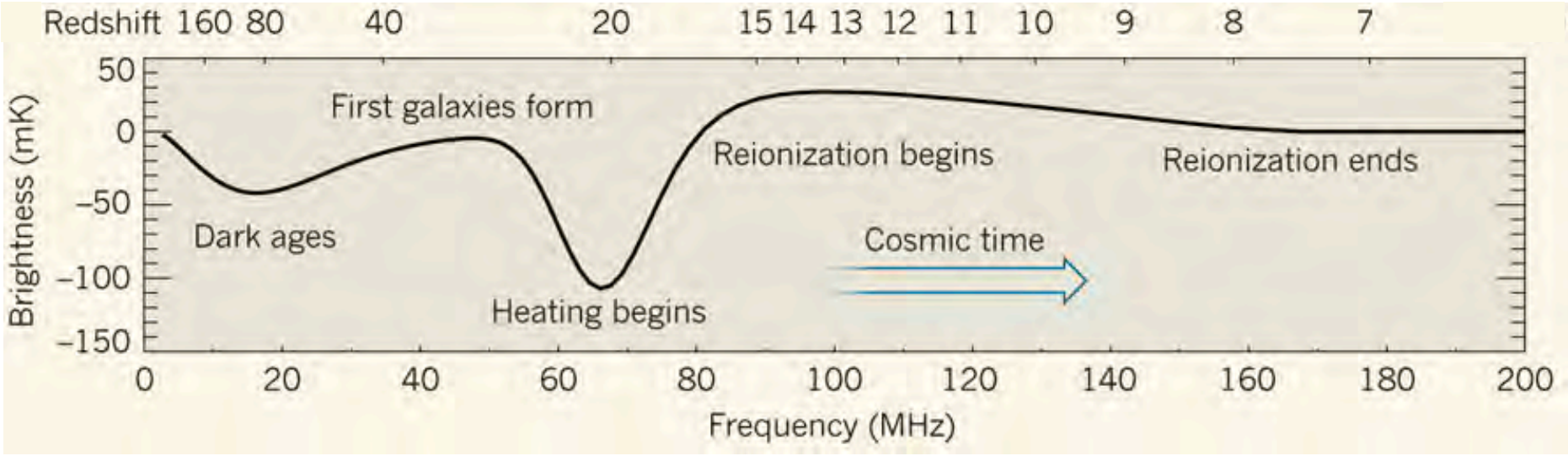
The Current State of Global Signal Theory



Pritchard & Loeb, Nature, 468, 722 (2010)

