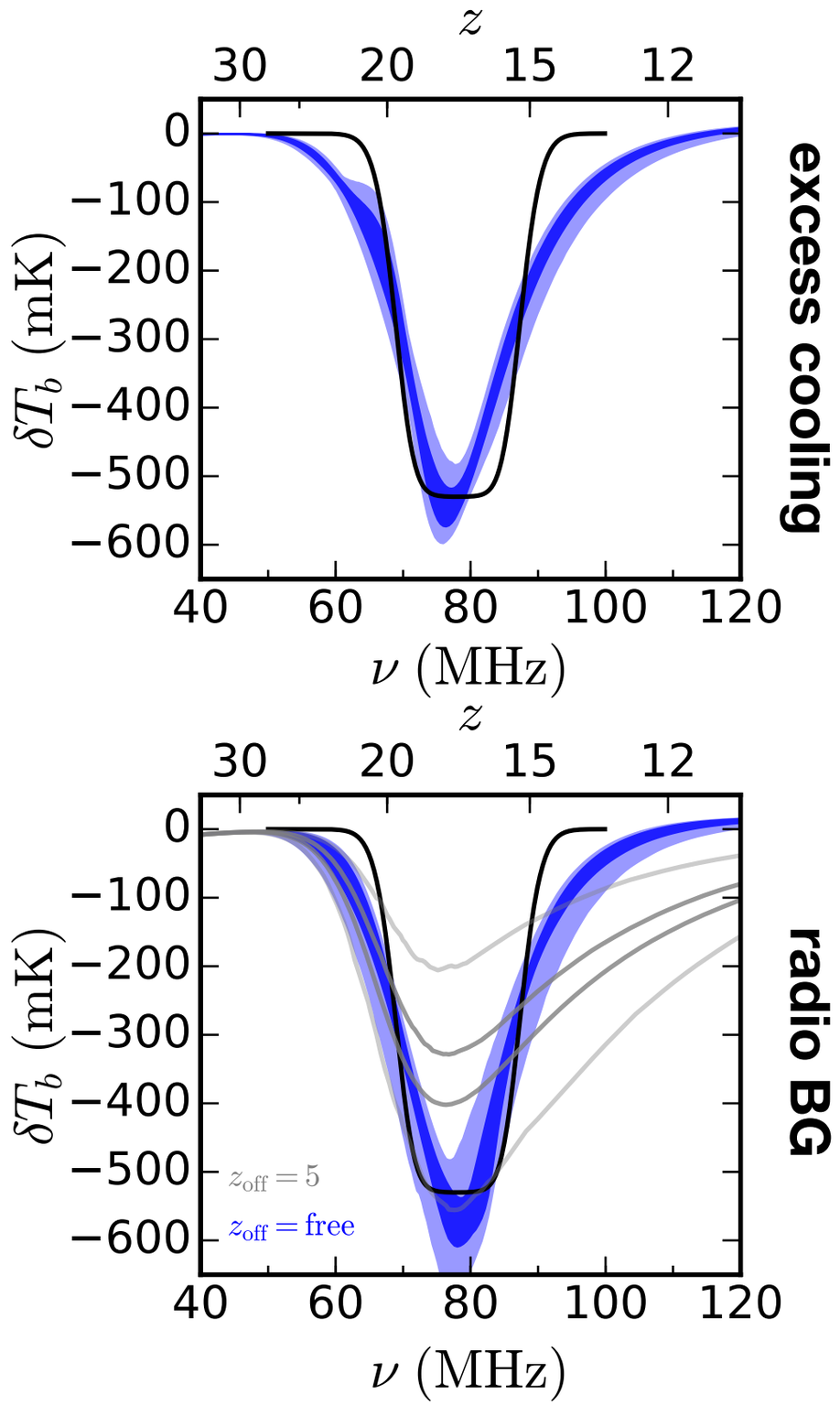

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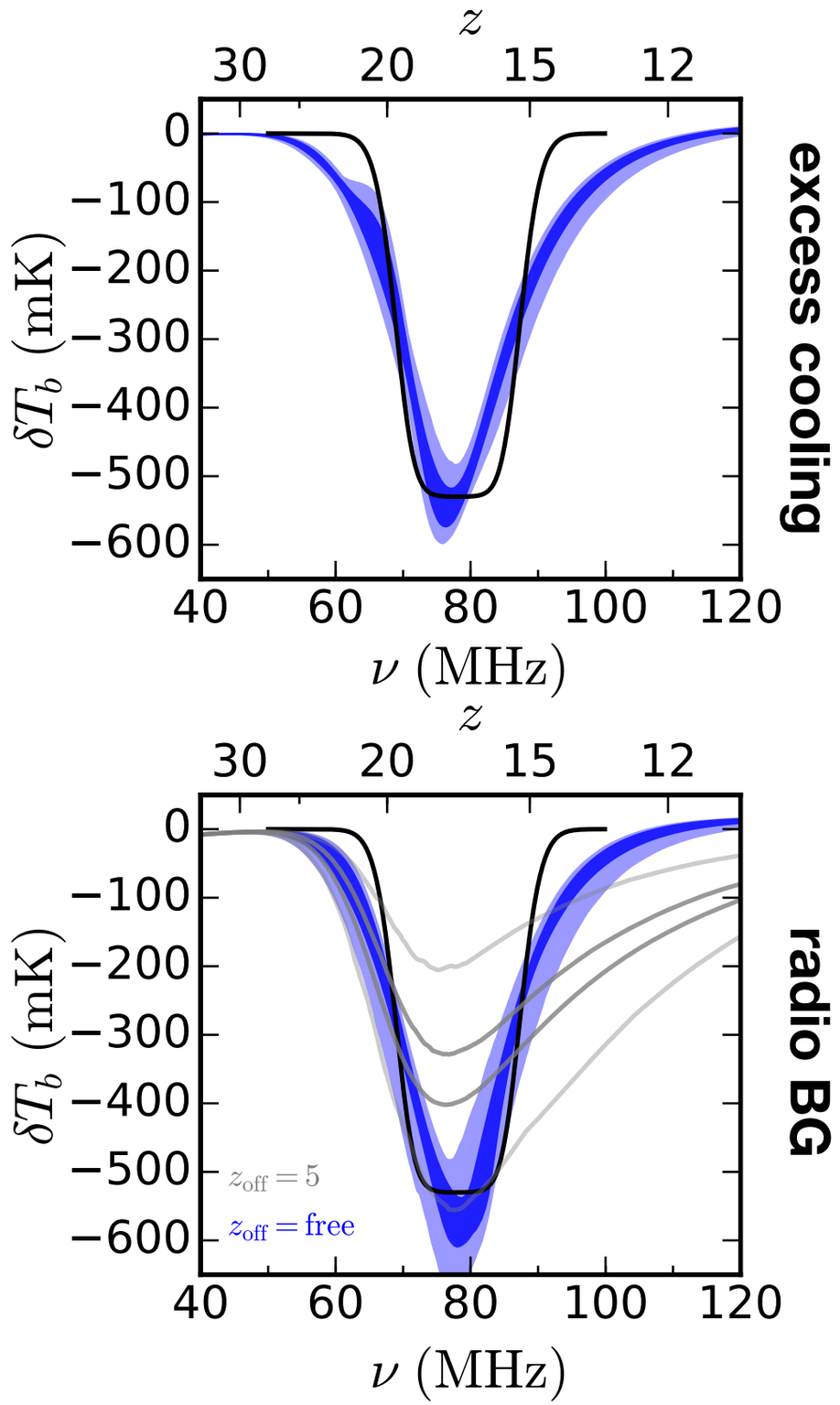

