# Population III Stars and the Cosmic 21-cm Background

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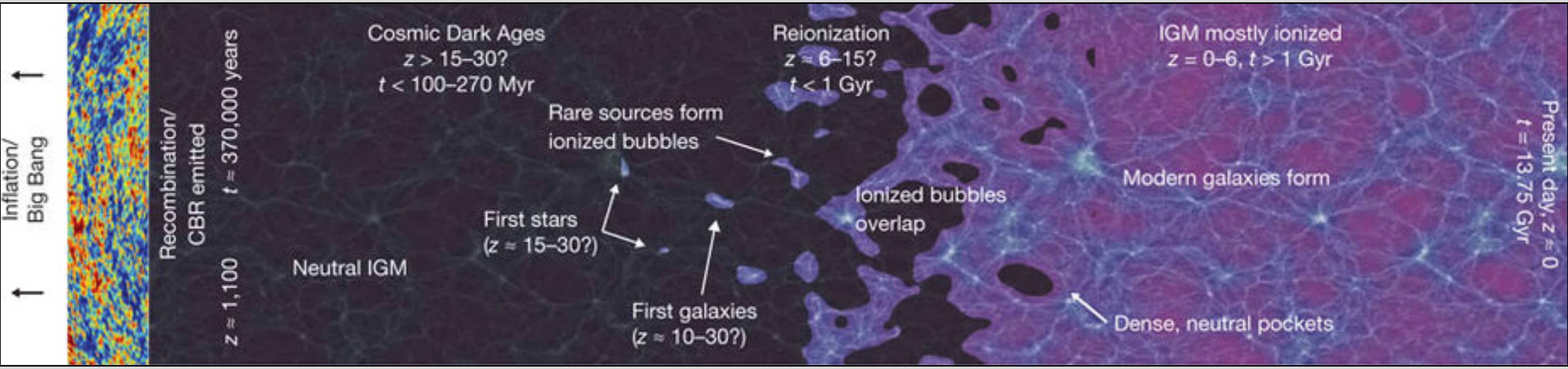



Robertson et al. 2010

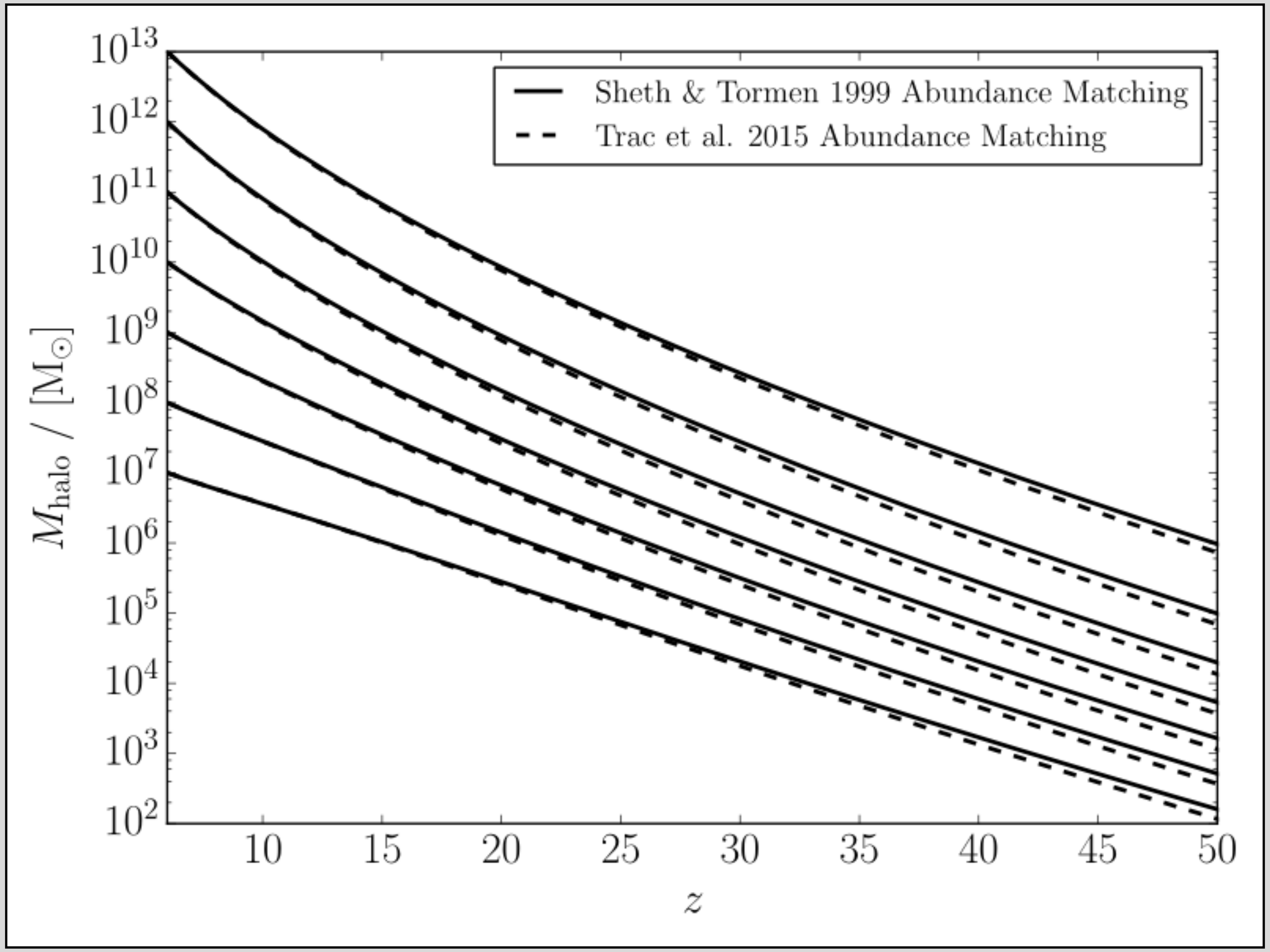
**Semi-analytic models are powerful tools for studying the dark ages and reionization.**

- Pop III star formation models are largely unconstrained as there are no observations.

- We use a semi-analytic model to incorporate important physics and test a wide range of assumptions.

# Mass accretion at high redshifts can be treated as a smooth process.

- Seen at very high redshift in simulations (Behroozi & Silk 2015)
- Assume halos stay at same comoving number density
- Track growth directly from the mass function (abundance matching)
- High mass resolution, but no mergers

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# Pop III stars in our model.

- Massive (fiducial IMF has $M_{min} = 20\ M_\odot$)
- Form in minihalos below atomic cooling threshold ($10^4$ K)
- Form in isolation

# The first stars formed through molecular hydrogen cooling.

- $H_2$ forms through

$$\mathrm{H} + \mathrm{e}^- \rightarrow \mathrm{H}^- + h\nu$$

$$\mathrm{H}^- + \mathrm{H} \rightarrow \mathrm{H}_2 + \mathrm{e}^-$$

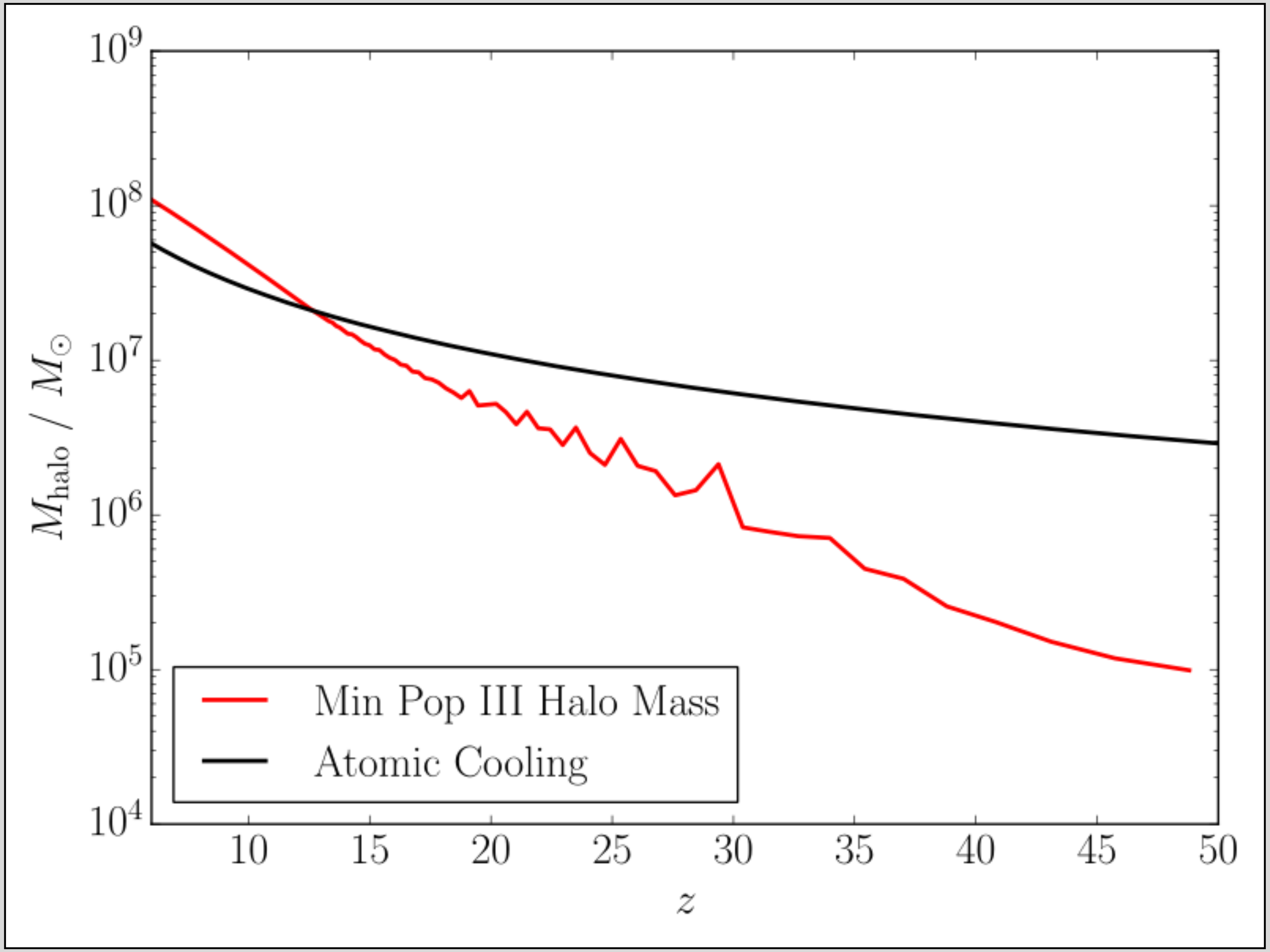
- $H^-$ is destroyed easily by CMB photons