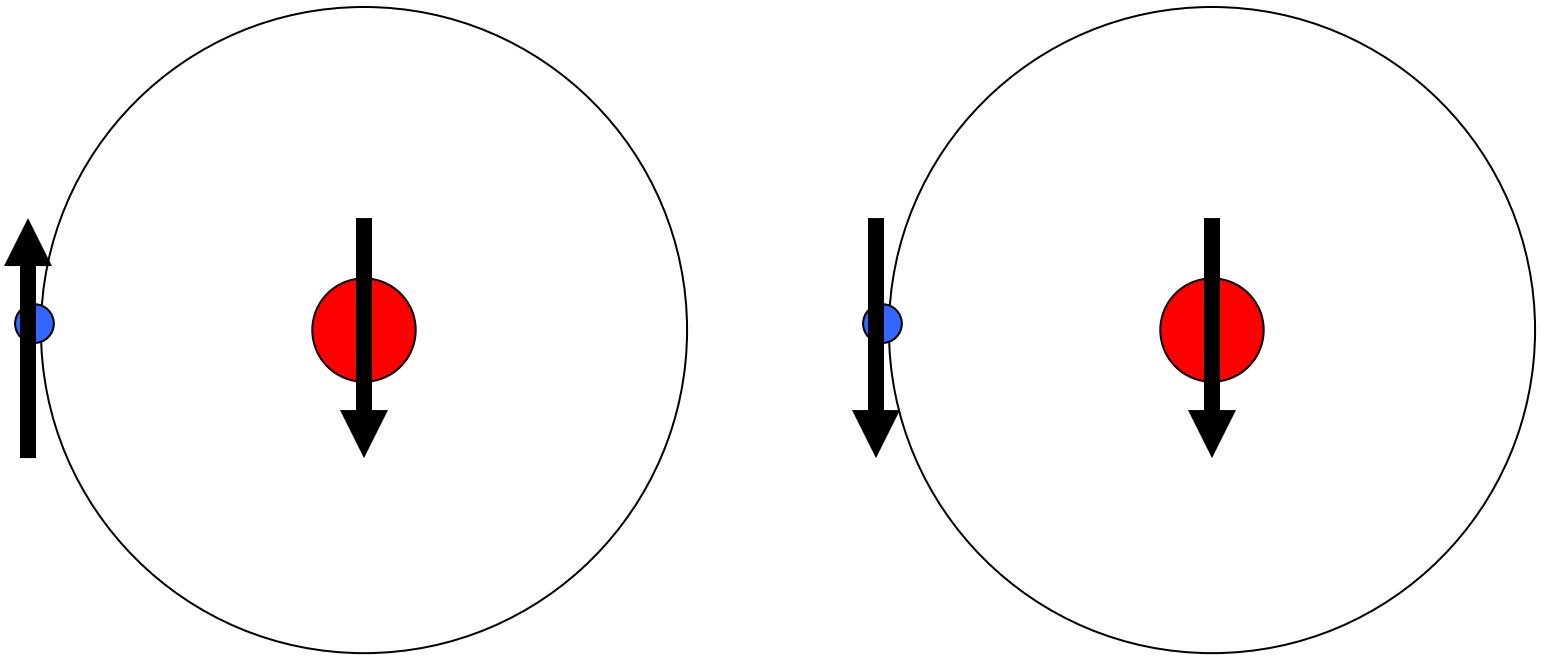
CAASTRO, 19th November 2012

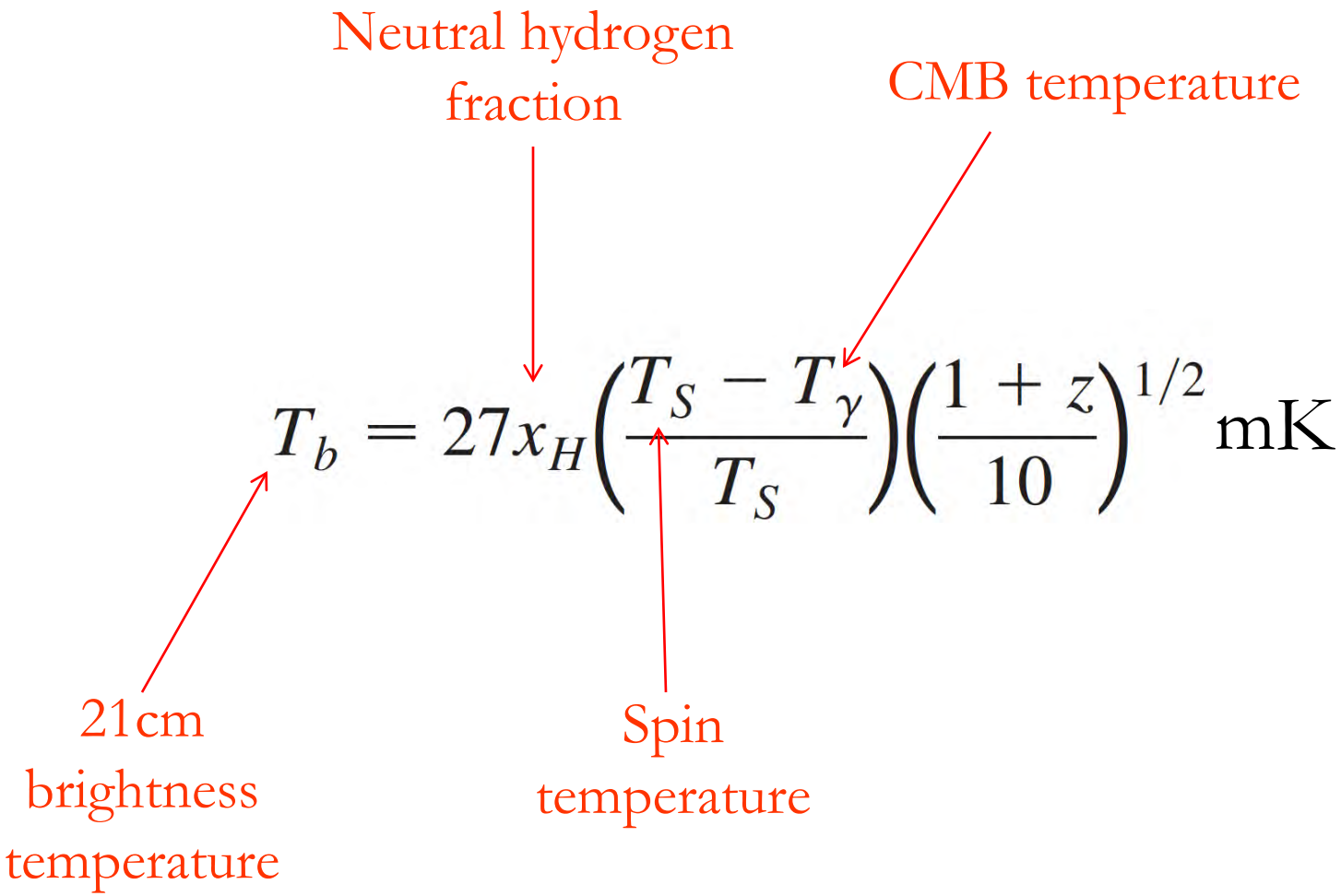
Adrian Liu

Recent theoretical developments do not change the basic picture

$$\frac{n_1}{n_0} = \frac{g_1}{g_0} e^{-E_{10}/k_B T_S}$$

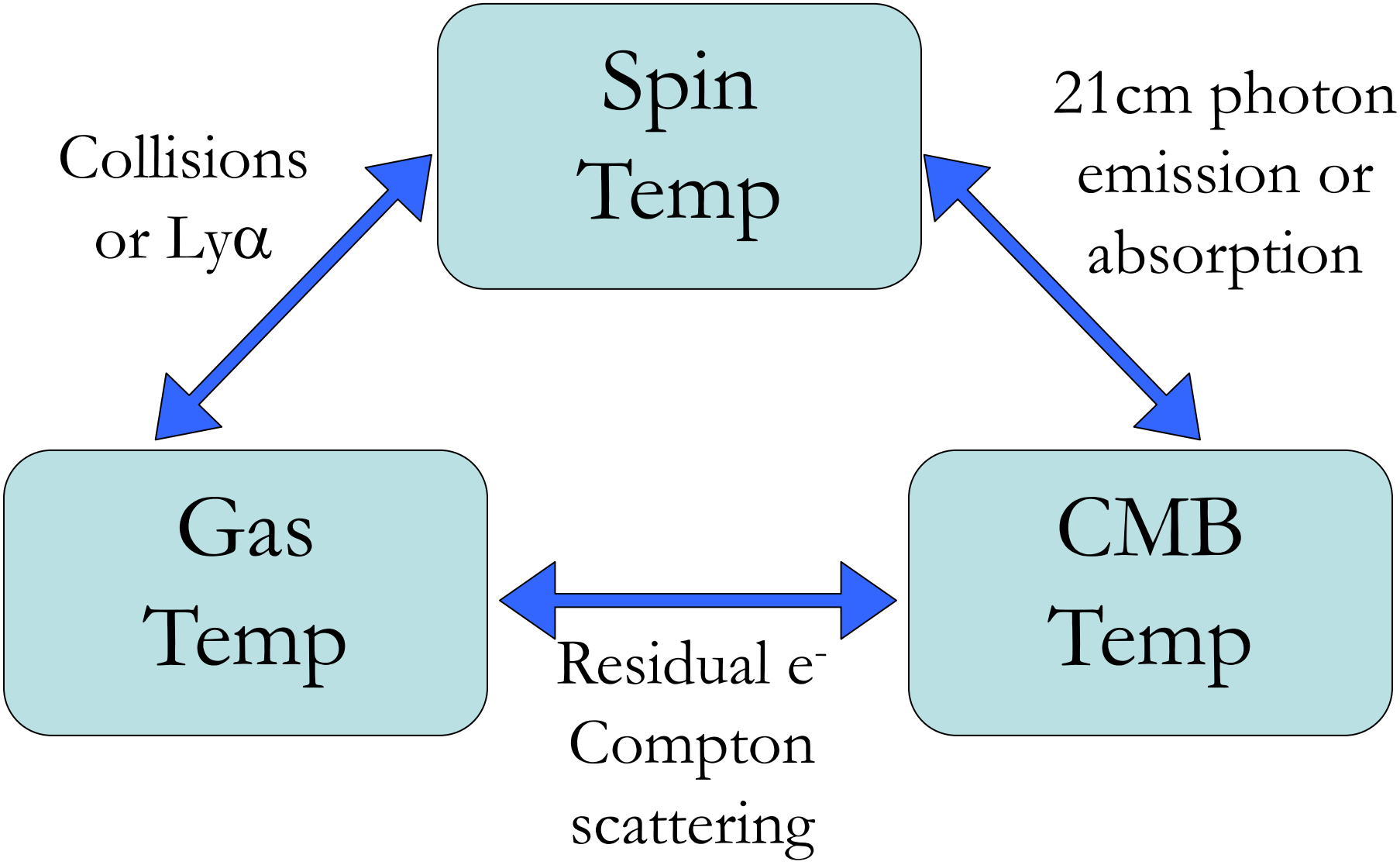
Spin Temp



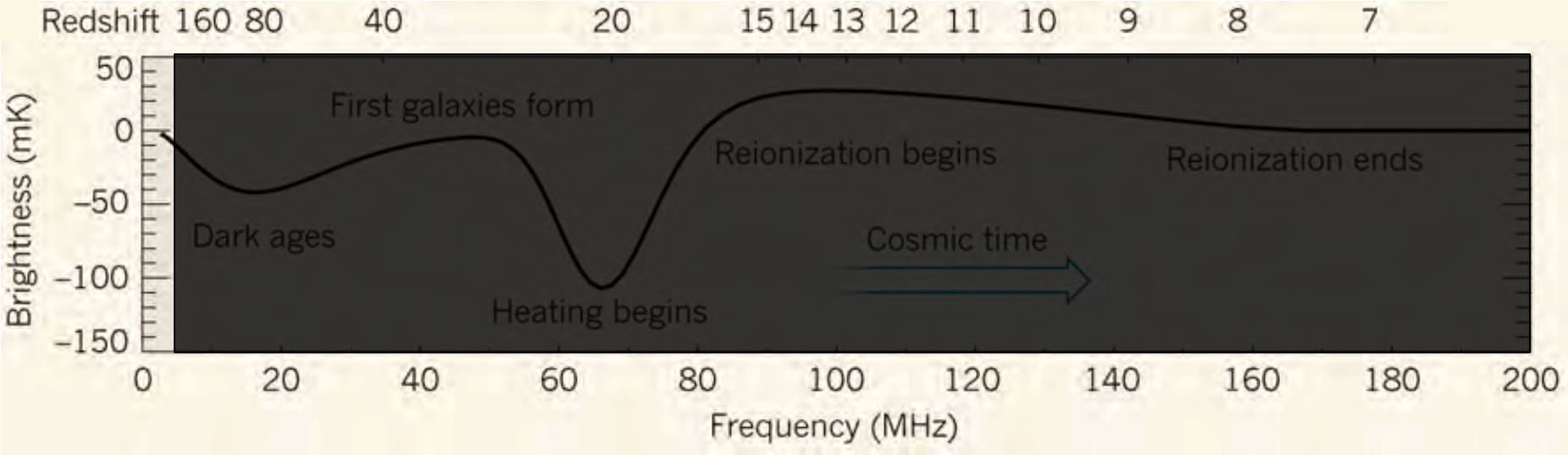

Neutral hydrogen fraction
CMB temperature
$T_b = 27 x_H \left(\frac{T_S - T_\gamma}{T_S}\right)\left(\frac{1+z}{10}\right)^{1/2}$ mK
21cm brightness temperature
Spin temperature

$$T_b = 27 x_H \left(\frac{T_S - T_\gamma}{T_S}\right)\left(\frac{1+z}{10}\right)^{1/2} \text{mK}$$

Did we get this right?


Spin Temp
Collisions or Lyα
21cm photon emission or absorption
Gas Temp
CMB Temp
Residual e- Compton scattering

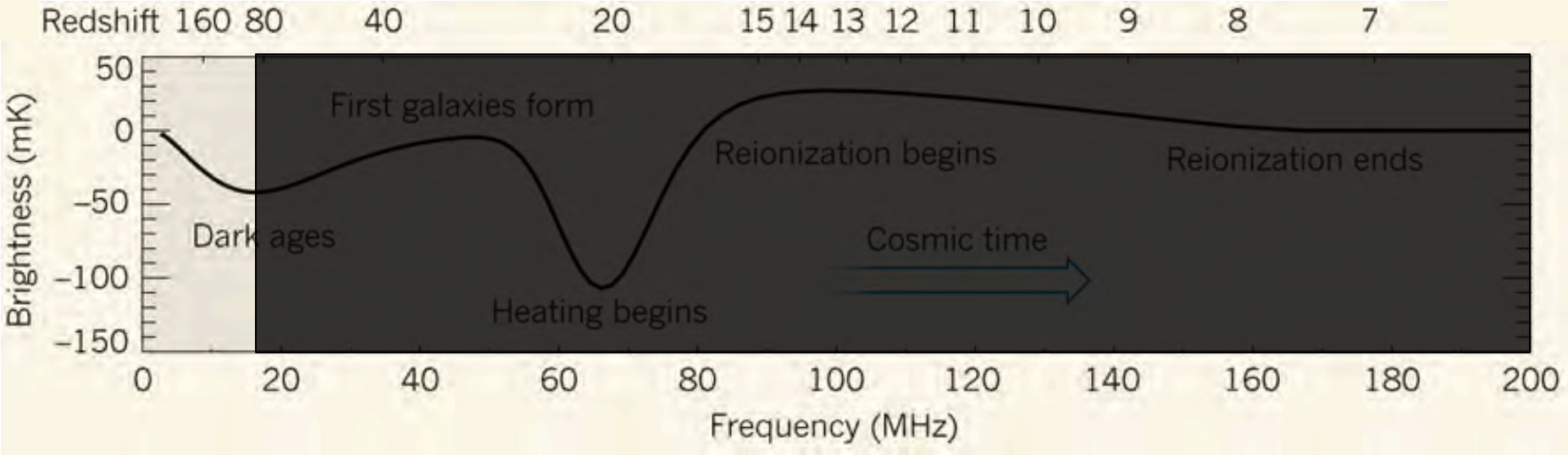
Phase I: No Signal



- Residual electrons drive T_{gas} to T_{CMB} via Compton scattering
- Collisions drive T_{gas} to T_{spin}