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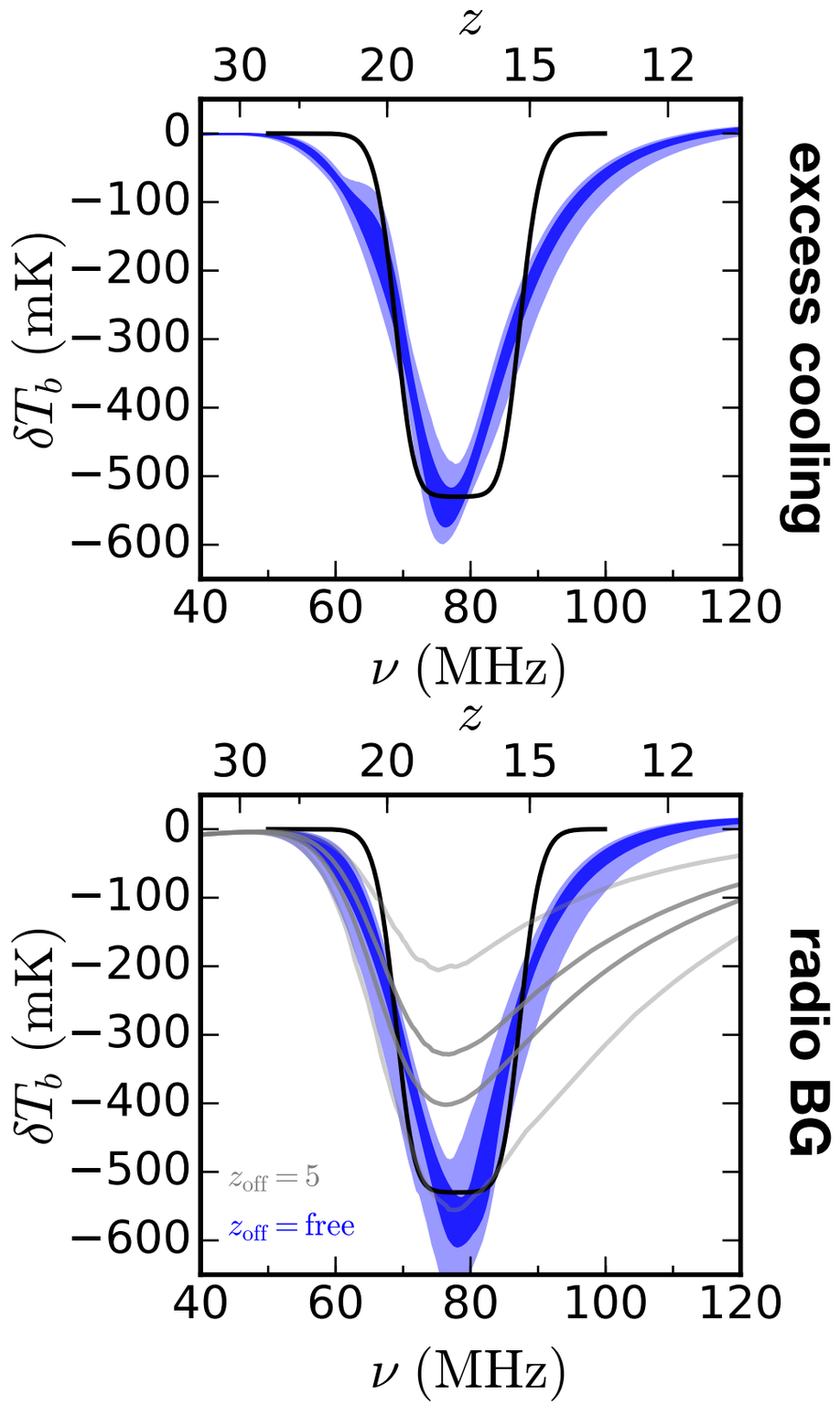
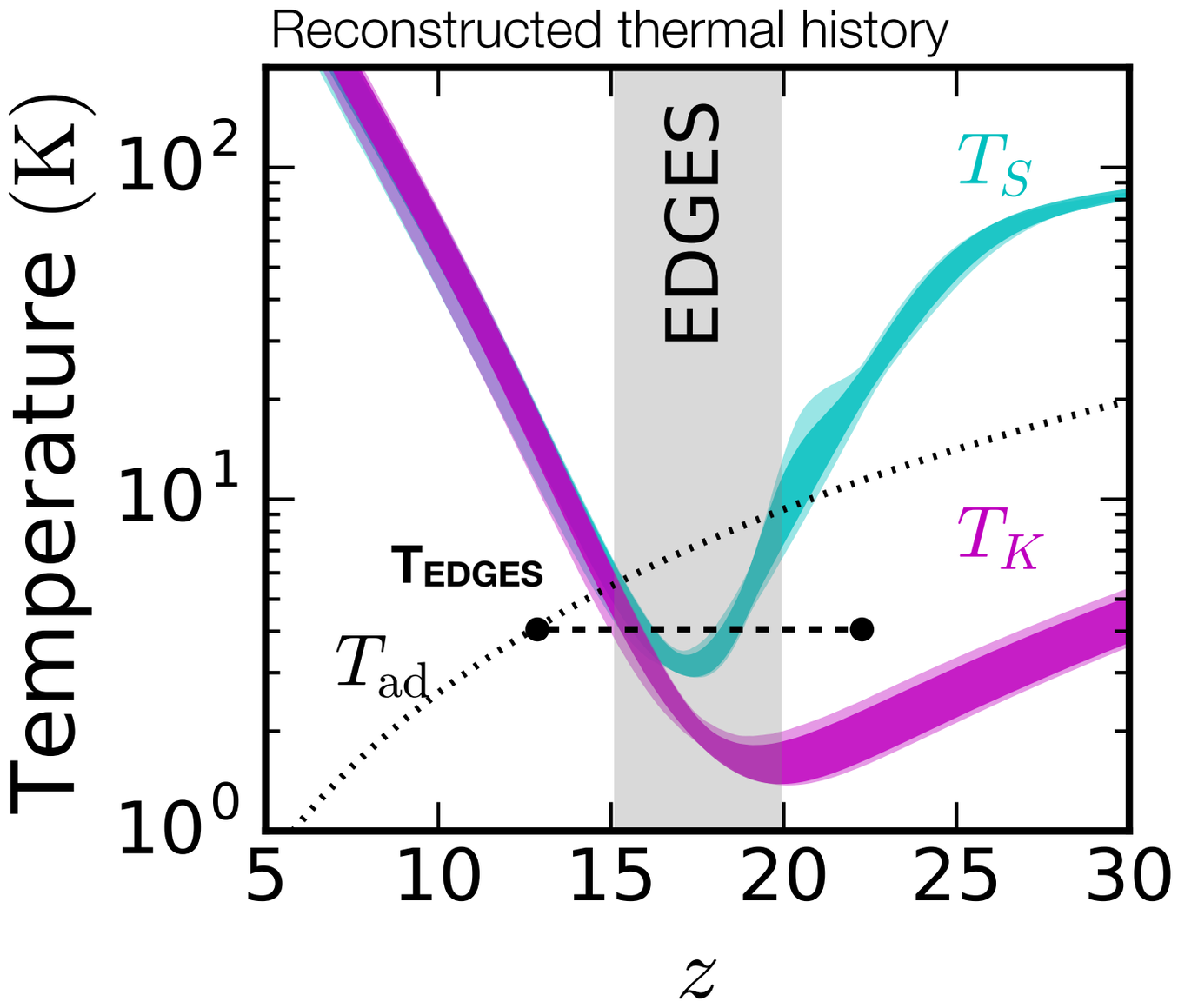