- Balance creation and destruction rate to find when cooling becomes efficient (e.g., Tegmark et al. 1997)

# Lyman-Werner photons can also dissociate a halo's $H_2$.

- Photodissociation continuum begins at 14.7 eV
- Photons with $E > 13.6$ eV absorbed by neutral IGM
- Lyman-Werner photons (11.2 – 13.6 eV) dissociate $H_2$ through Solomon process
- Can find mass needed to self-shield from simulations (e.g., Visbal et al. 2014)

# The minimum Pop III halo mass is set by the CMB and global LW feedback.

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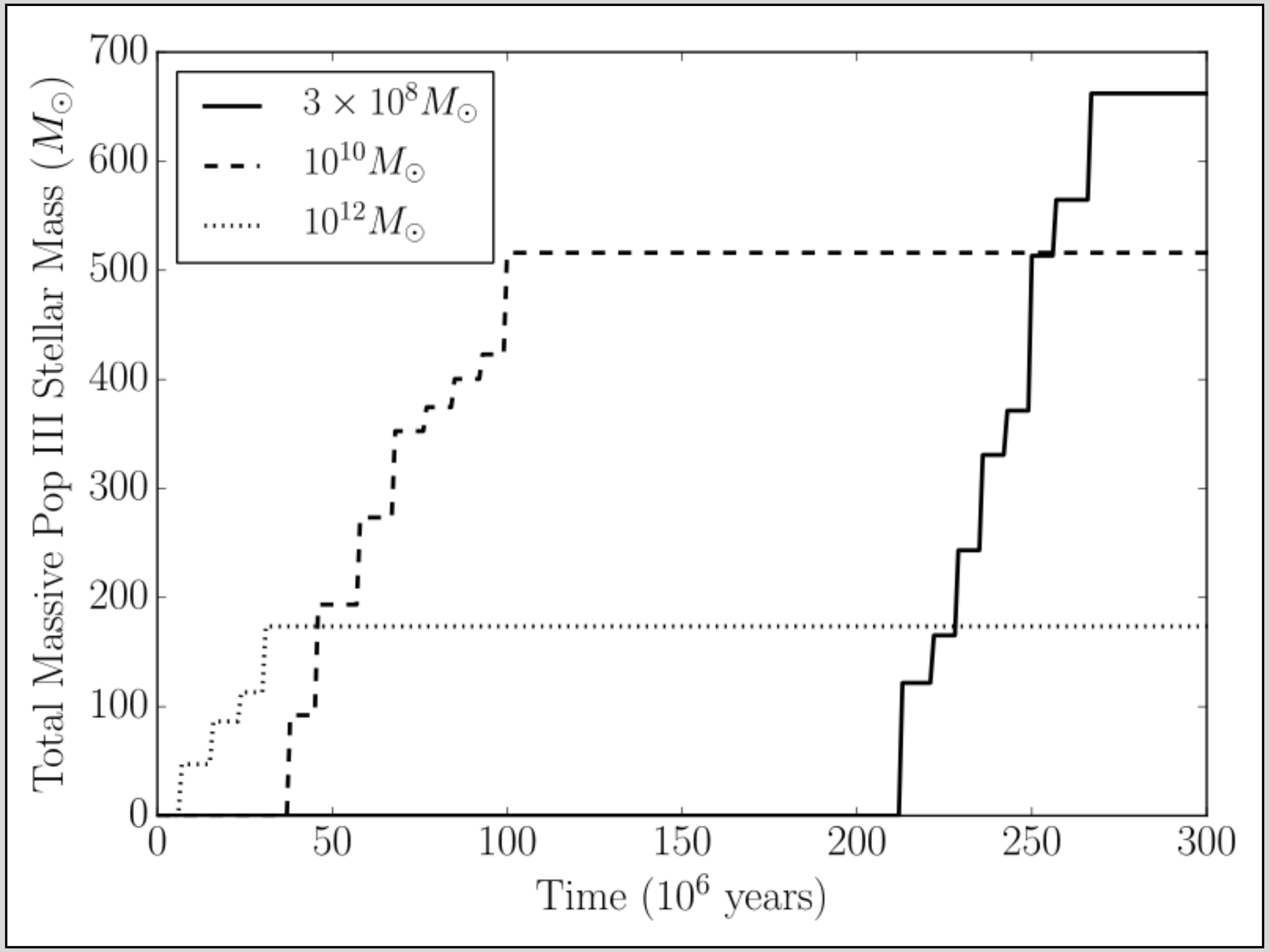
# Pop III halos were small and susceptible to supernova feedback.

- Pop III supernovae eject gas and metals
- Halo can "forget" about previous star formation
- More massive halos become stable to supernovae quicker, forming fewer Pop III stars

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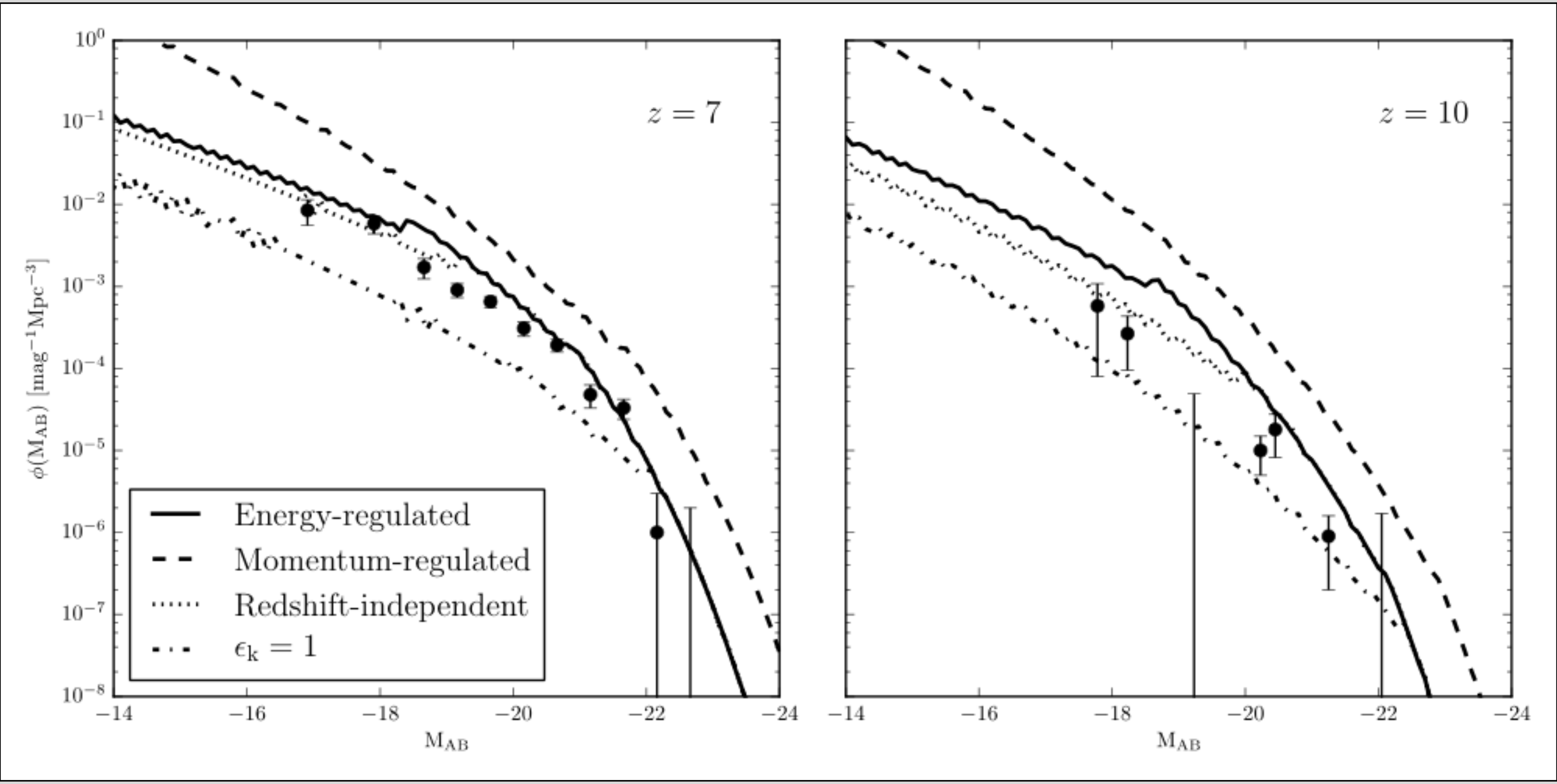
# Pop II models provide reasonable fits to data.