NO SIGNAL

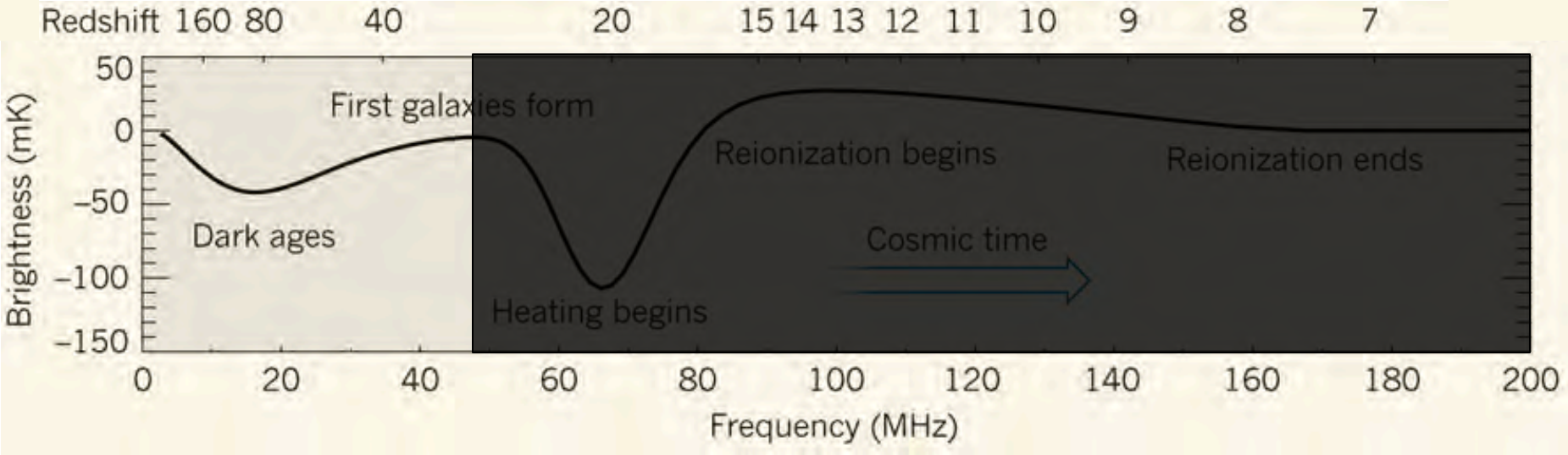
Phase II: Absorption Signal



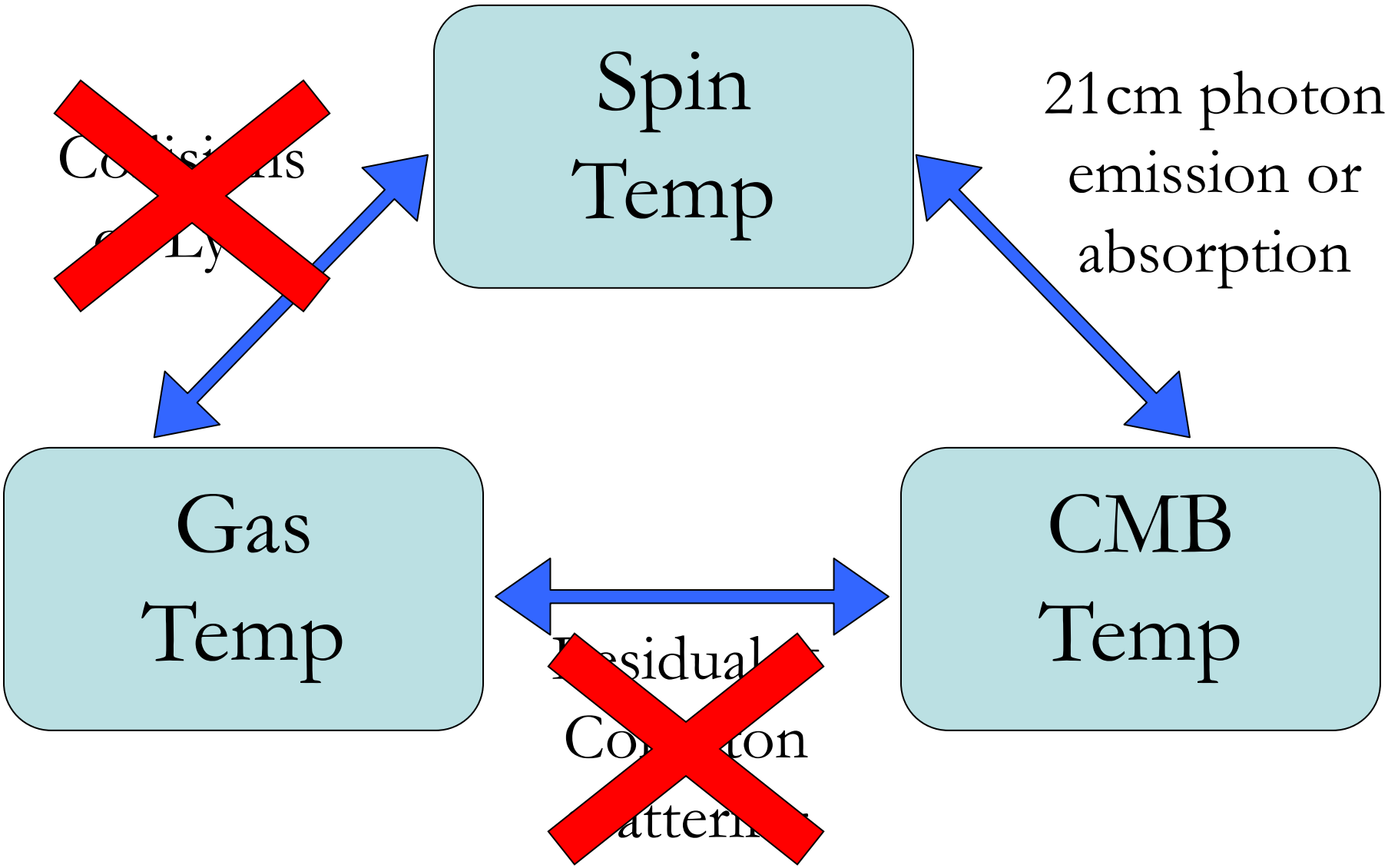
- Collisions maintain T_{gas} and T_{spin} equilibrium
- CMB has become too dilute for T_{CMB} and T_{gas} coupling
- $T_{spin} = T_{gas} \sim a^{-2}$ while $T_{CMB} \sim a^{-1}$

ABSORPTION

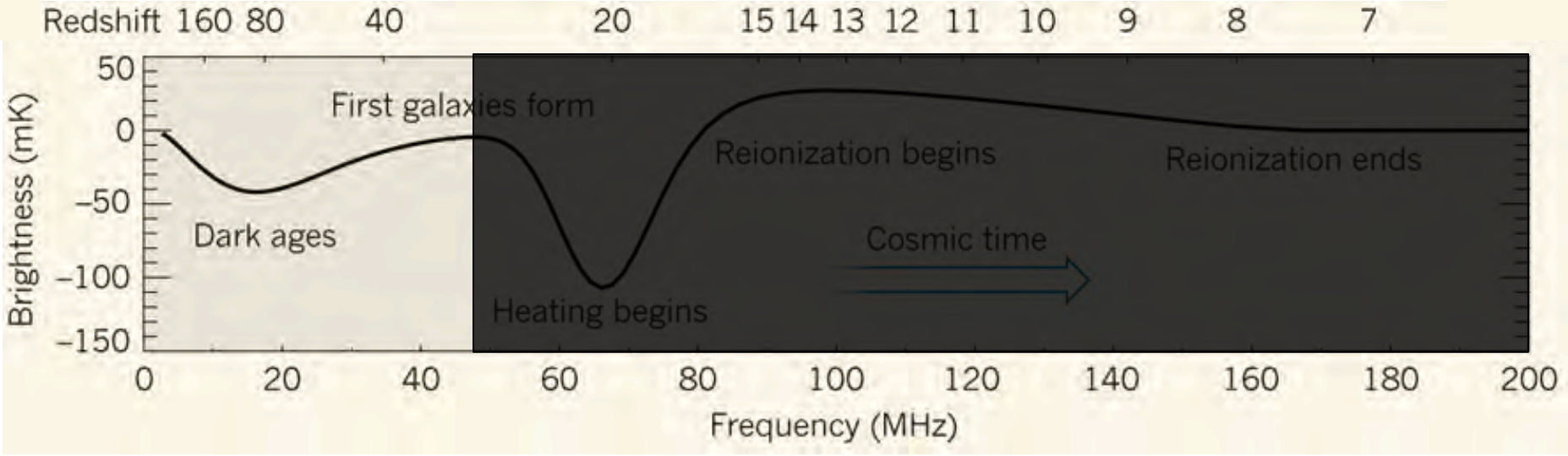
Phase III: Back to nothing



- Gas becomes too dilute for collisions to keep T_{gas} and T_{spin} in equilibrium


Spin Temp
21cm photon emission or absorption
Gas Temp
CMB Temp

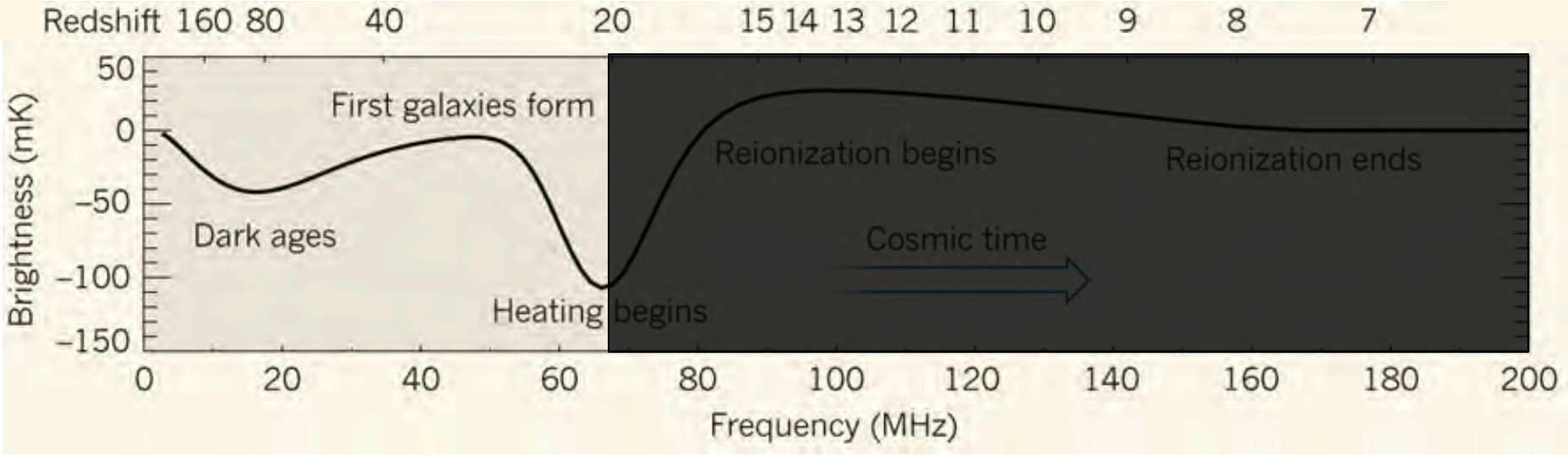
Phase III: Back to nothing



- Gas becomes too dilute for collisions to keep T_{gas} and T_{spin} in equilibrium
- Absorp./emission of 21cm photons makes $T_{spin} = T_{CMB}$