Mirocha & Furlanetto (2018), astro-ph/1803.03272

Words of Caution



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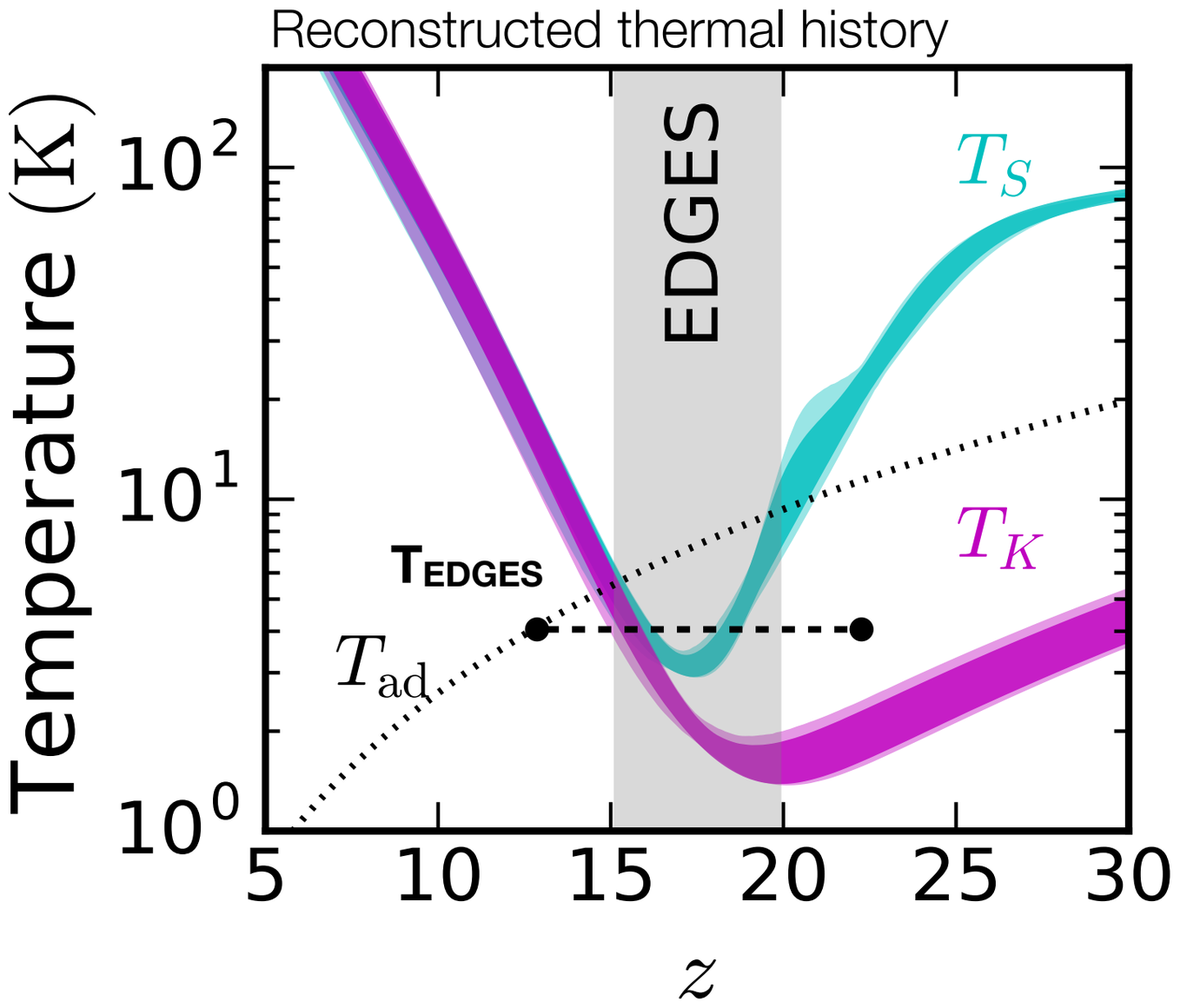

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Mirocha & Furlanetto (2018), astro-ph/1803.03272

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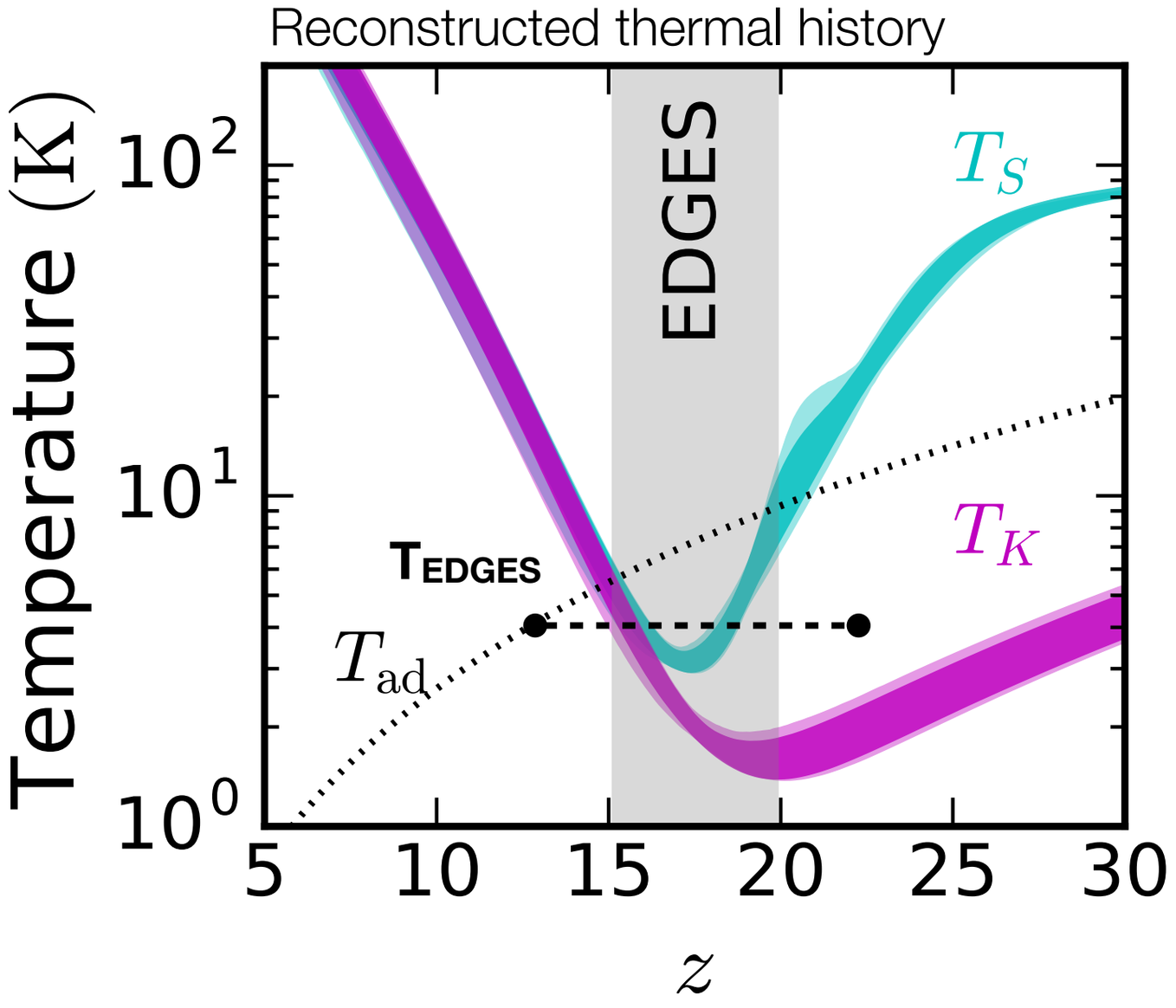

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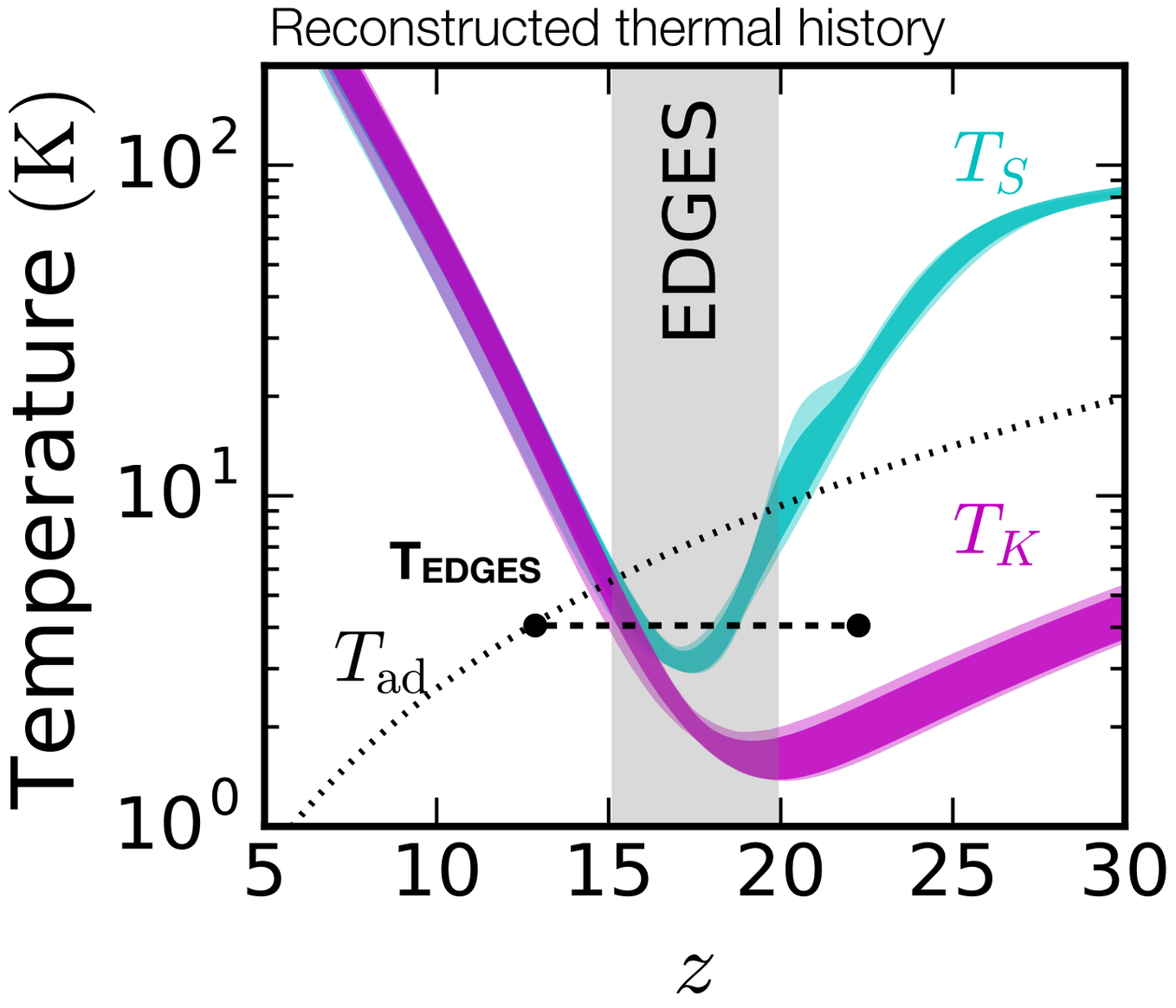