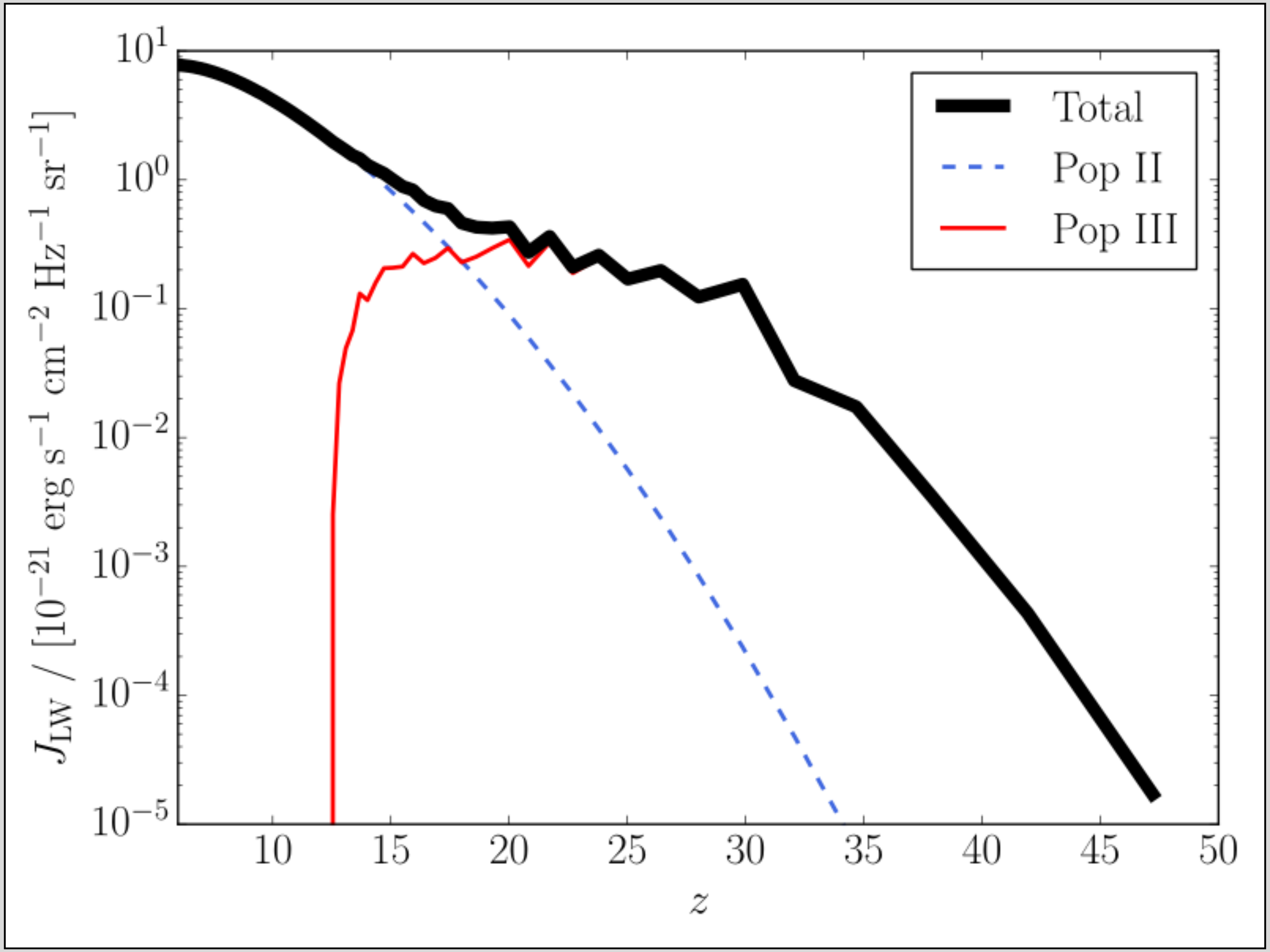

LF data from Bouwens et al. 2015





Pop II models from Furlanetto et al. 2017

# Pop II stars contribute the bulk of Lyman-Werner photons and end the Pop III phase.

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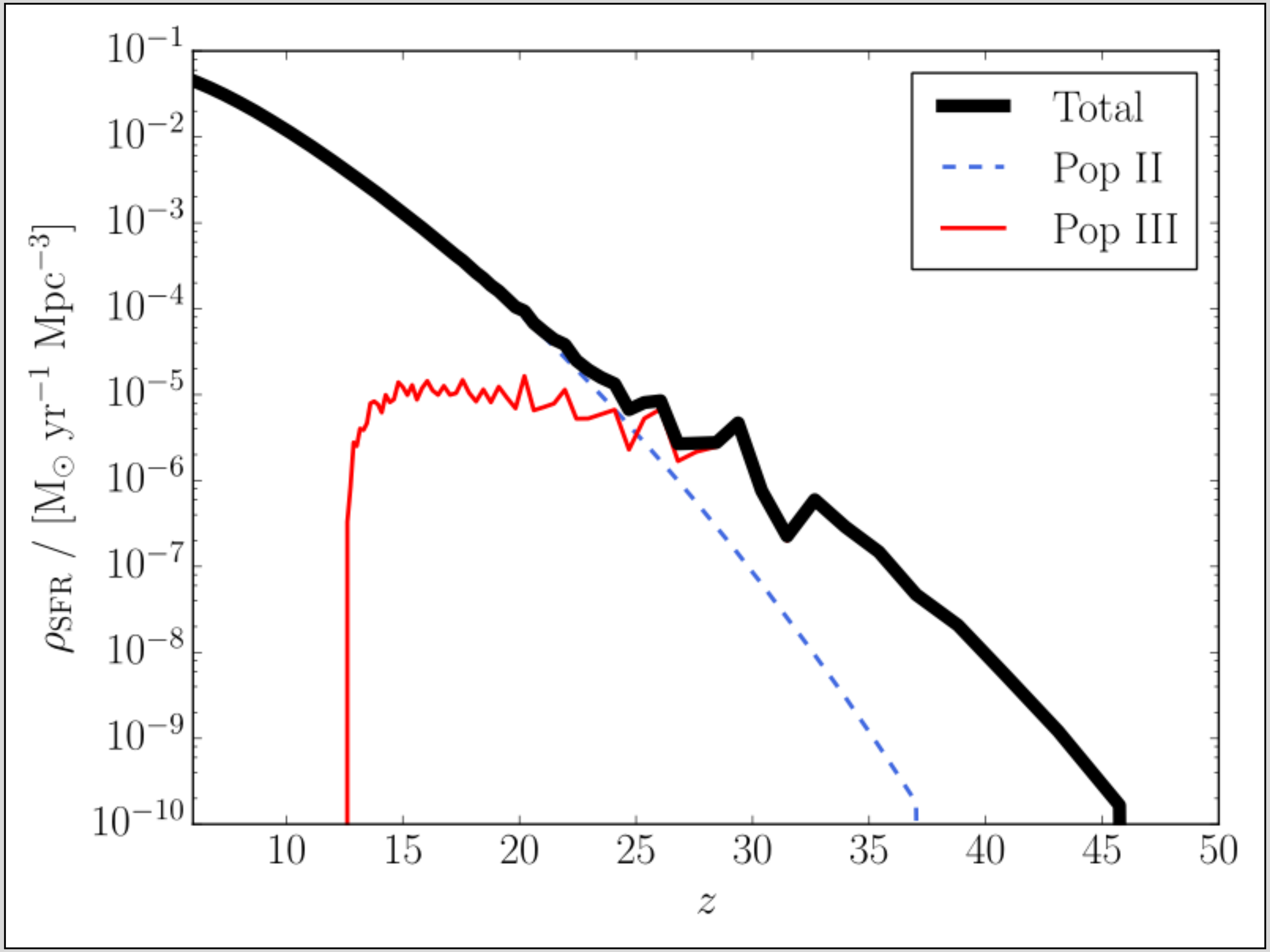
# Pop III star formation generally plateaus and ends well before z~6.




Mebane et al. 2018

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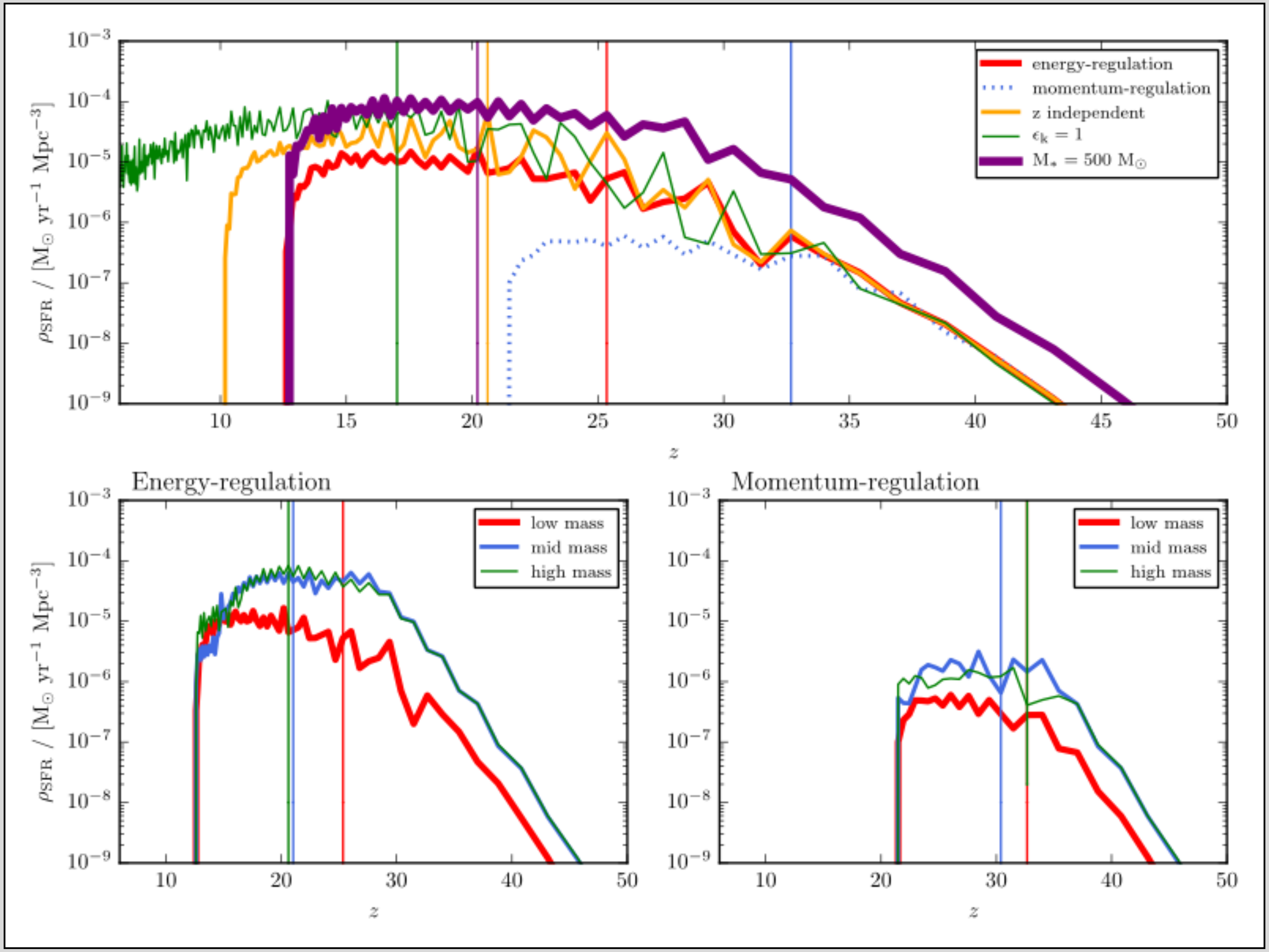