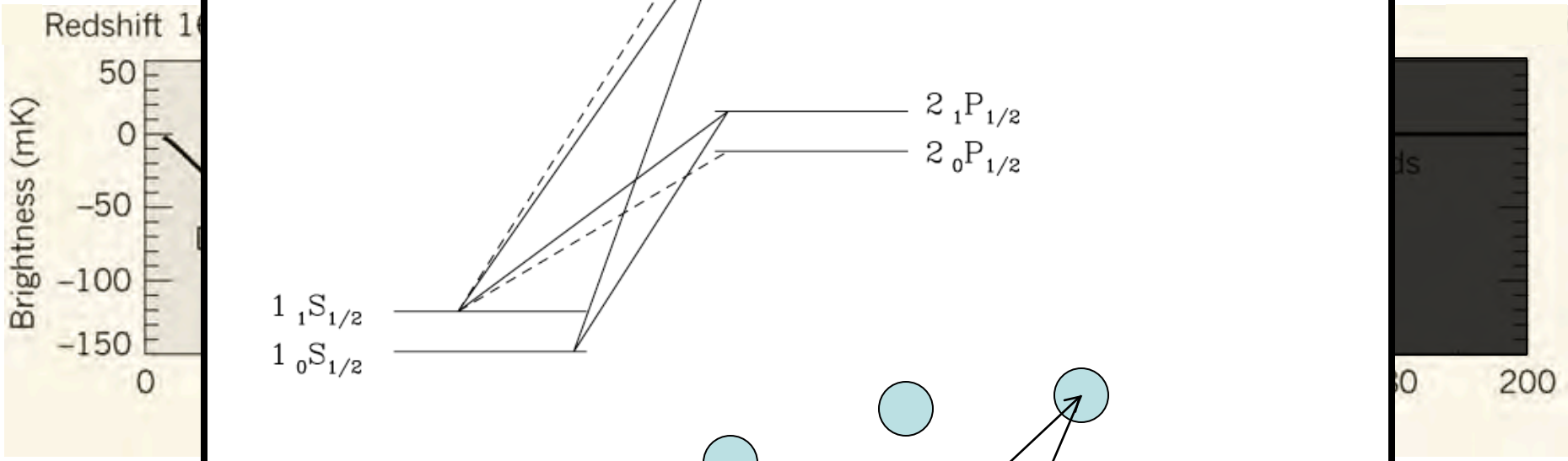
NO SIGNAL

Phase IV: First stars/galaxies form



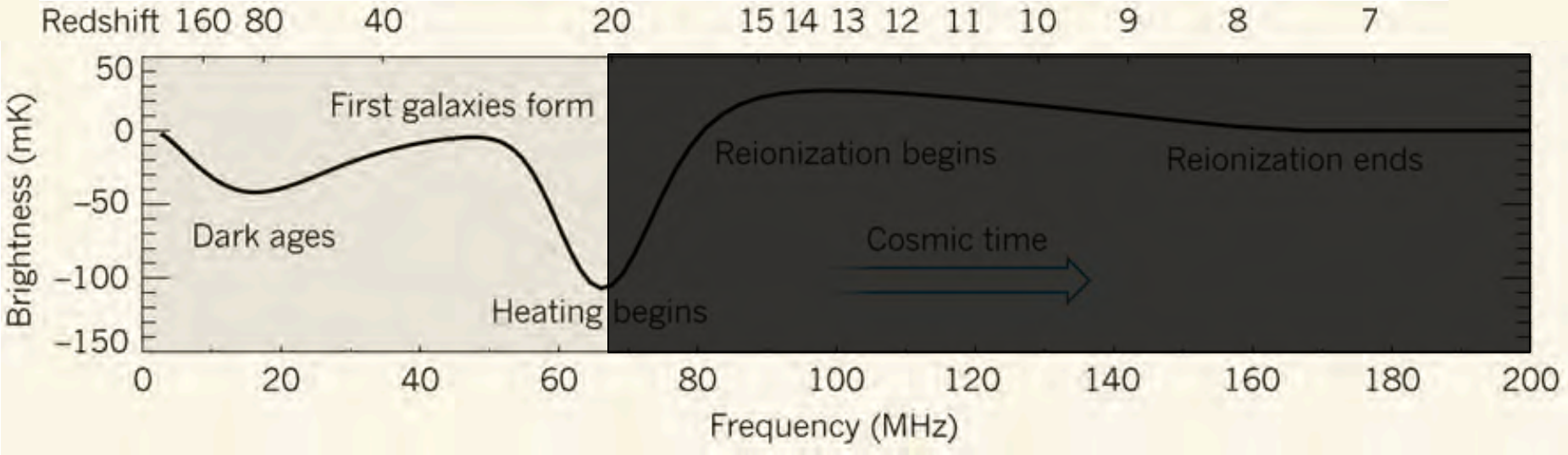
- First stars create Lya photons, causes coupling between T_{gas} and T_{spin} via Wouthuysen-Field effect

Ph m



- Firs een T_{gas}

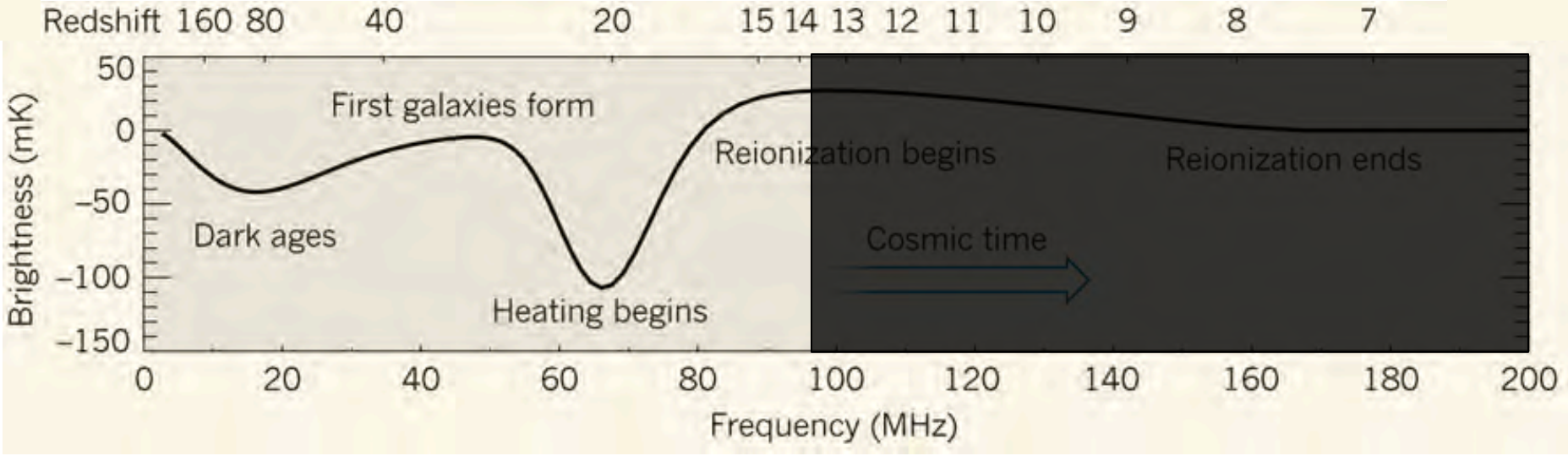
Phase IV: First stars/galaxies form



- First stars create Lya photons, causes coupling between T_{gas} and T_{spin} via Wouthuysen-Field effect
- $T_{spin} = T_{gas} < T_{CMB}$, so…

ABSORPTION

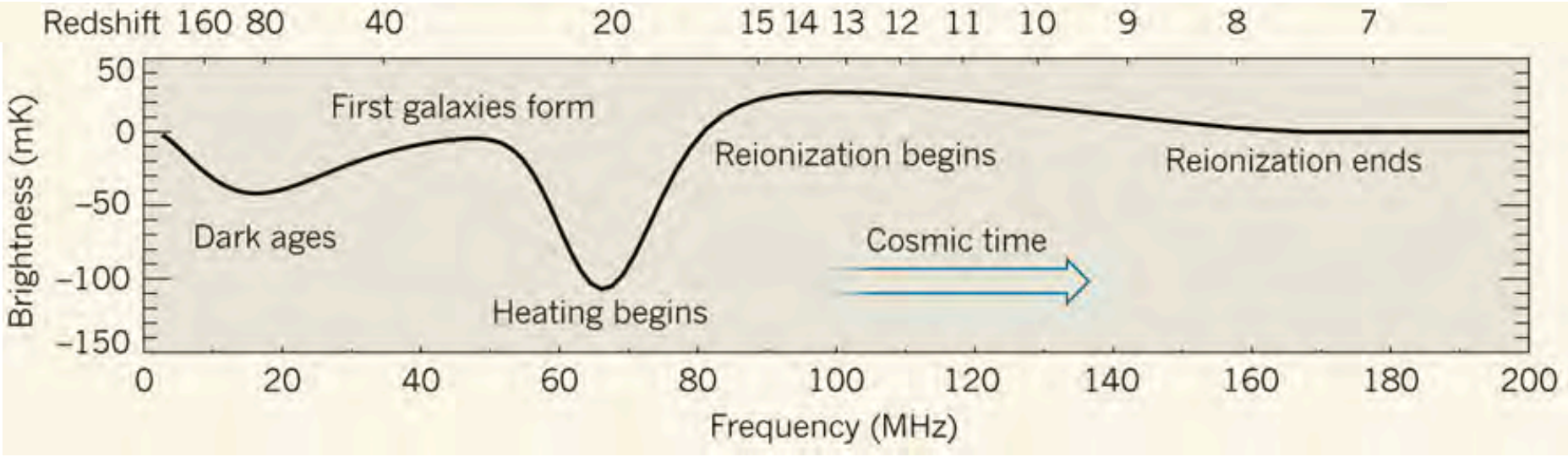
Phase V: X-ray reheating



- X-rays from early AGNs heat the IGM, raising T_{gas}
- Electrons are now going insane in atoms, giving off all sorts of photons causing $T_{spin} = T_{gas} > T_{CMB}$