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- T_K has already been affected by sources!
- Another situation in which galaxy formation physics is a nuisance for DM-focused inference.

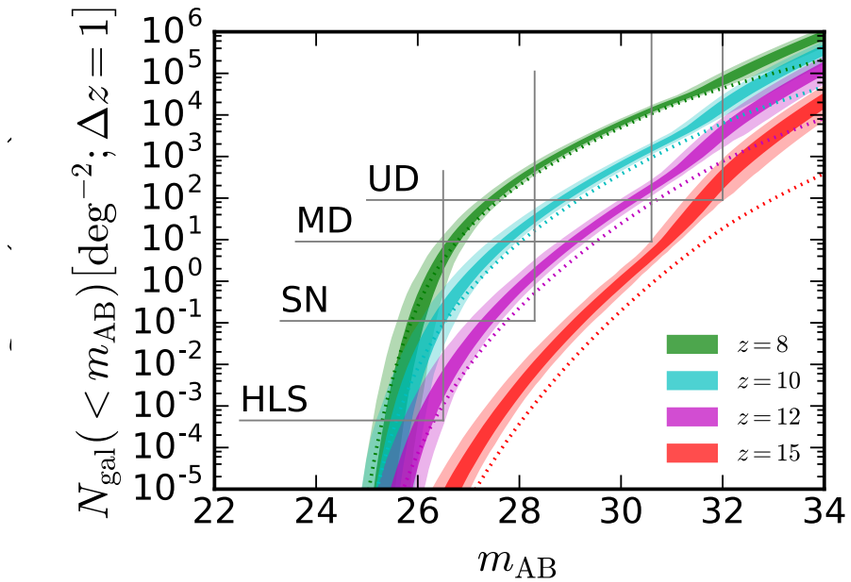
Mirocha & Furlanetto (2018), astro-ph/1803.03272

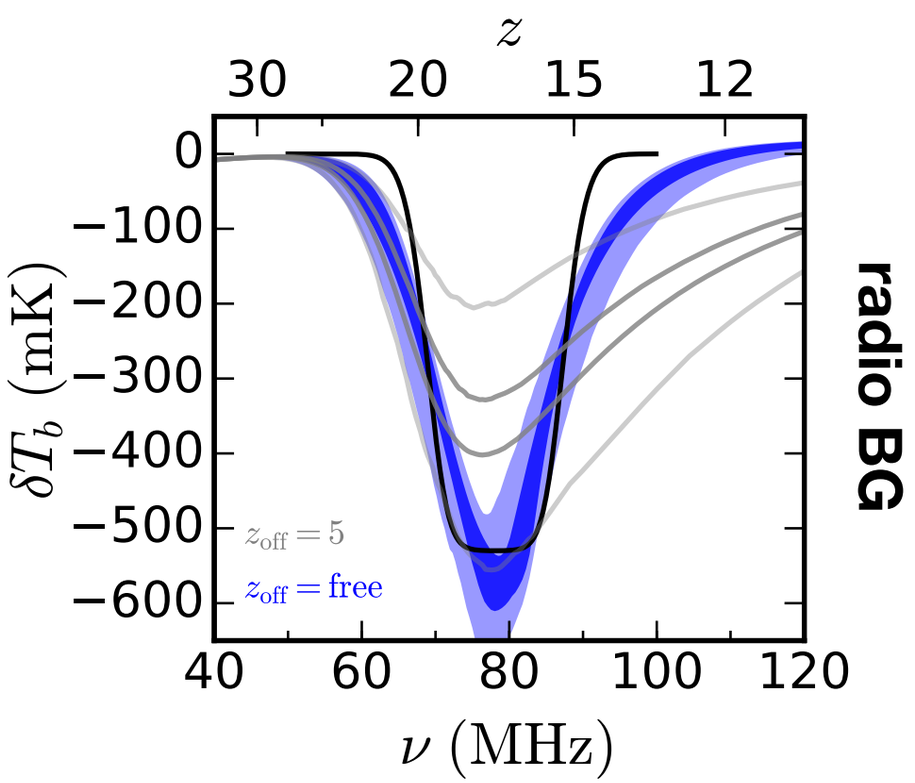
Conclusions

- Viable charged DM parameter space is quite limited.

- Radio background explanation puts a lot of pressure on astrophysical sources, both to generate a strong enough background at z > 20 and to shut down beyond z ~ 10-15.

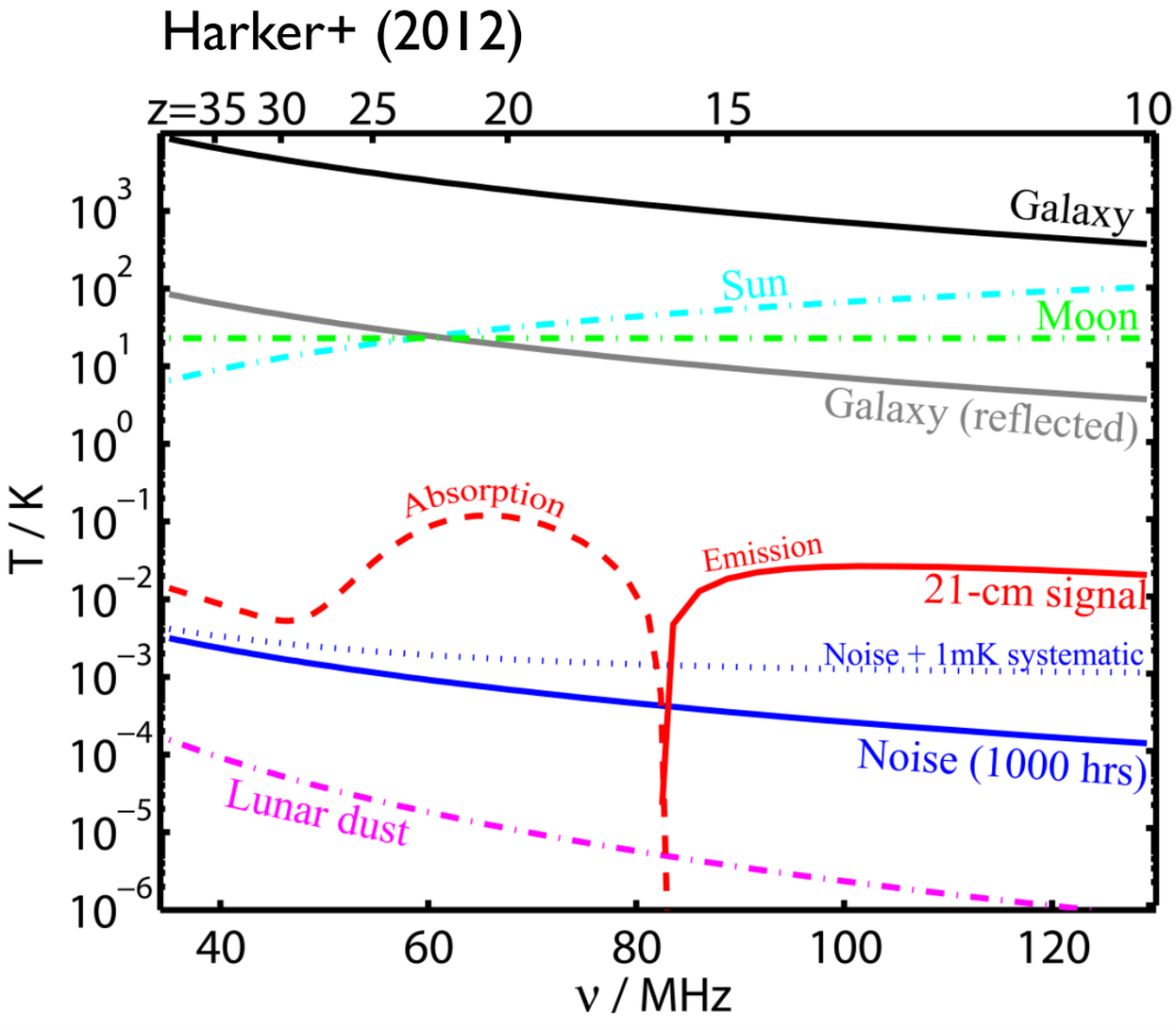
- The timing of the EDGES signal is also odd, implying there is more star formation at z > 10 than simple models predict, independent of amplification mechanism.