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# The best chances for detection will come from supernovae or 21-cm.

- Pop III halos too dim for direct detection ($M_{AB}$ ~ -5 to -10)
- May see supernovae with JWST ($z < 30$) or WFIRST ($z < 20$) (Whalen et al. 2013)
- Possible signature of Pop III in cosmic 21-cm signal



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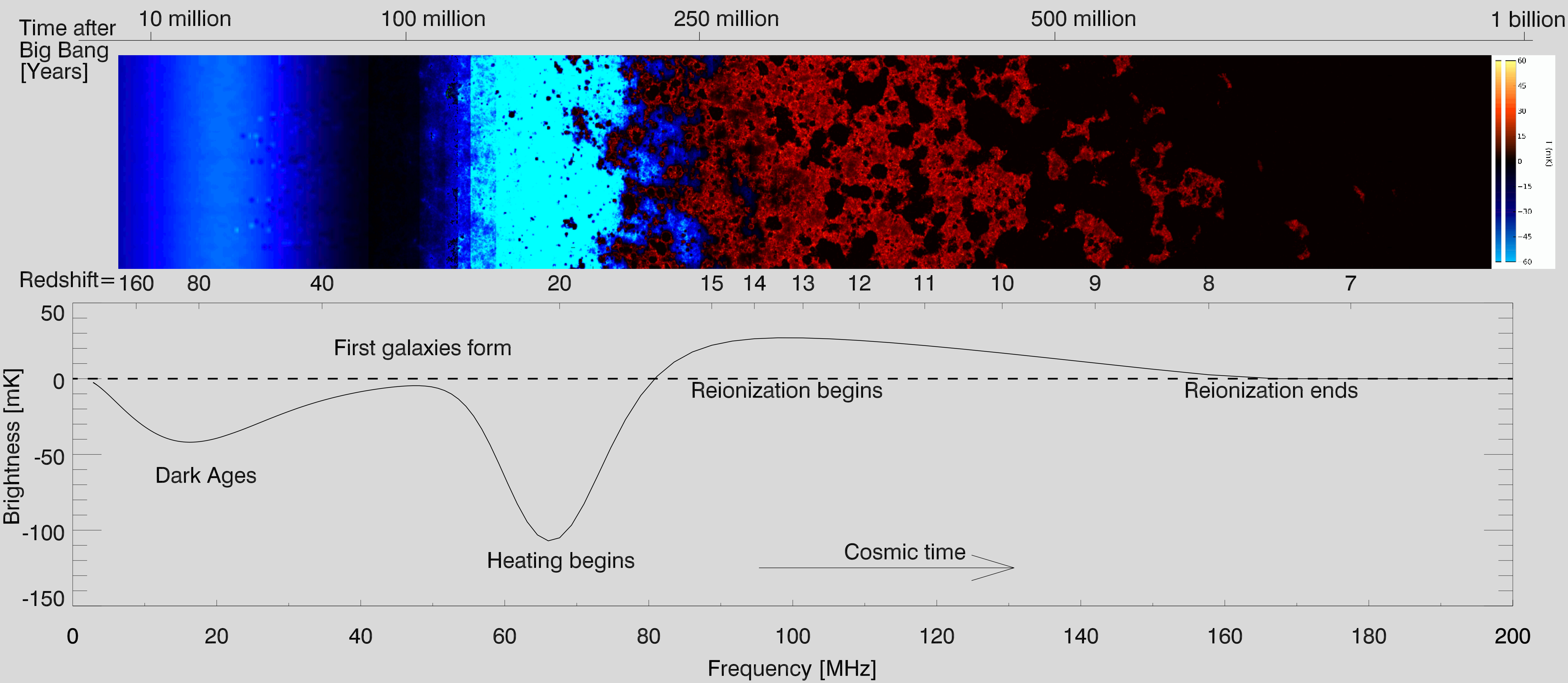
# The cosmic 21-cm signal can give us details on the first sources in the universe.




$$\delta T_b \simeq 27 x_{\mathrm{HI}} (1+\delta) \left(\frac{\Omega_{\mathrm{b}} h^2}{0.023}\right) \left(\frac{0.15}{\Omega_{\mathrm{m}} h^2} \frac{1+z}{10}\right)^{1/2} \left(\frac{T_{\mathrm{S}} - T_{\mathrm{radio}}}{T_{\mathrm{S}}}\right) \mathrm{mK}$$





Pritchard & Loeb 2012

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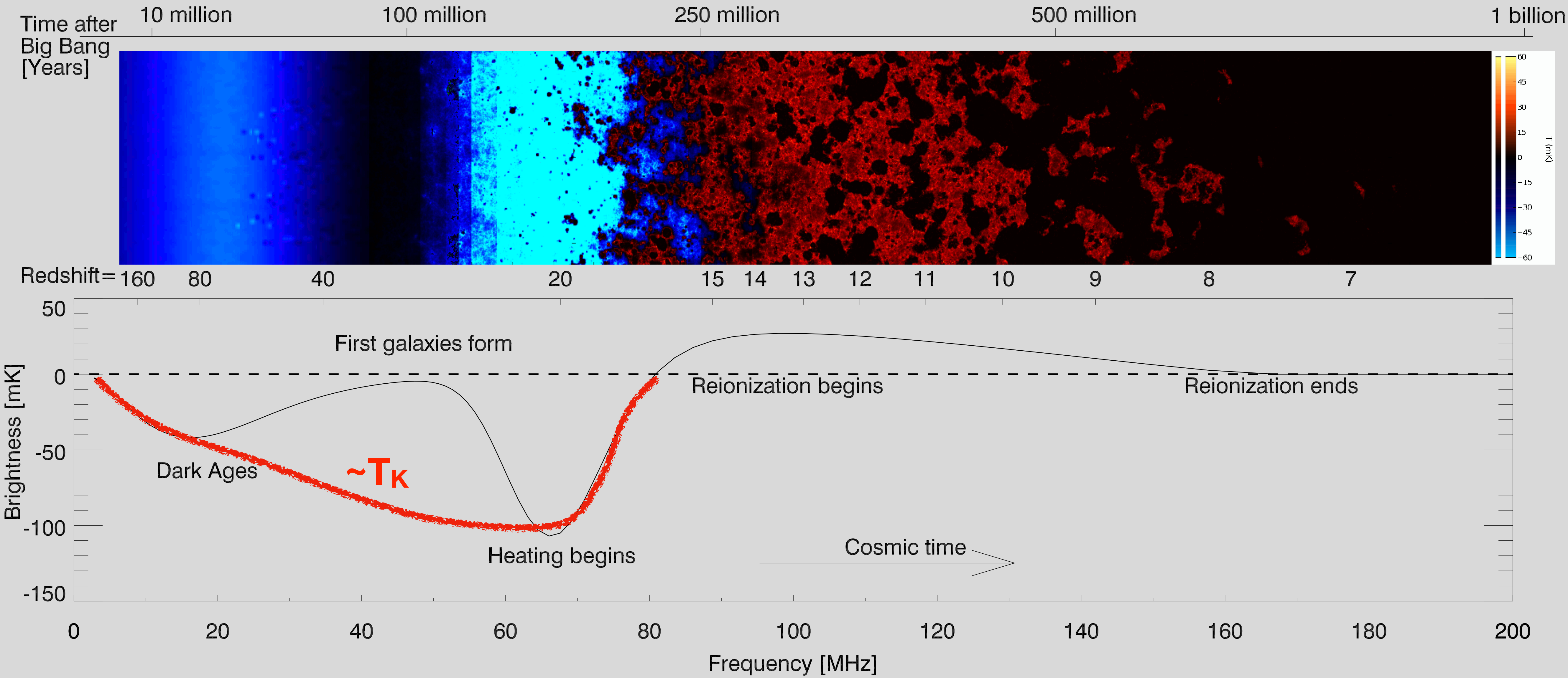