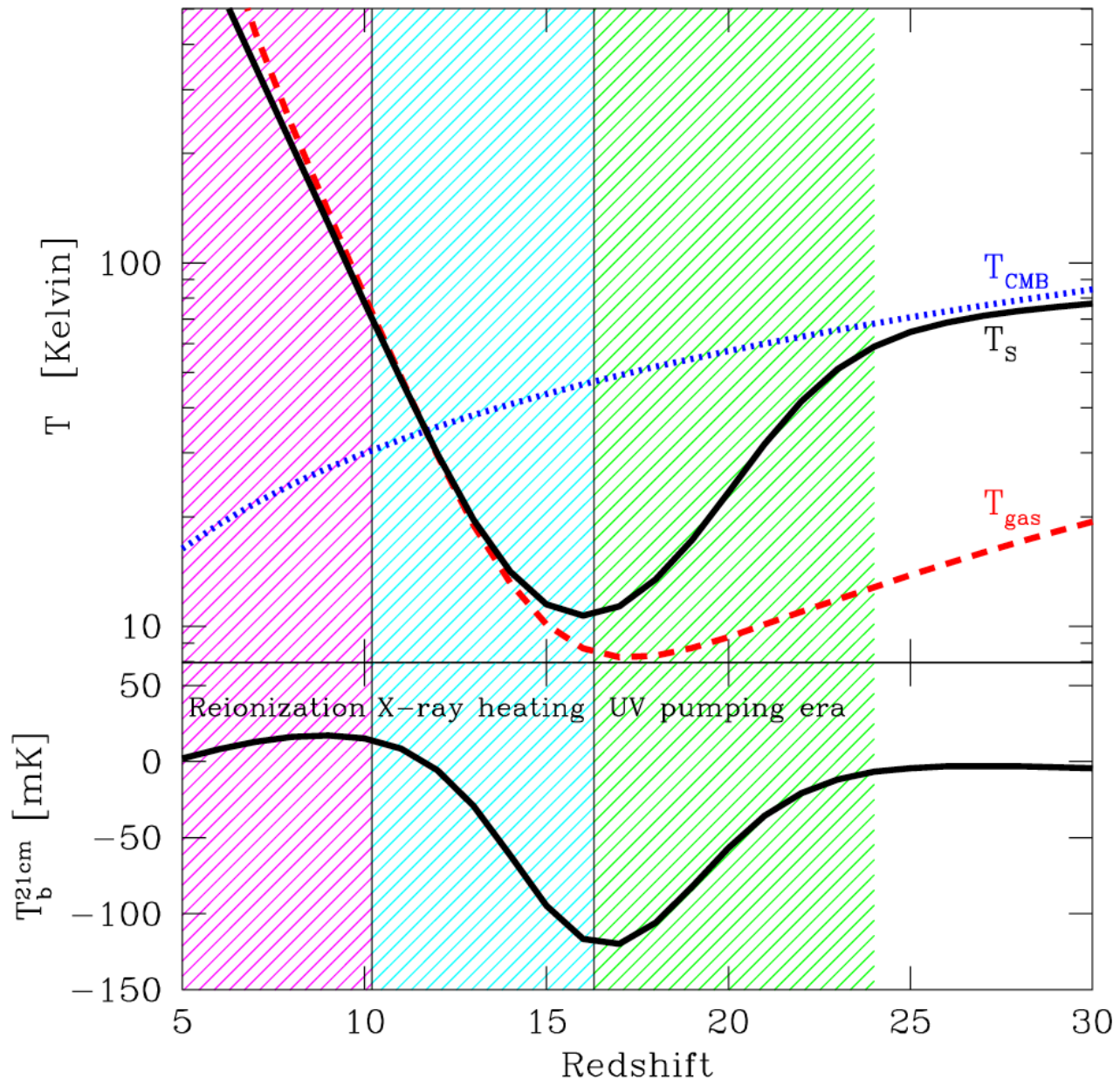
EMISSION

Phase VI: Reionization



- Eventually, reionization rids us of all neutral hydrogen atoms.

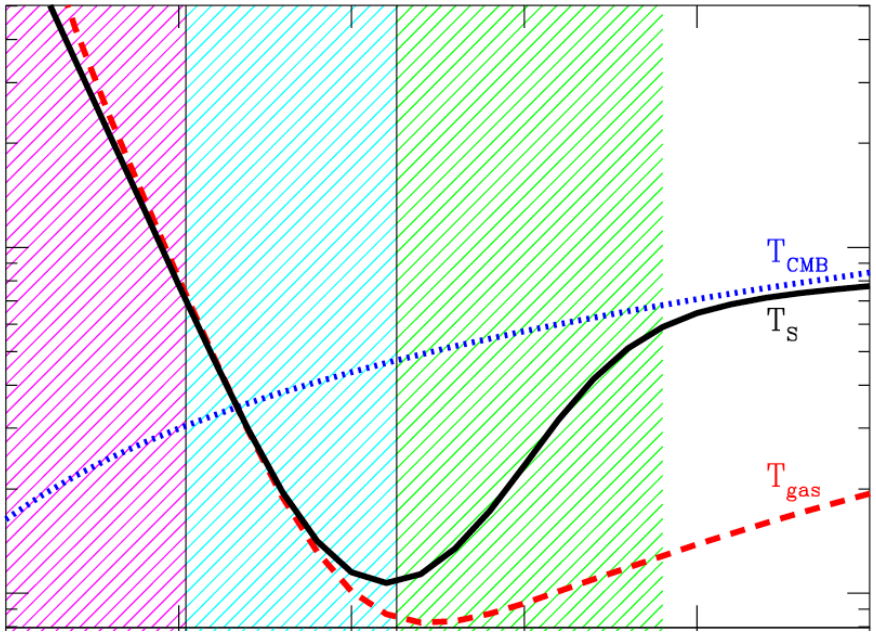
NO MORE SIGNAL



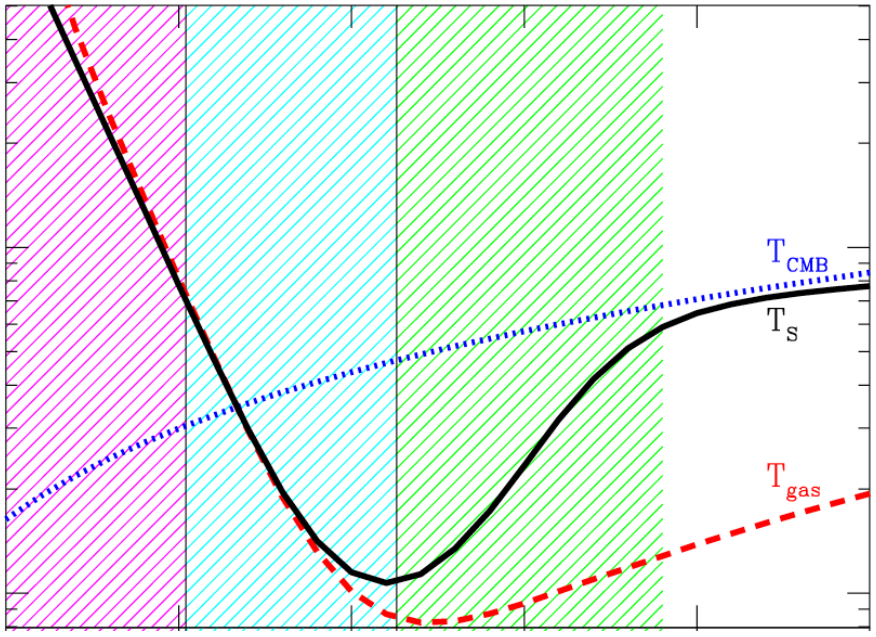
McQuinn & O'Leary (2012)

Nightmare scenario: might the absorption feature vanish with better modeling?

What might go wrong?

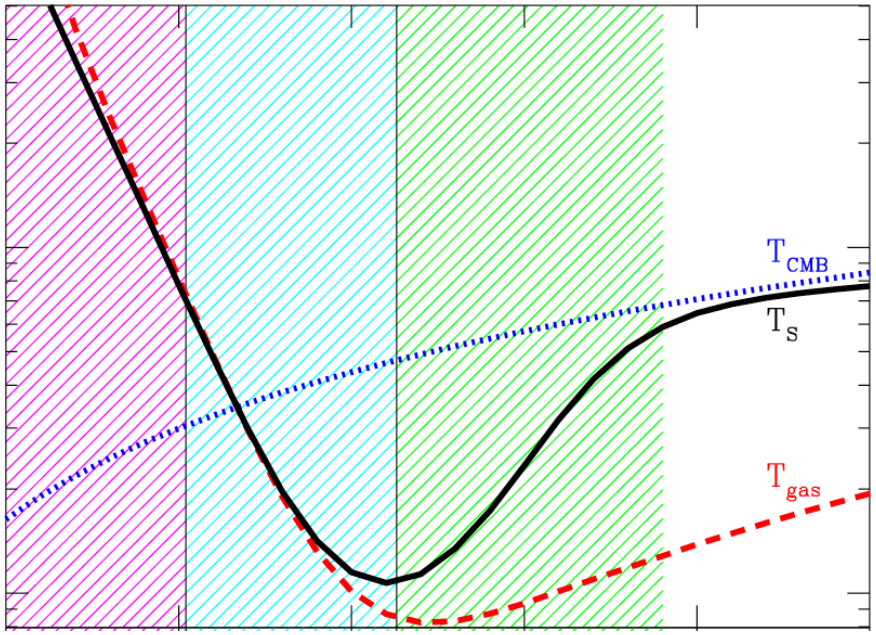


What might go wrong?



1. IGM physics may cause T_{gas} to deviate from adiabatic cooling.
2. X-ray heating may prematurely raise T_{spin}.

What might go wrong?