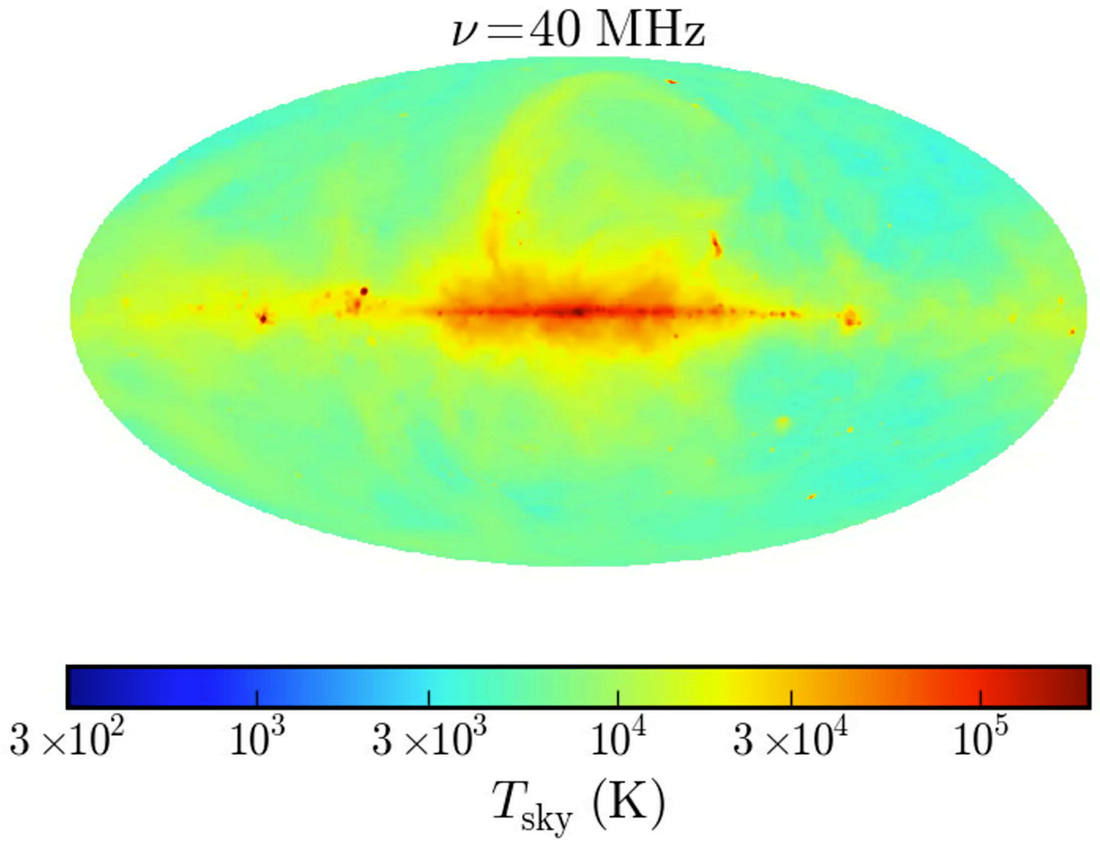




Backup Slides

The Foreground Problem

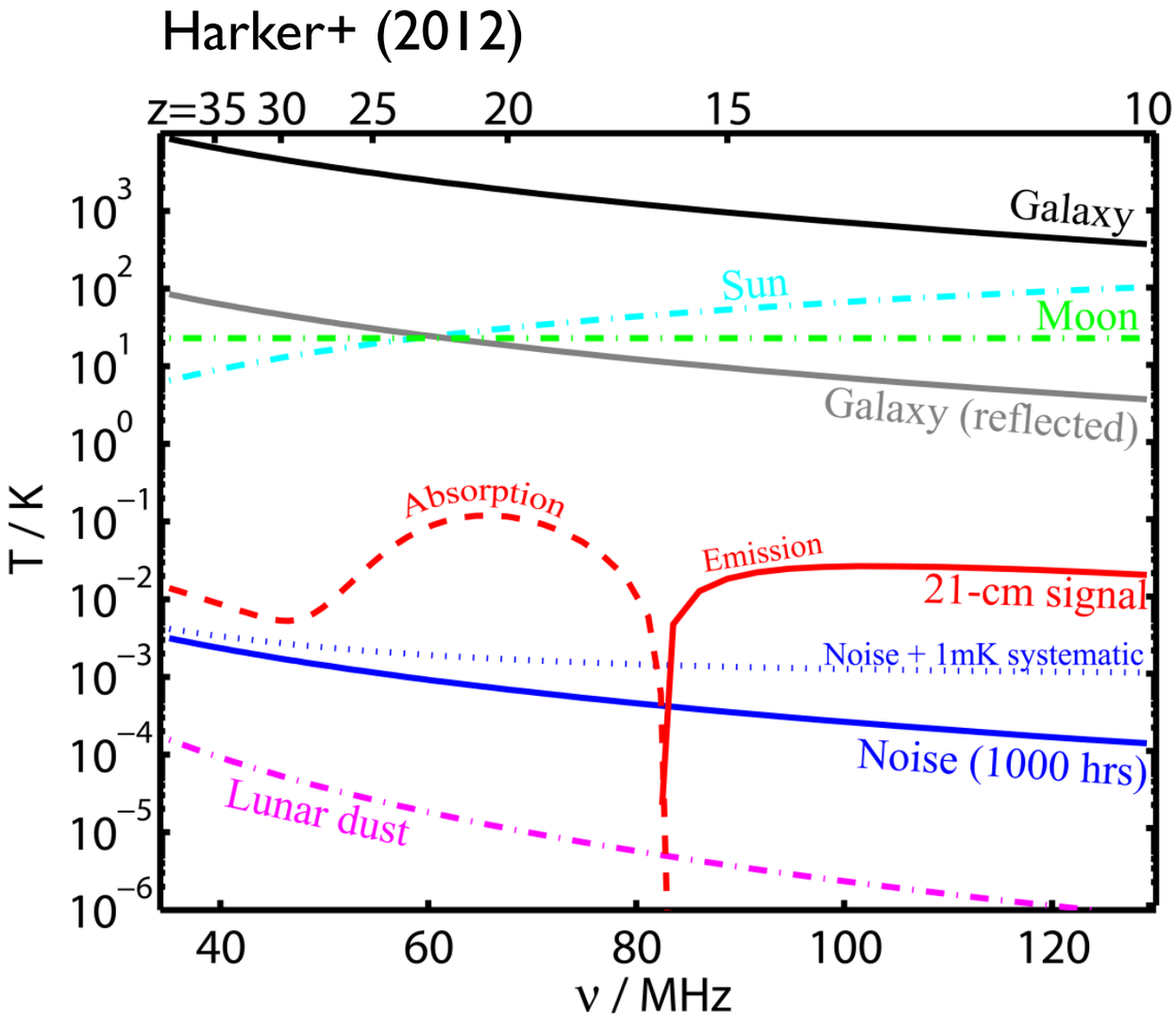


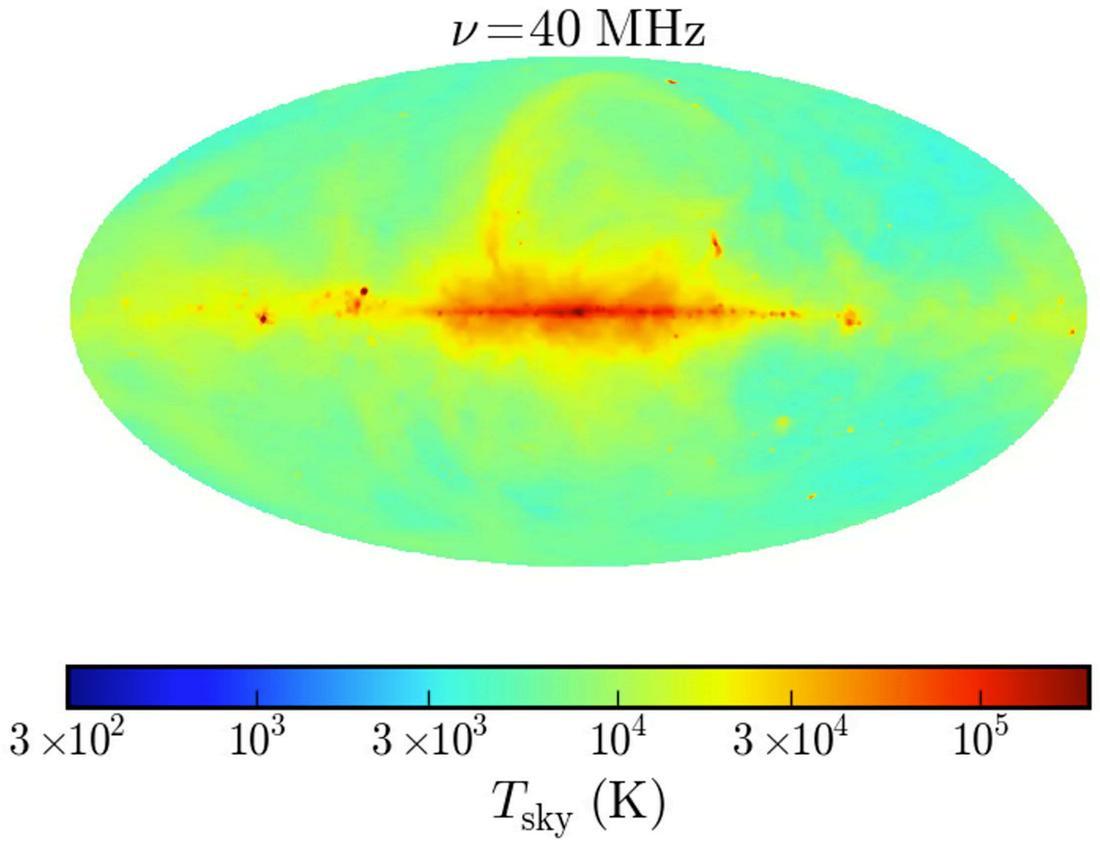


(mostly synchrotron)