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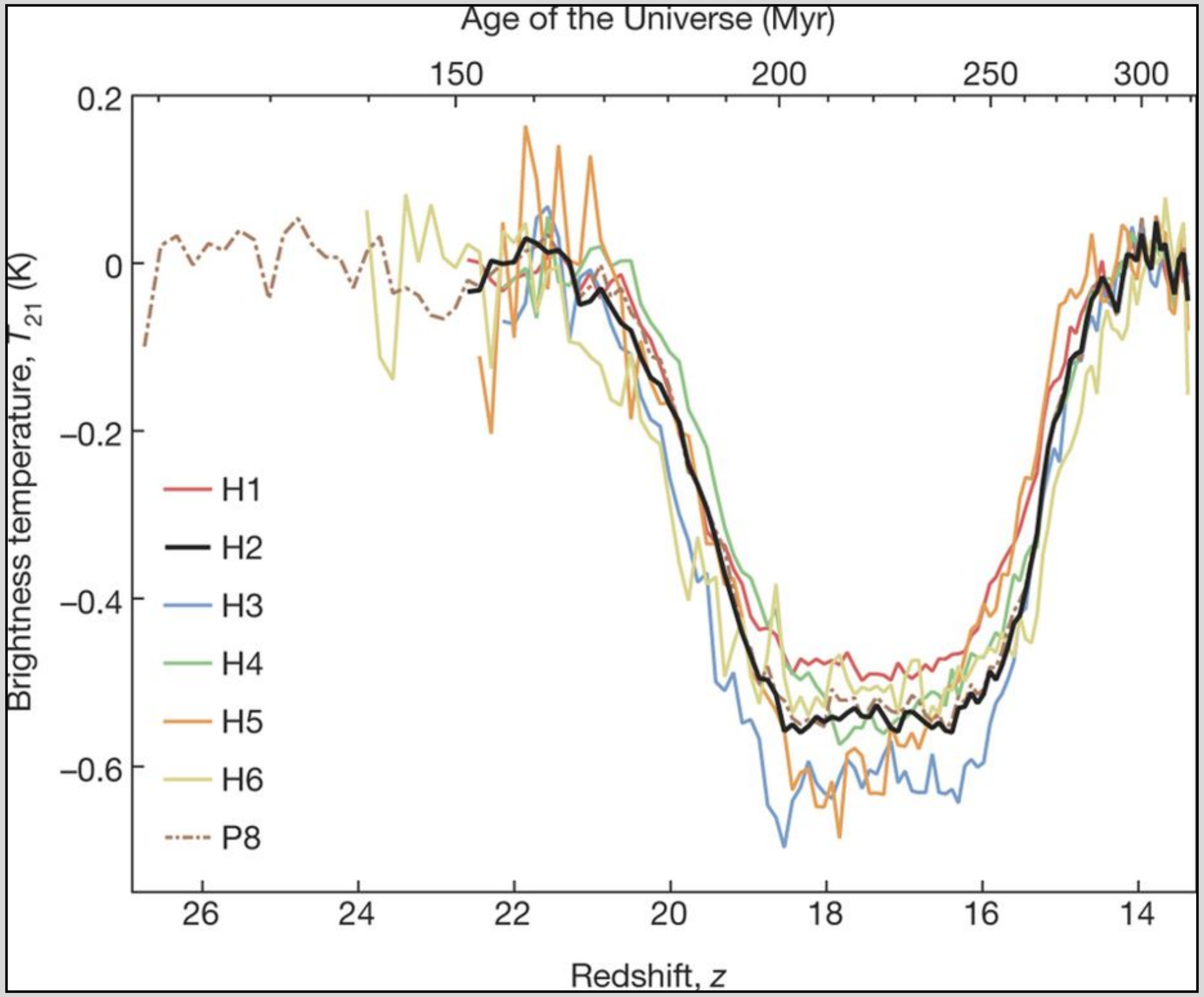
Pritchard & Loeb 2012

# EDGES reported the first cosmic 21-cm detection last year.

- Signal earlier than expected (z~18)
- Very deep trough (~ -0.5 K)
- Signal very sharp and flat




Bowman et al. 2018

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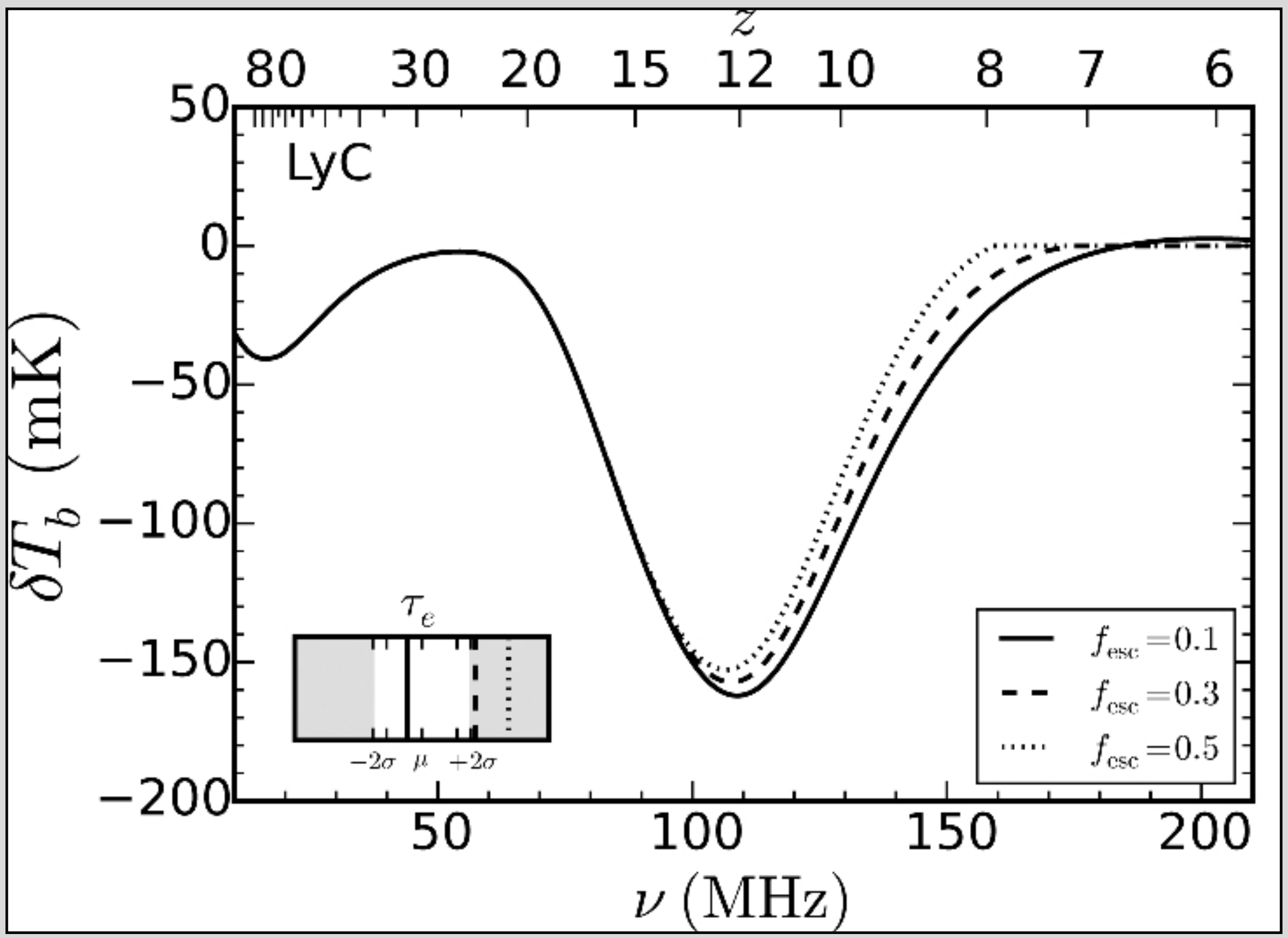