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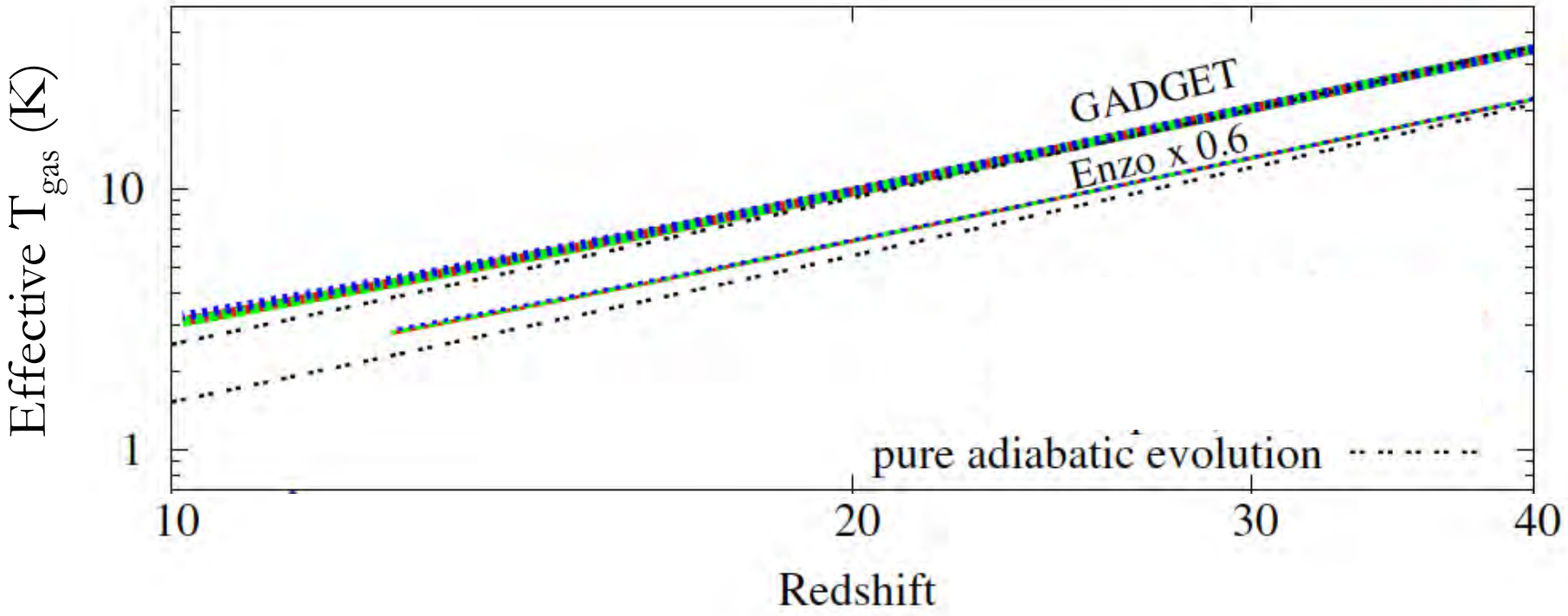
Supersonic flows could shock-heat the IGM at high redshifts

Supersonic flows could shock-heat the IGM at high redshifts

- Tseliakovich & Hirata (2010):
  - Relative velocity of baryons and dark matter supersonic after recombination.
  - Coherent flows of order v ~ 30 km/s on Mpc scales.
- McQuinn & O'Leary (2012):
  - At z ~20, a 0.3 km/s flow was supersonic, so it needs to be considered.

Shock-heating probably won't destroy the global signal trough



McQuinn & O'Leary (2012)

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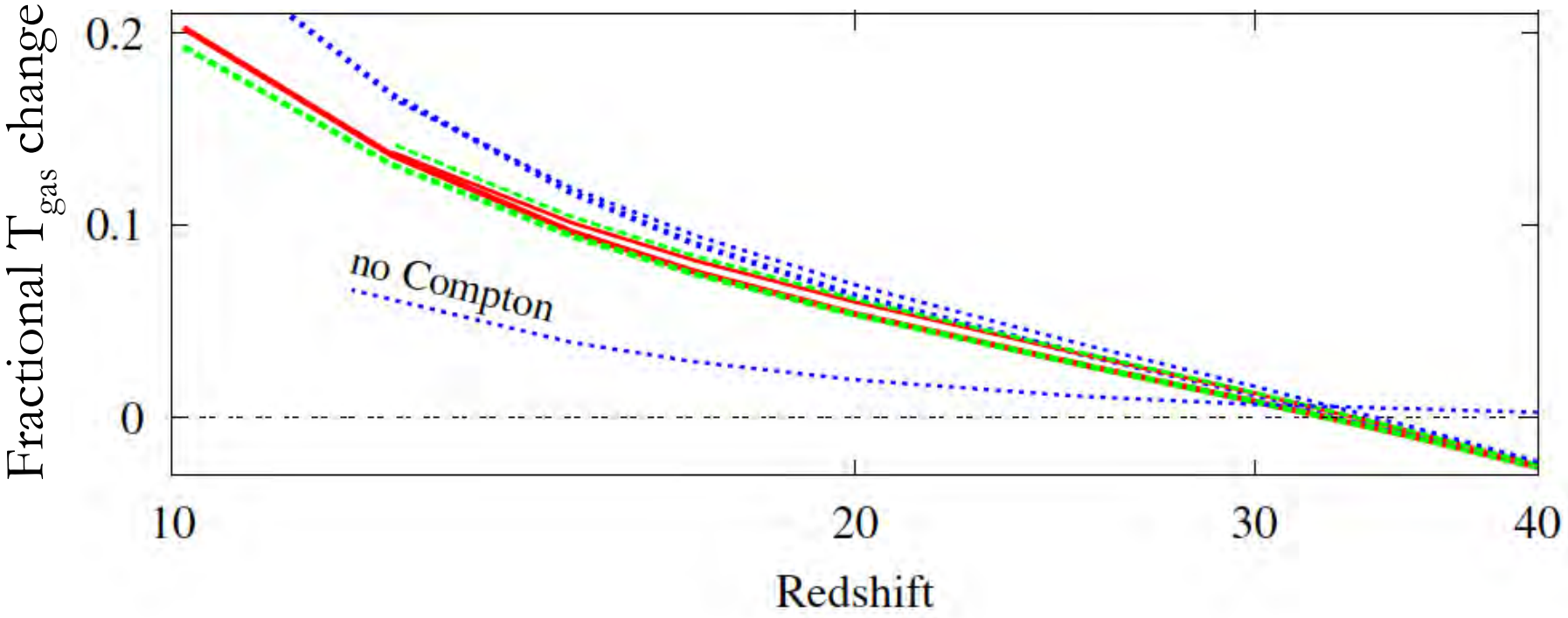
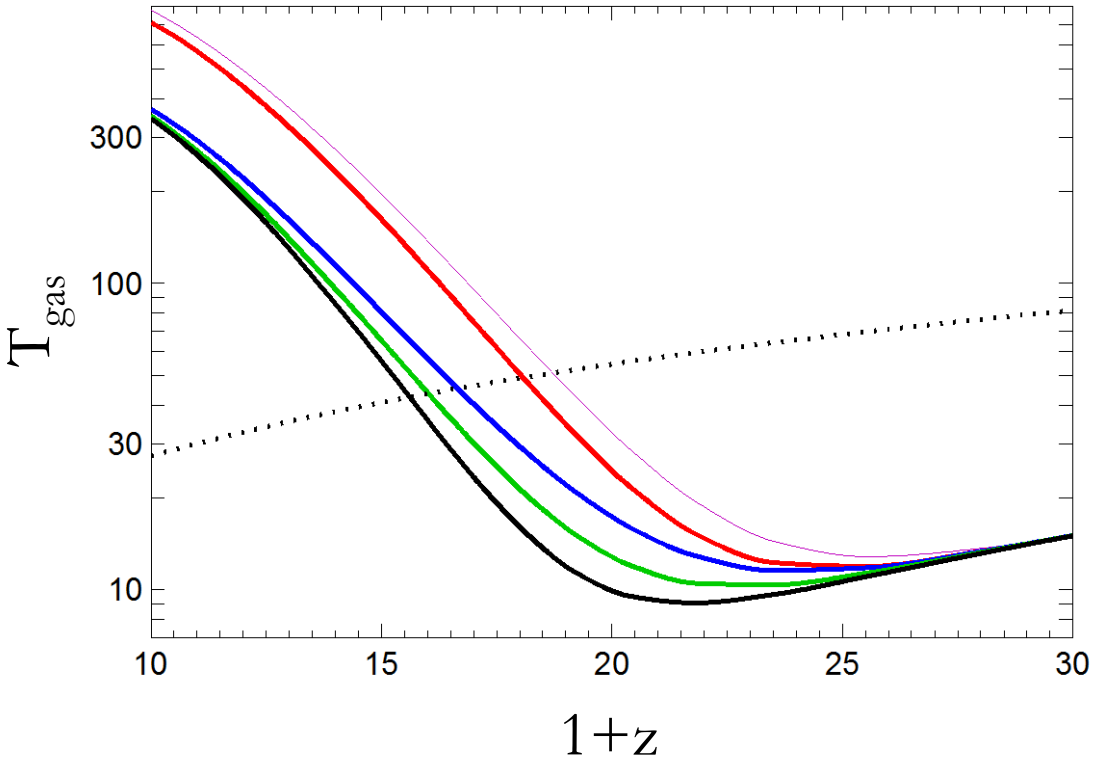


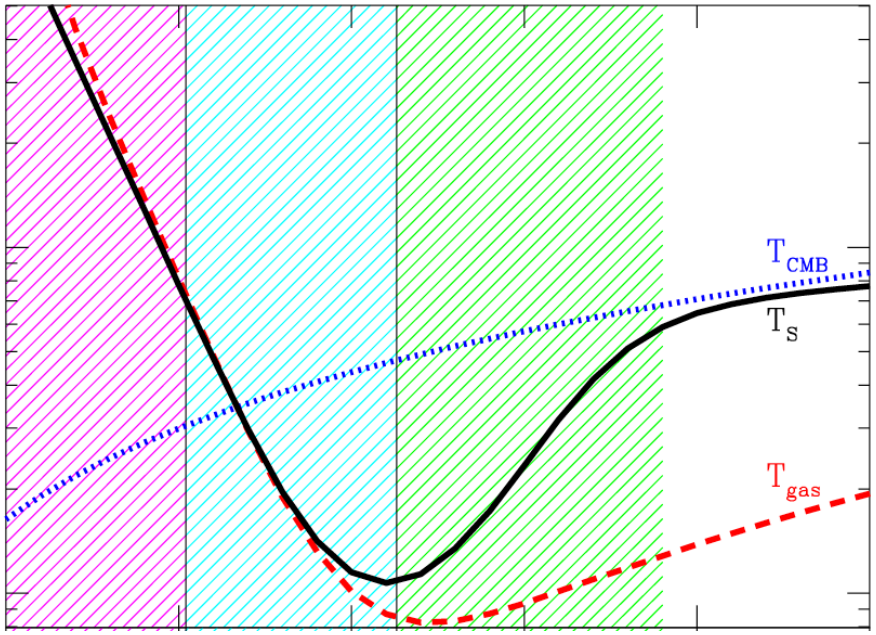
McQuinn & O'Leary (2012)