This is a *really hard* measurement.

The Foreground Problem





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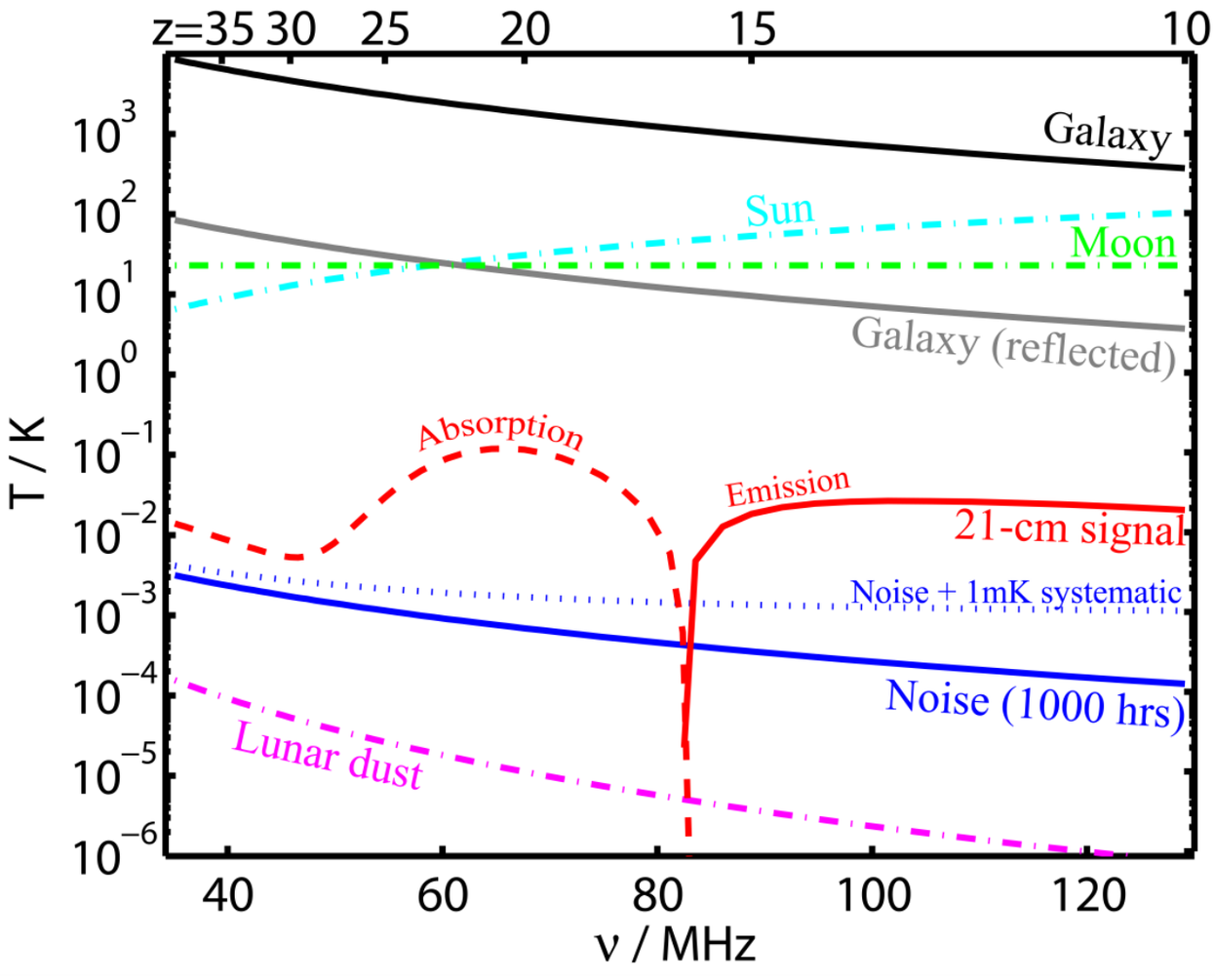
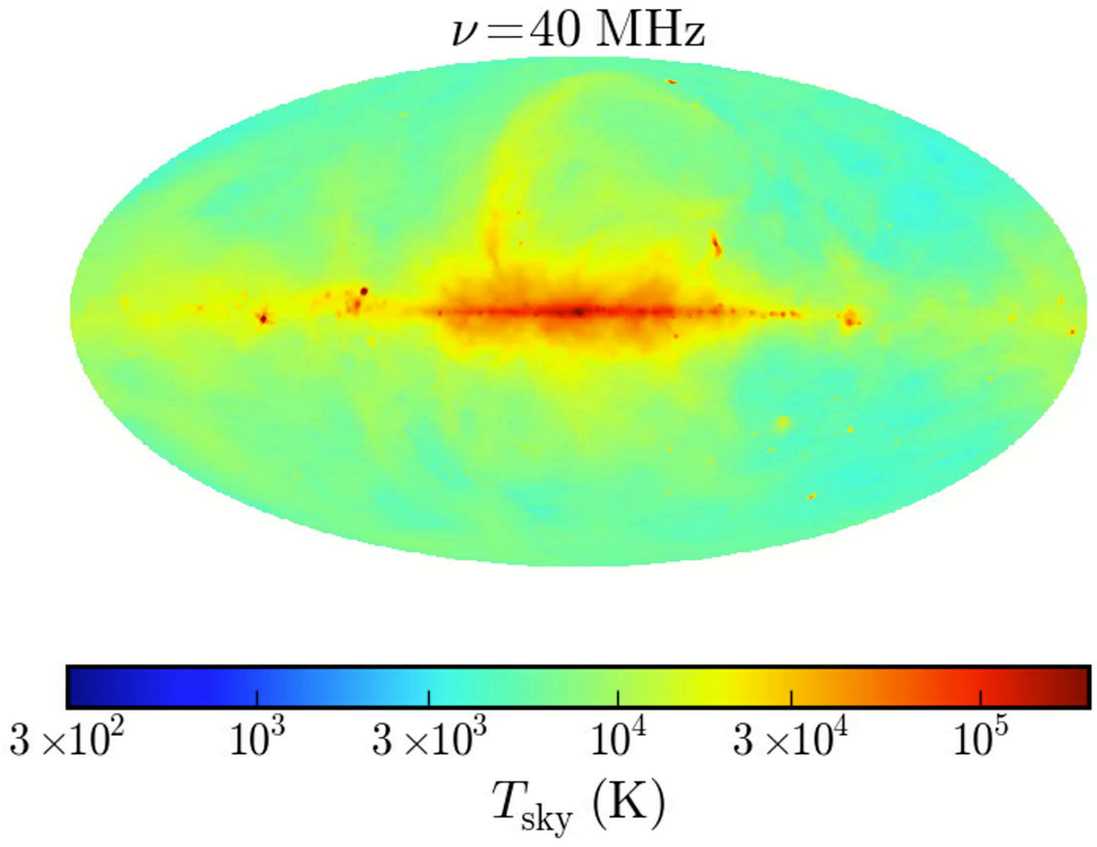
The Foreground Problem