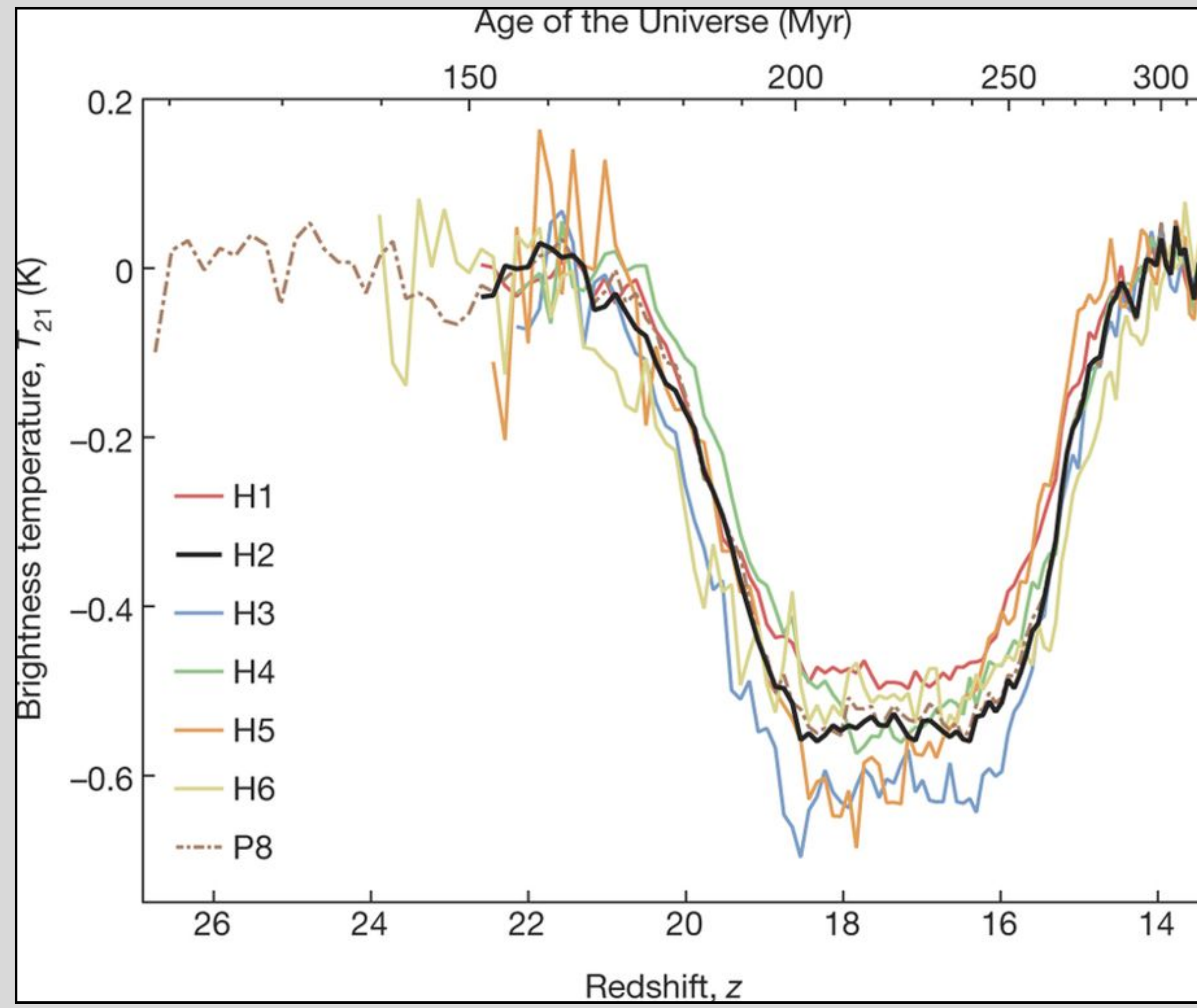


Mirocha et al. 2017

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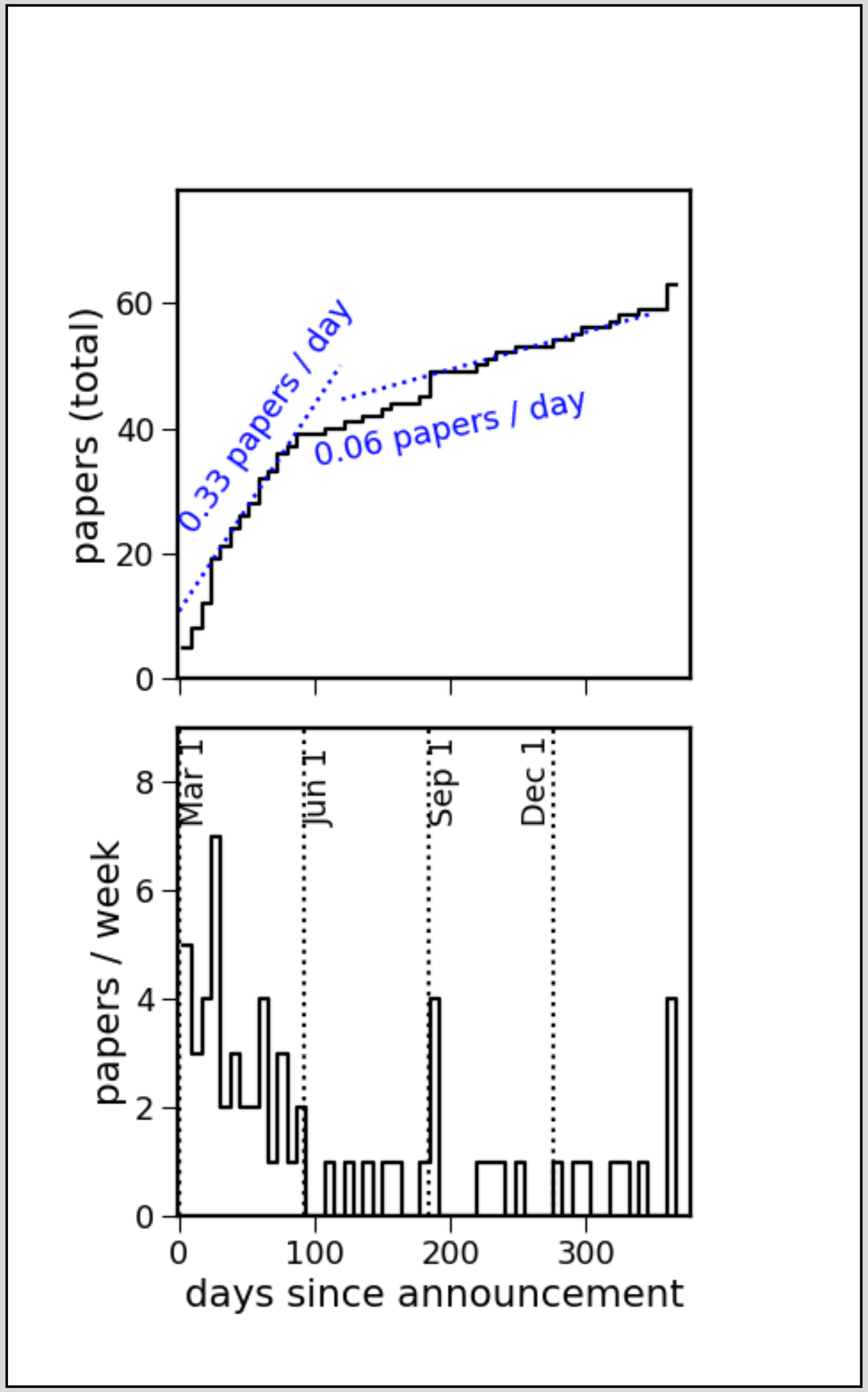






Credit: Jordan Mirocha

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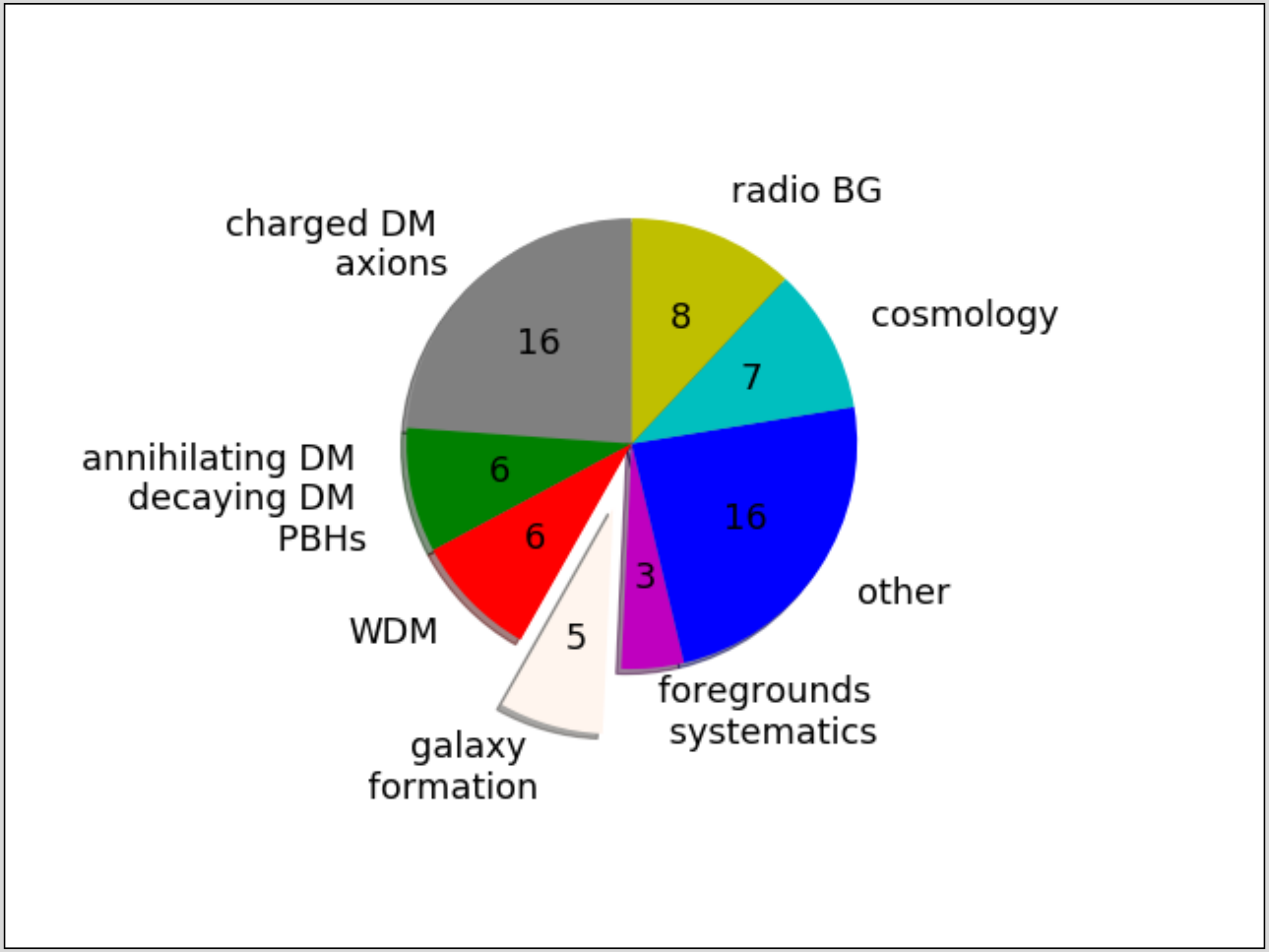