Now put in star formation, heating, and feedback as well…



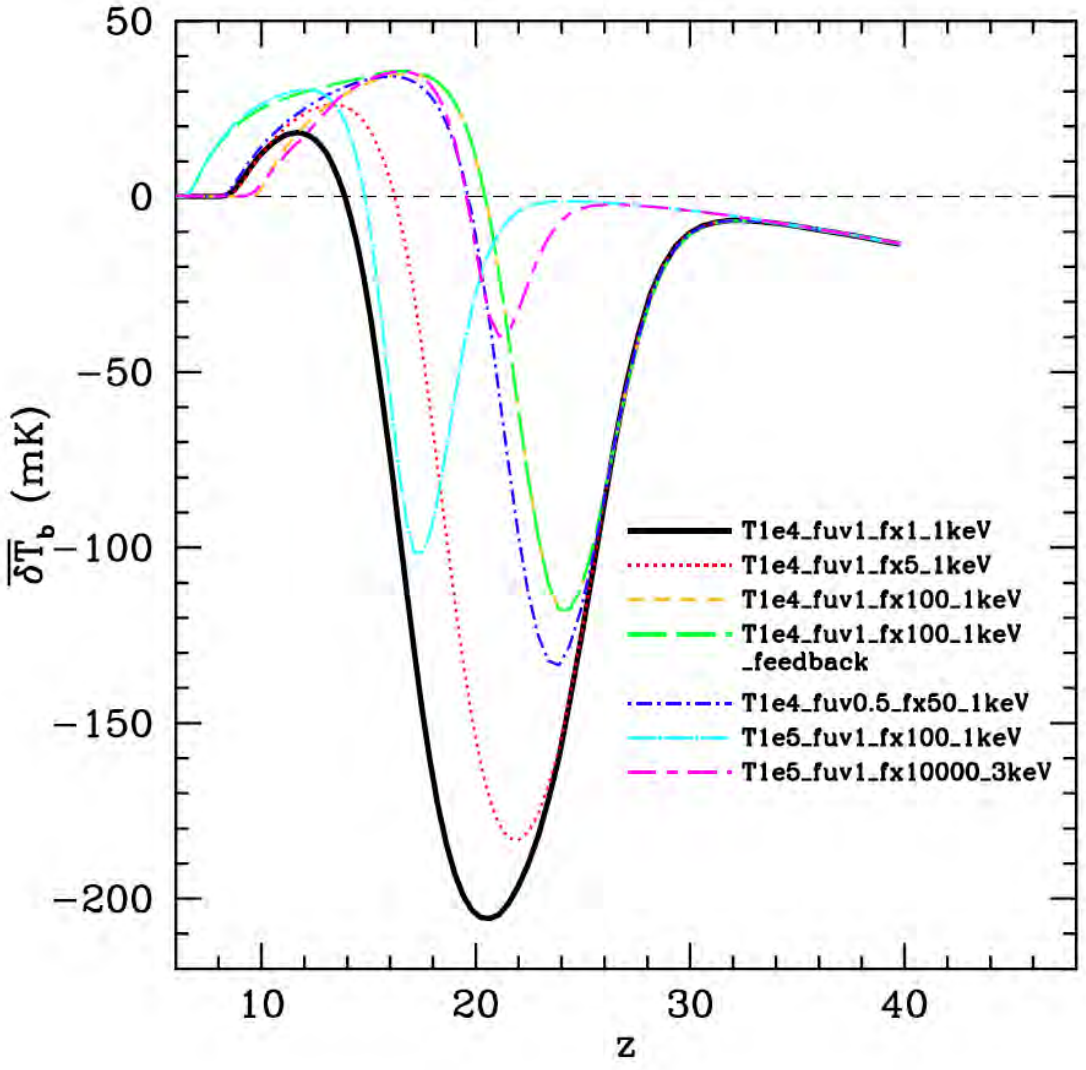
Fialkov et al. (submitted, 2012)

What might go wrong?



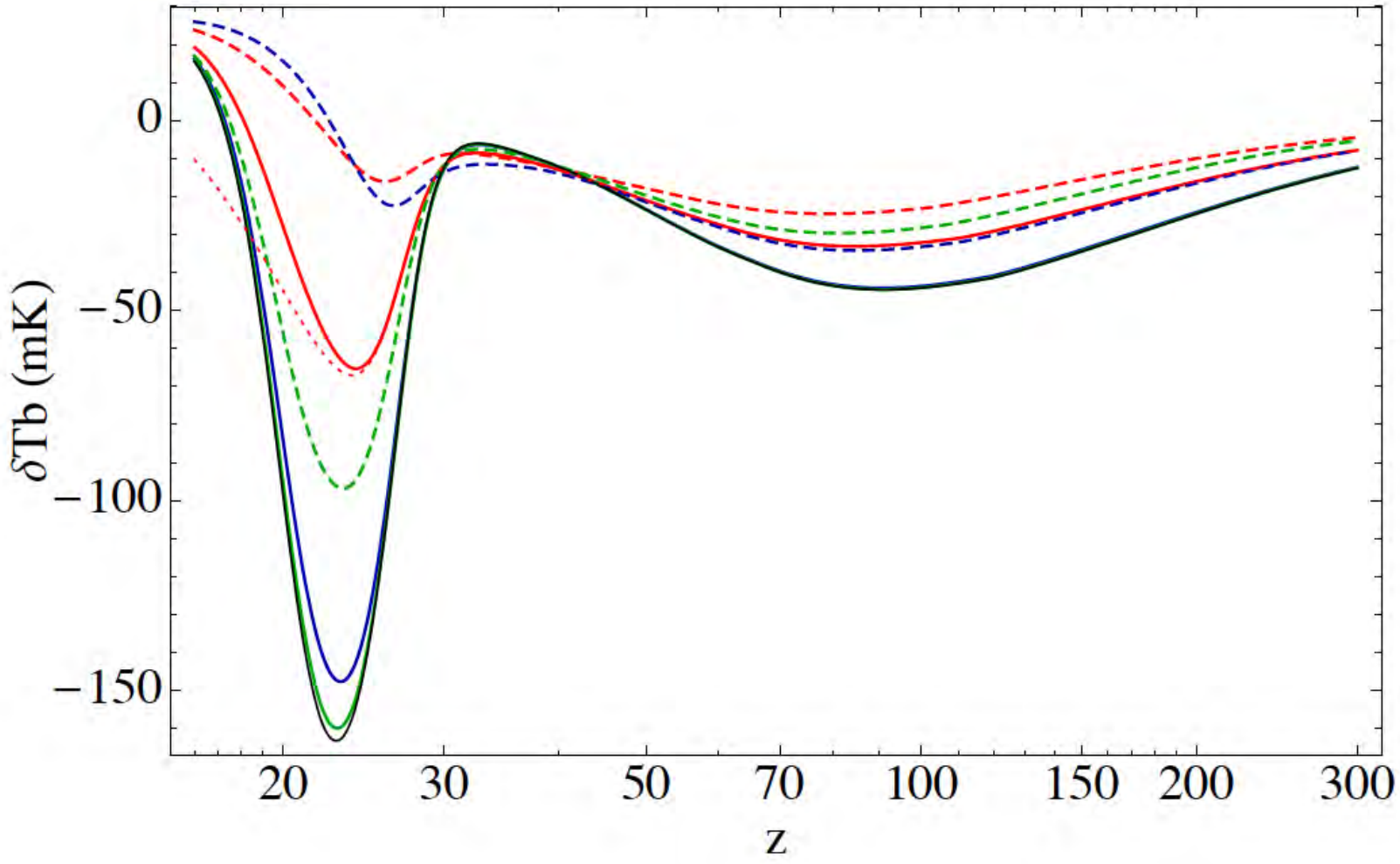
1. IGM physics may cause T_{gas} to deviate from adiabatic cooling.
2. X-ray heating may prematurely raise T_{spin}.

Even Xtreme X-rays preserve the trough



Mesinger, Ferrara, Spiegel (2012)

The trough persists even for (most) models with dark matter annihilations



Valdés et al. (2012)