Harker+ (2012)



deOliveira-Costa+ (2008) sky model



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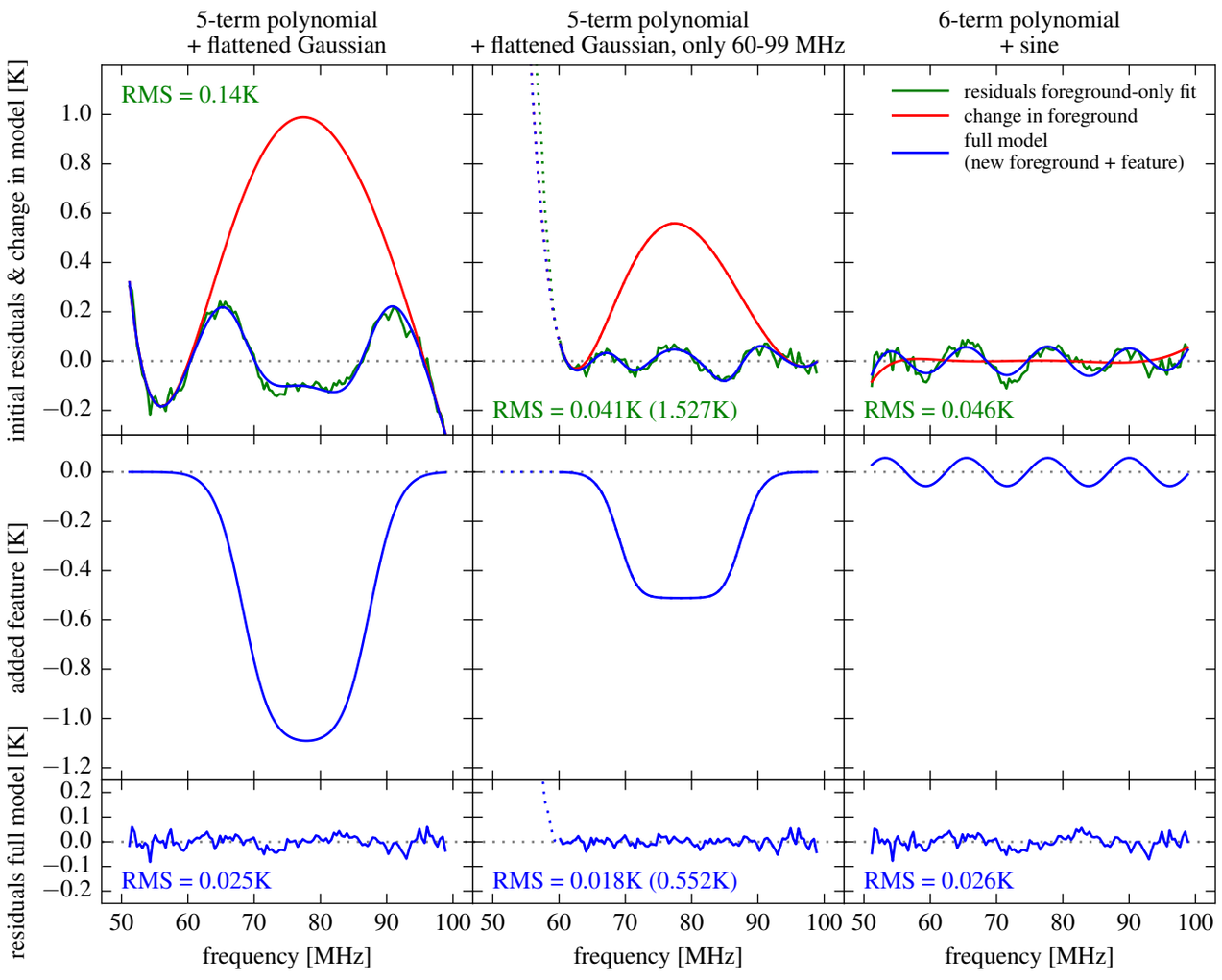
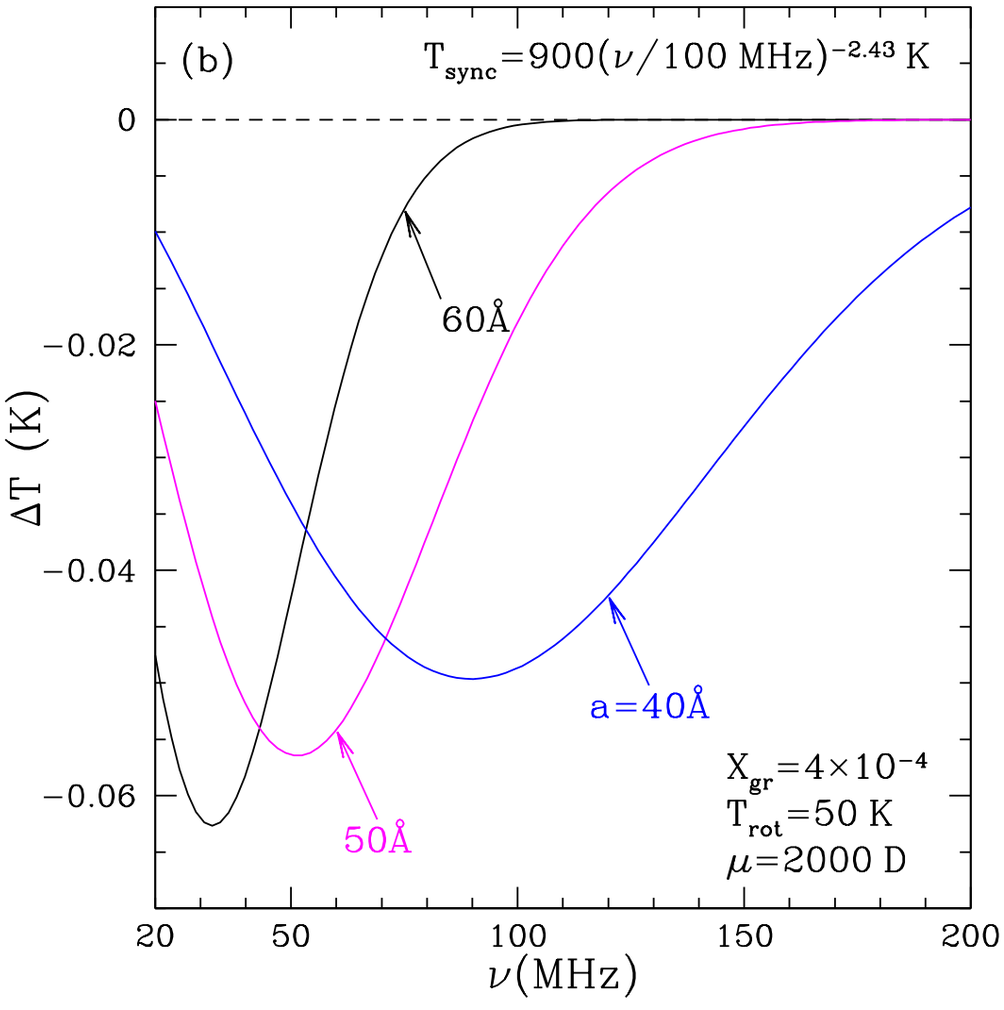
Challenges Thus Far

Hills, Kulkarni et al.



spurious instrumental artifacts?