Credit: Jordan Mirocha

# Can Pop III stars cause the EDGES signal?

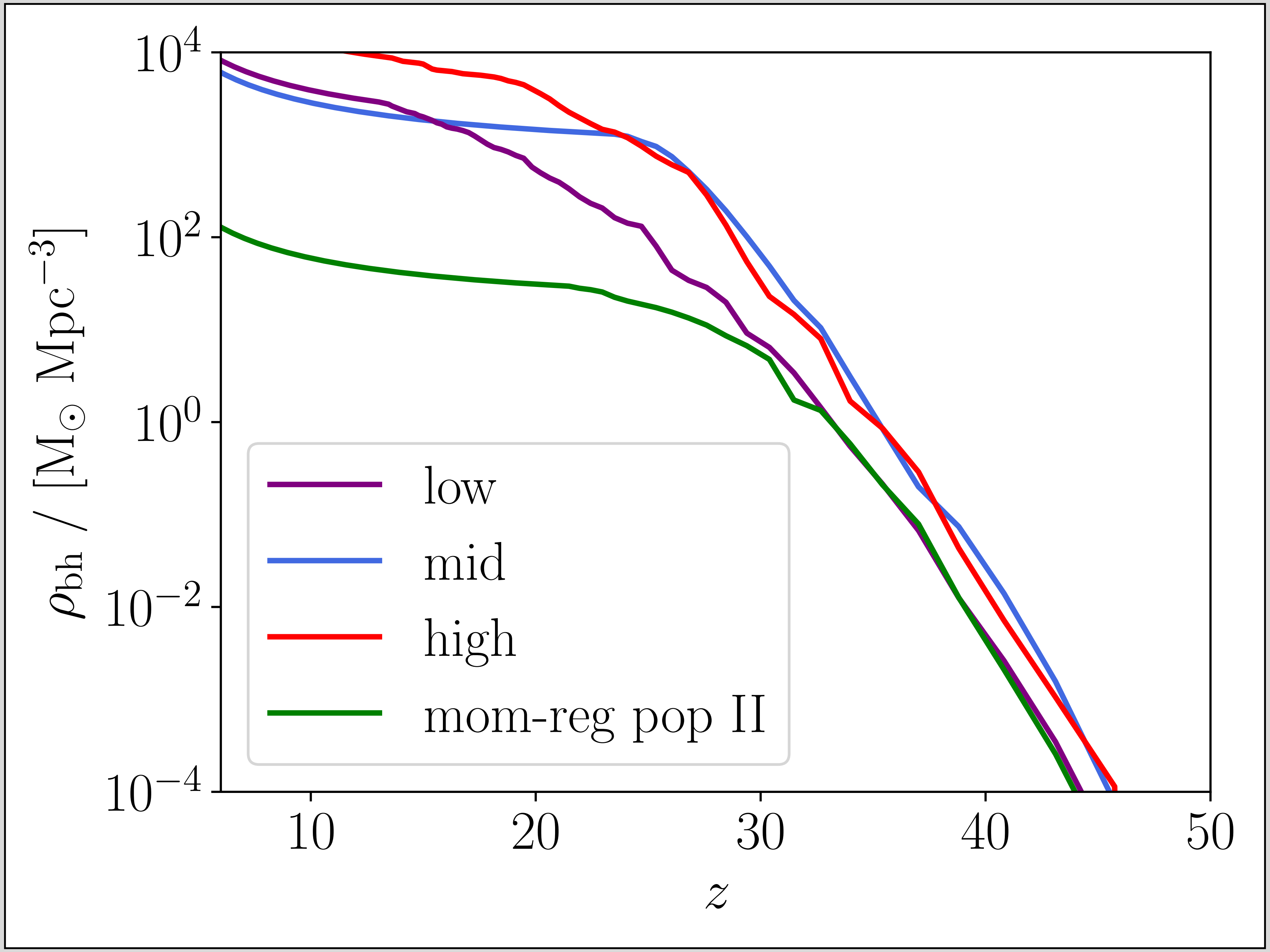
- Accreting Pop III remnants could produce a strong radio background (e.g., Ewall-Wice et al. 2018)

$$\epsilon_\nu(z) \propto f_{\rm duty}(z) f_{\rm edd}(z) \rho_{\rm bh}(z)$$

- Early formation means earlier Lyman-alpha background

- X-ray emission can push the signal in the "wrong" direction but may help with timing and shape

# The choice of Pop III IMF has important implications for BH production.

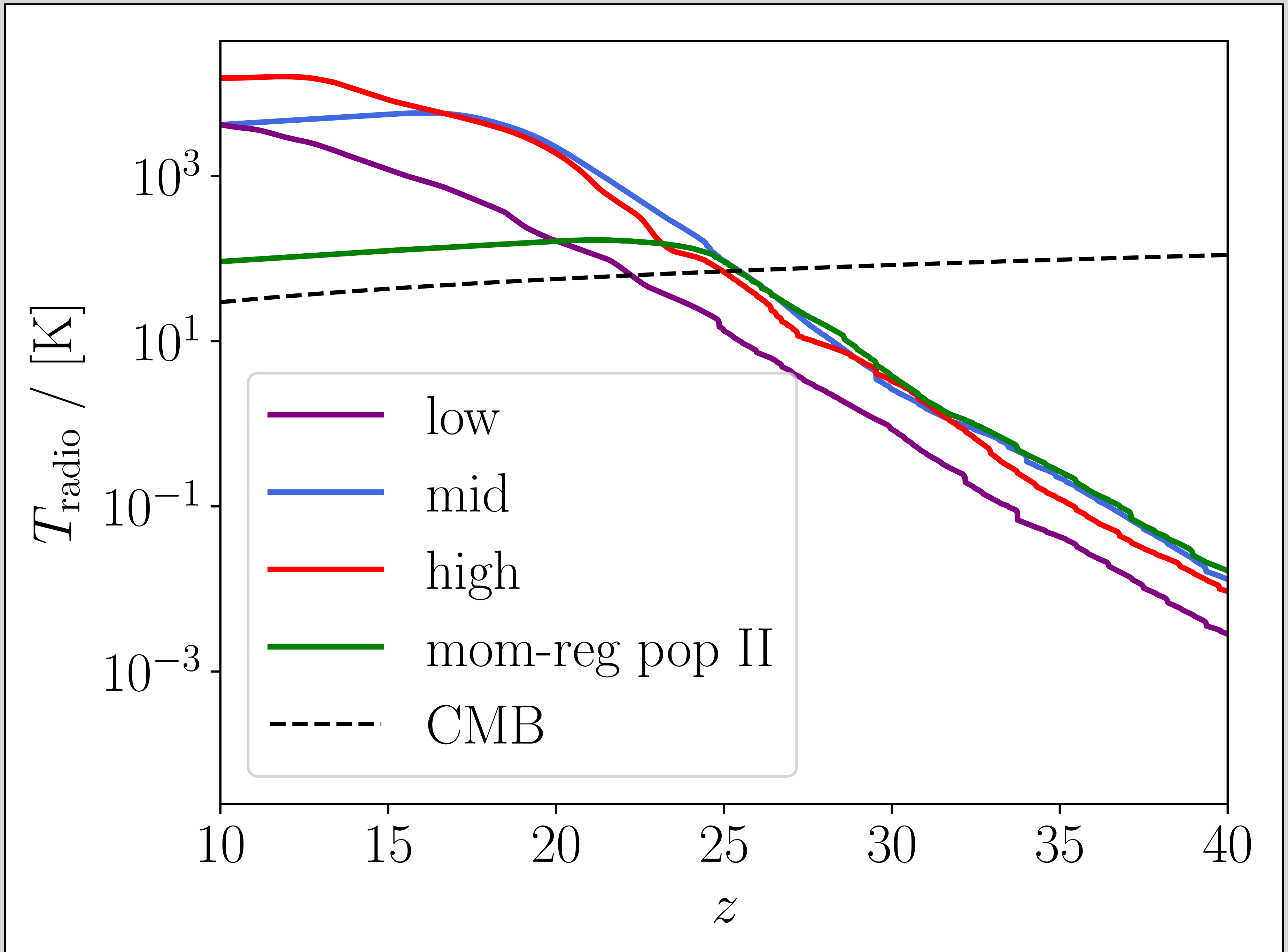







Mebane et al. in prep

# The resulting radio background temperature can be much higher than the CMB.

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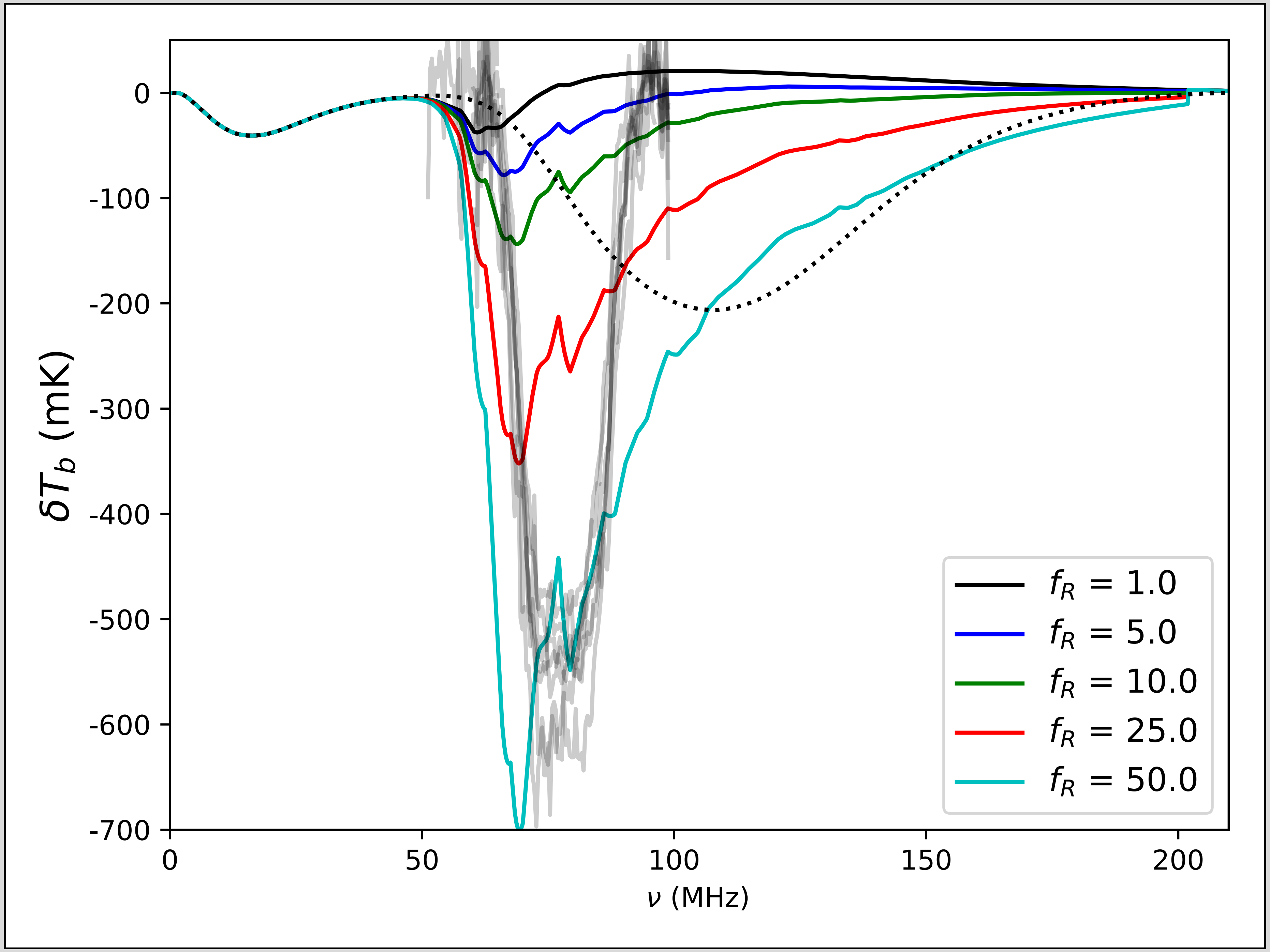
# An excess radio background can increase the strength of the signal.