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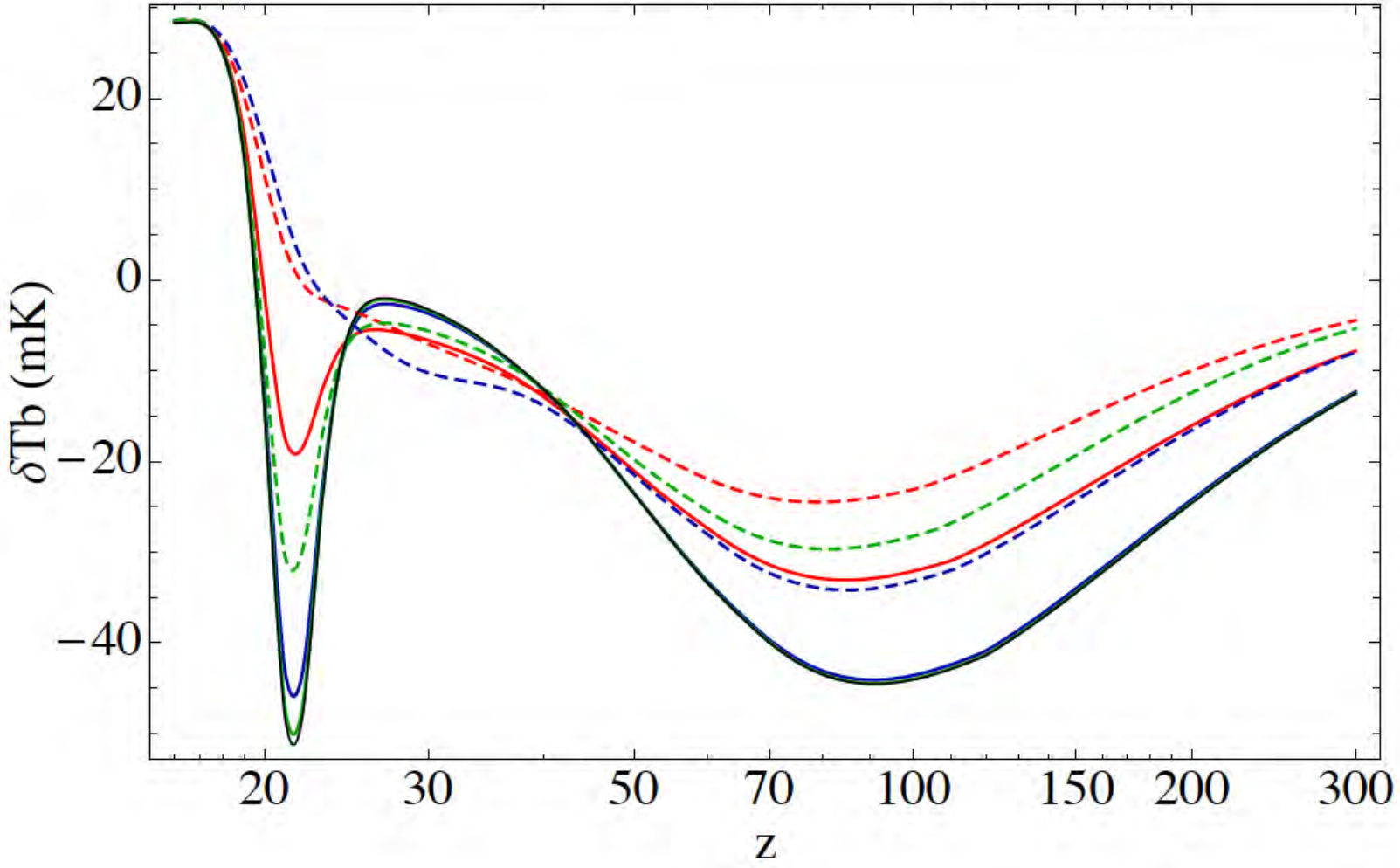
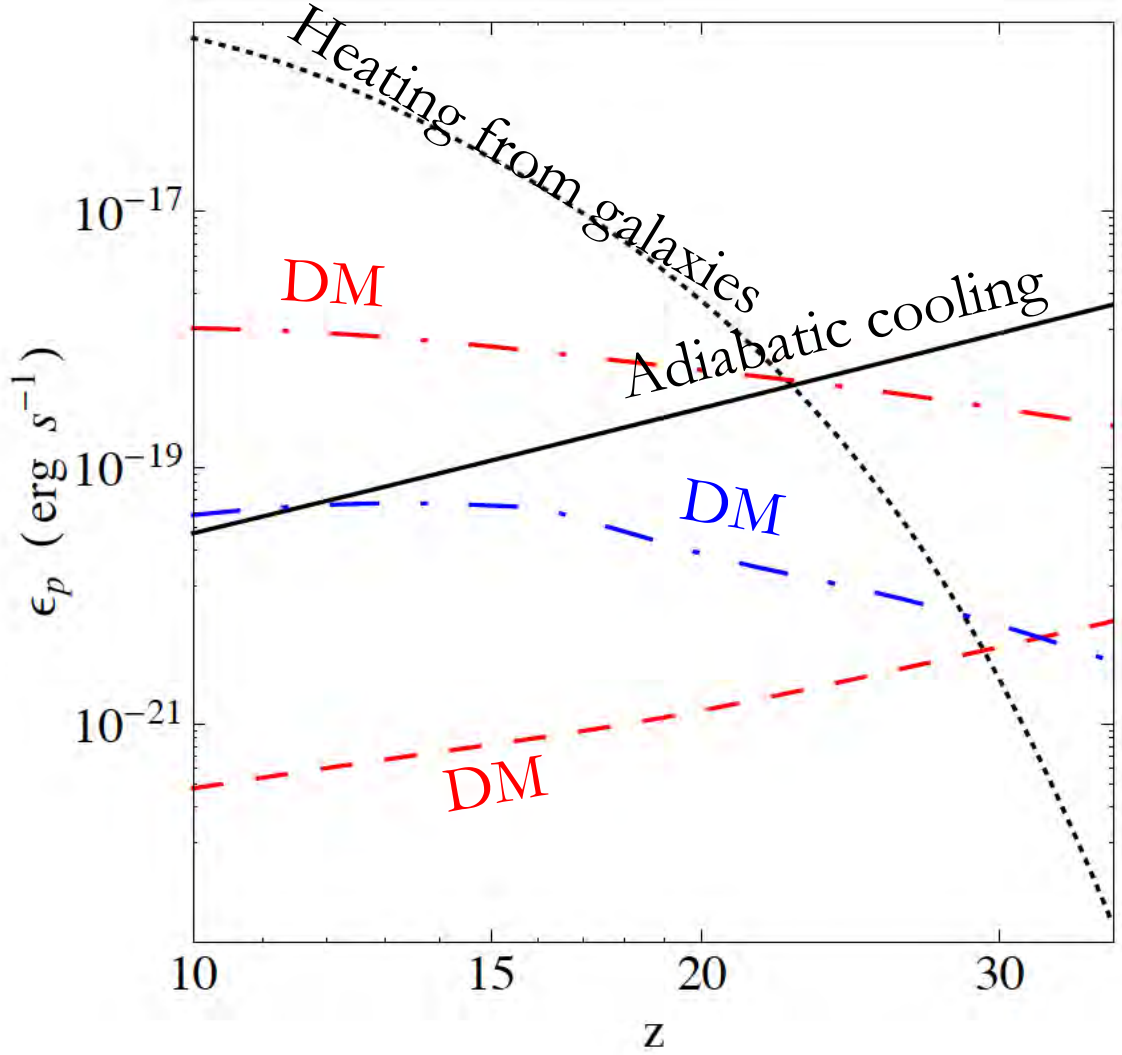


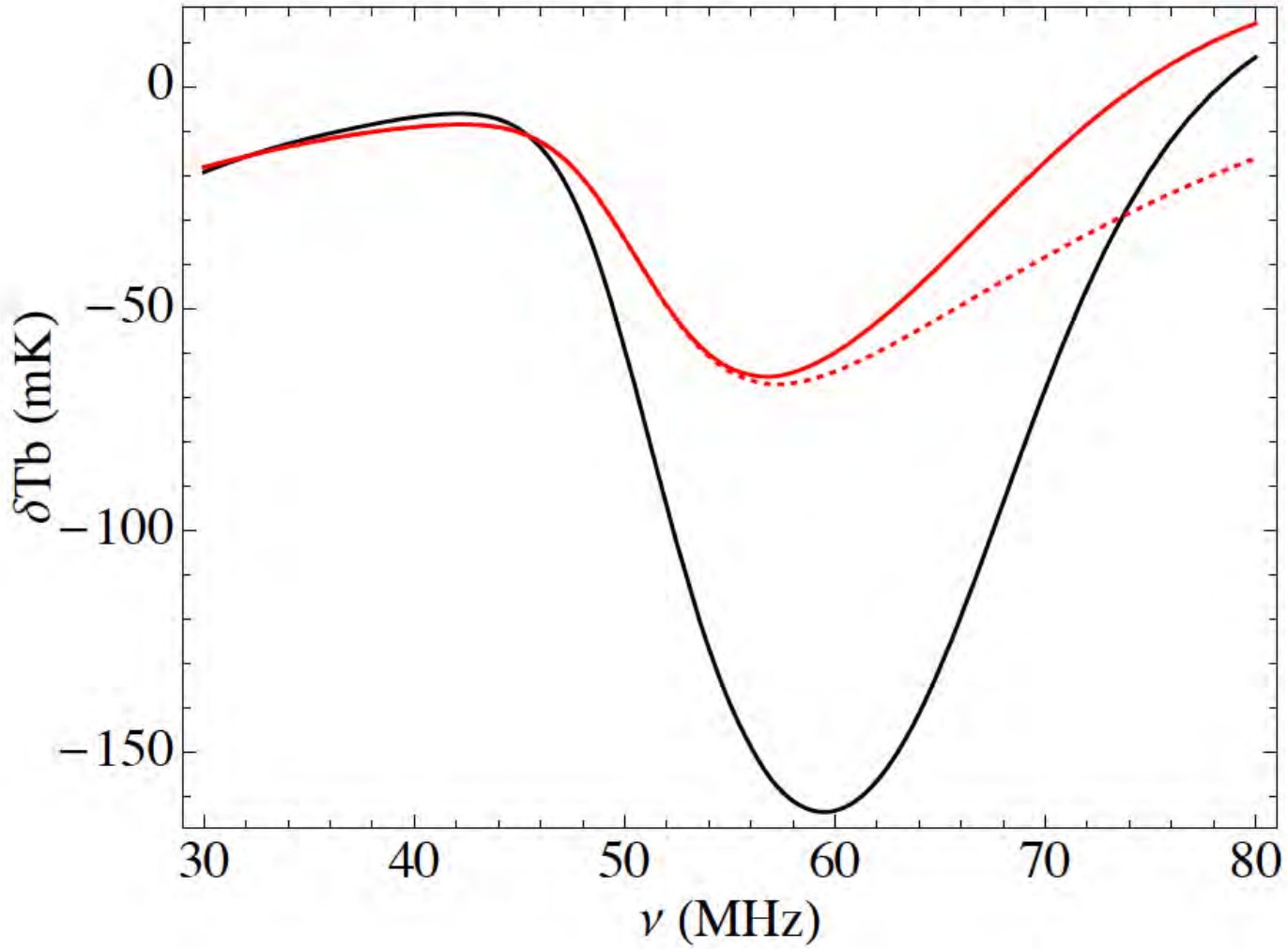
Valdés et al. (2012)

Heating rates are typically different for different sources



Valdés et al. (2012)

The slope of the spectrum may be a useful discriminant



Valdés et al. (2012)

Recent theoretical developments do not change the basic picture, but the considerable uncertainty in theory can result substantial variations.