Draine & Miralda-Escudé

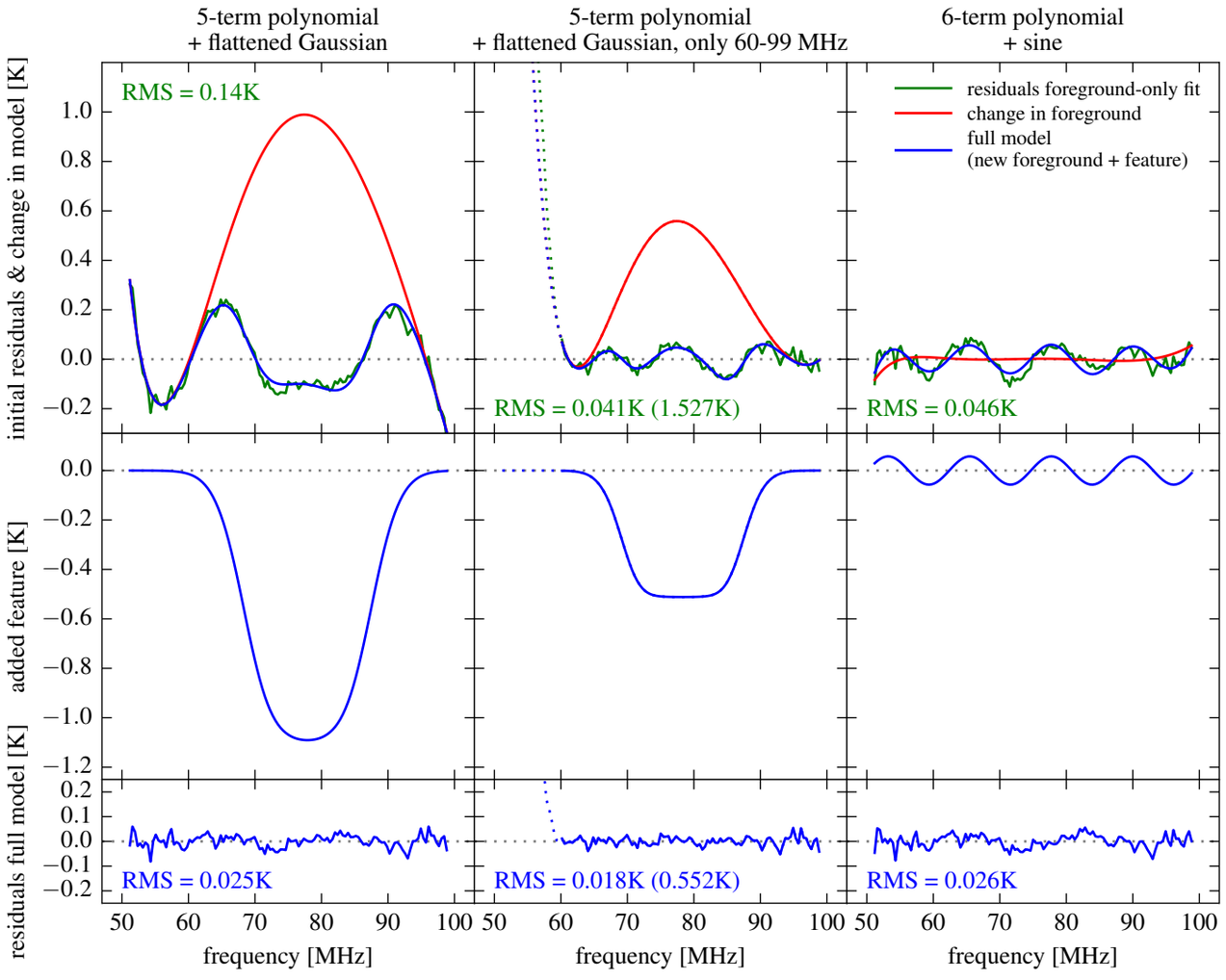


dust?

Challenges Thus Far

http://loco.lab.asu.edu/download

Hills, Kulkarni et al.



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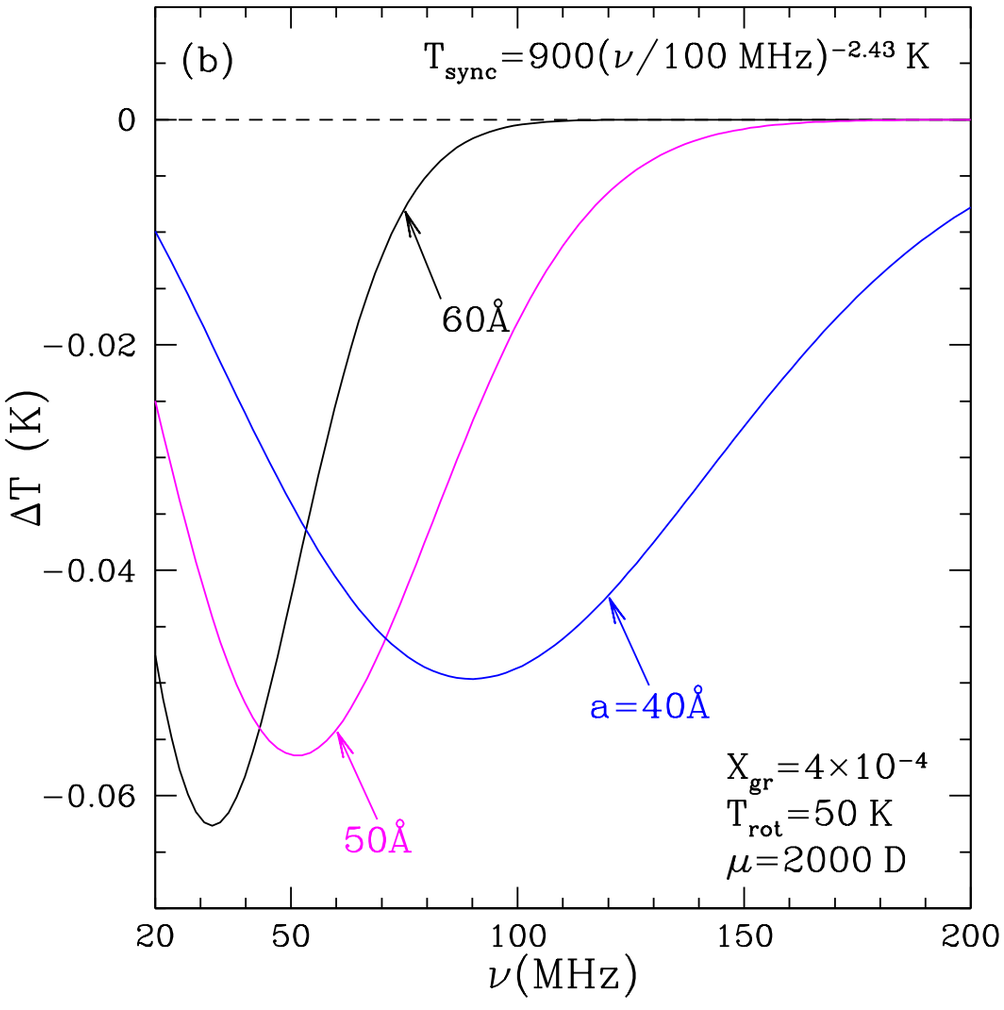

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