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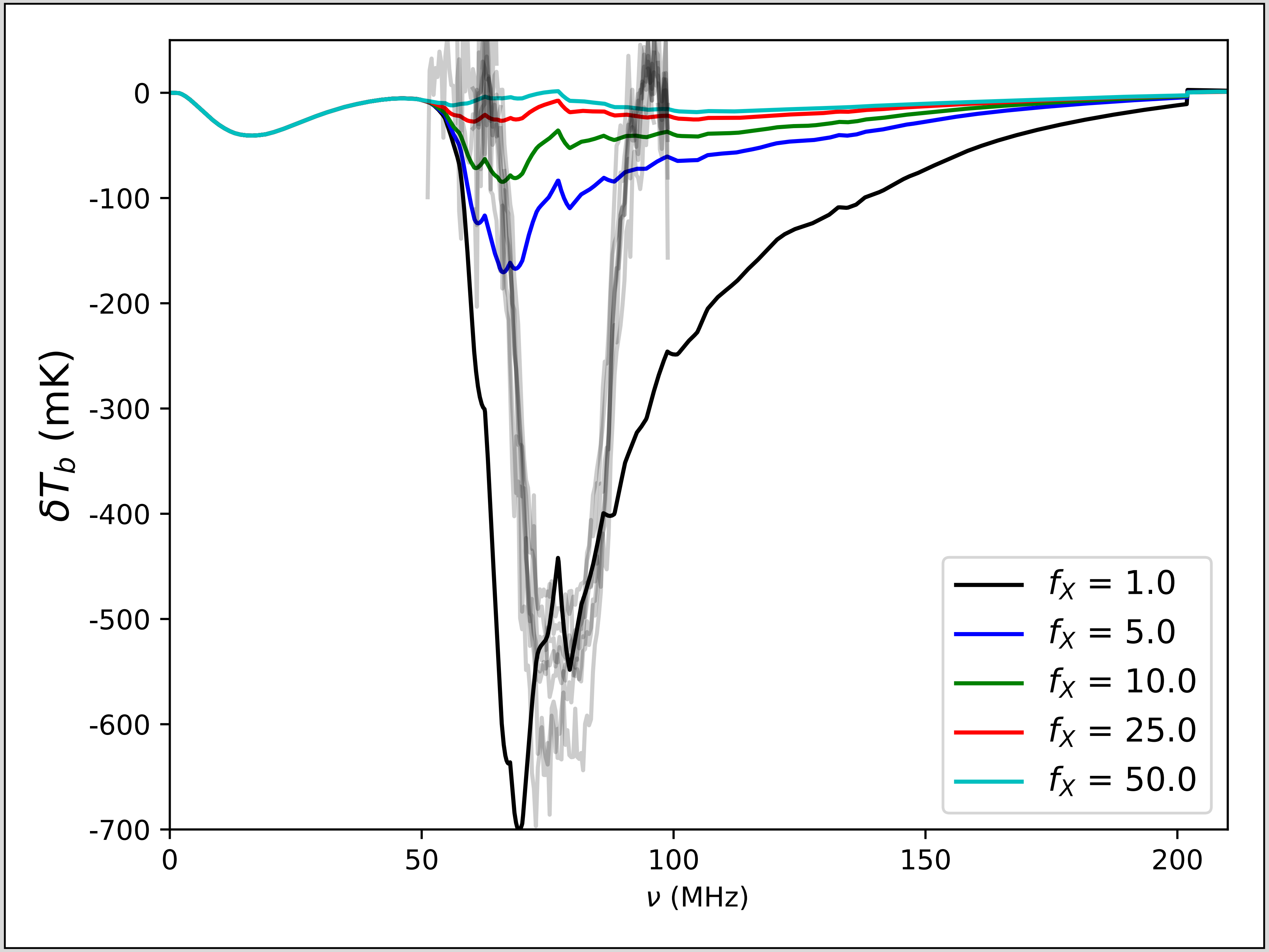
# The x-ray background comes from the same sources but heats the gas.

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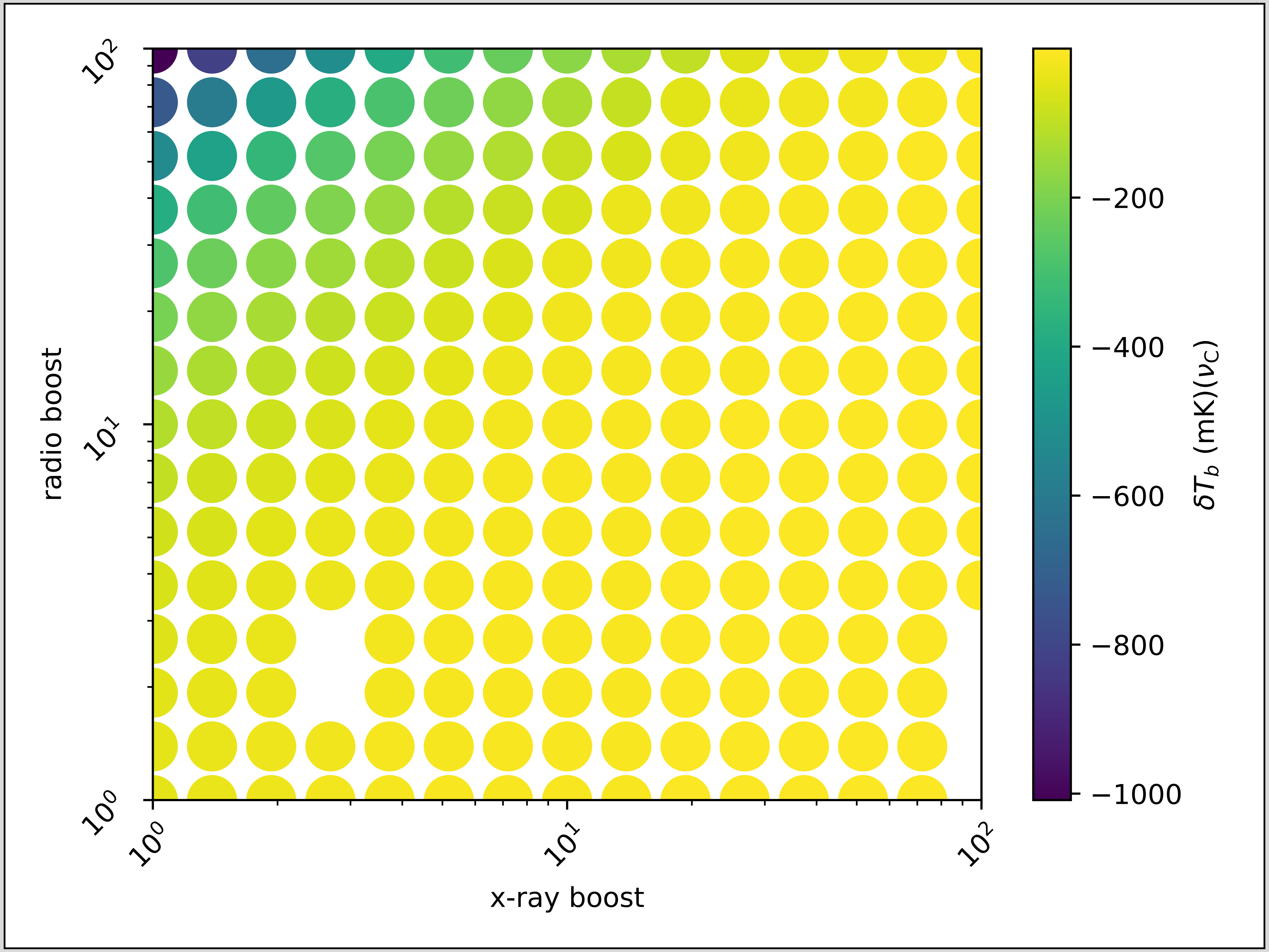
# Need a high radio background compared to x-rays to match EDGES depth.







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# Conclusions

- Pop III star formation is necessary to produce the metals required to form more traditional, metal-enriched stars.
- The Pop III phase ultimately ends due to Lyman-Werner feedback from Pop II halos.
- We will likely require supernova or 21-cm observations to detect the presence of Pop III stars.
- Depending on the details of radio and x-ray emissions from Pop III remnants, Pop III stars may be able to cause the EDGES signal.