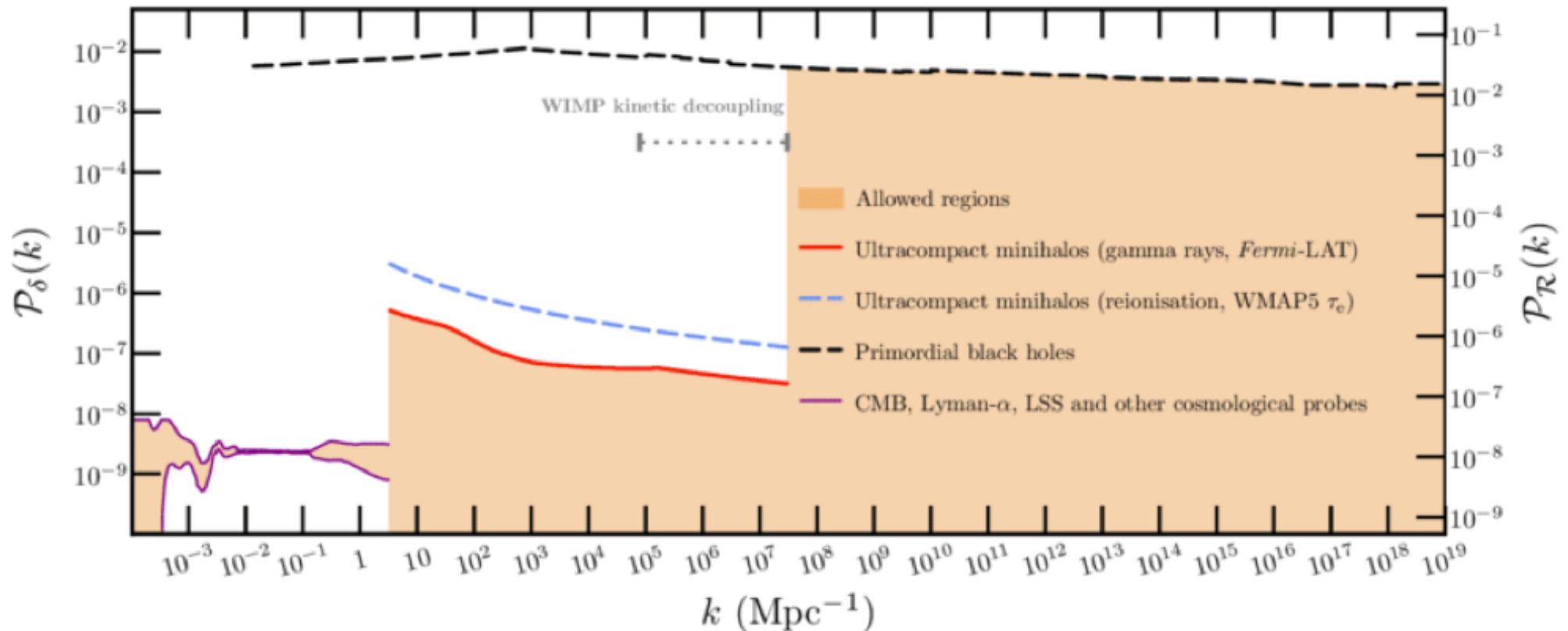


UCMHの個数と21-cm線 グローバルシグナルについて



Ultracompact minihalo (UCMH)?

The density profiles of ultracompact minihalos: implications for constraining the primordial power spectrum

M. Sten Delos,^{1,*} Adrienne L. Erickcek,^{1,†} Avery P. Bailey,^{2,1} and Marcelo A. Alvarez³

UCMHs:

A dark matter structure hypothesized to possess $\rho \propto r^{-9/4}$ density profile due to its formation at $z \geq 1000$.

(Filmore+ 1984, Bertschinger 1985)

Their purpose:

Confirming the UCMH density profile with N-body simulation

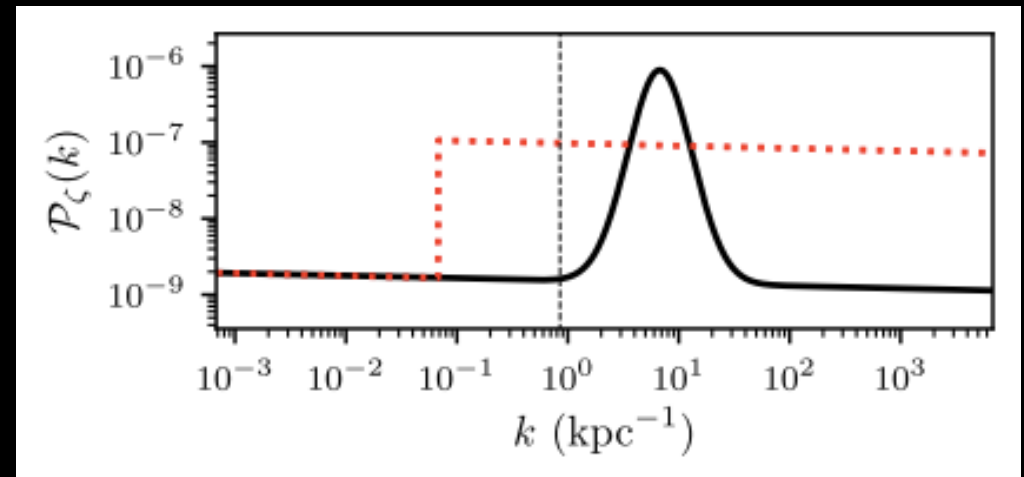
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Setup:

- spiked power spectrum on small scale ~ 1 kpc
- initial redshift: $z = 8 \times 10^6$
- box size: $L = 7.4$ ckpc
- particle number: $N = 512^3$
- GADGET-2 with radiation
- ROCKSTAR halo finder



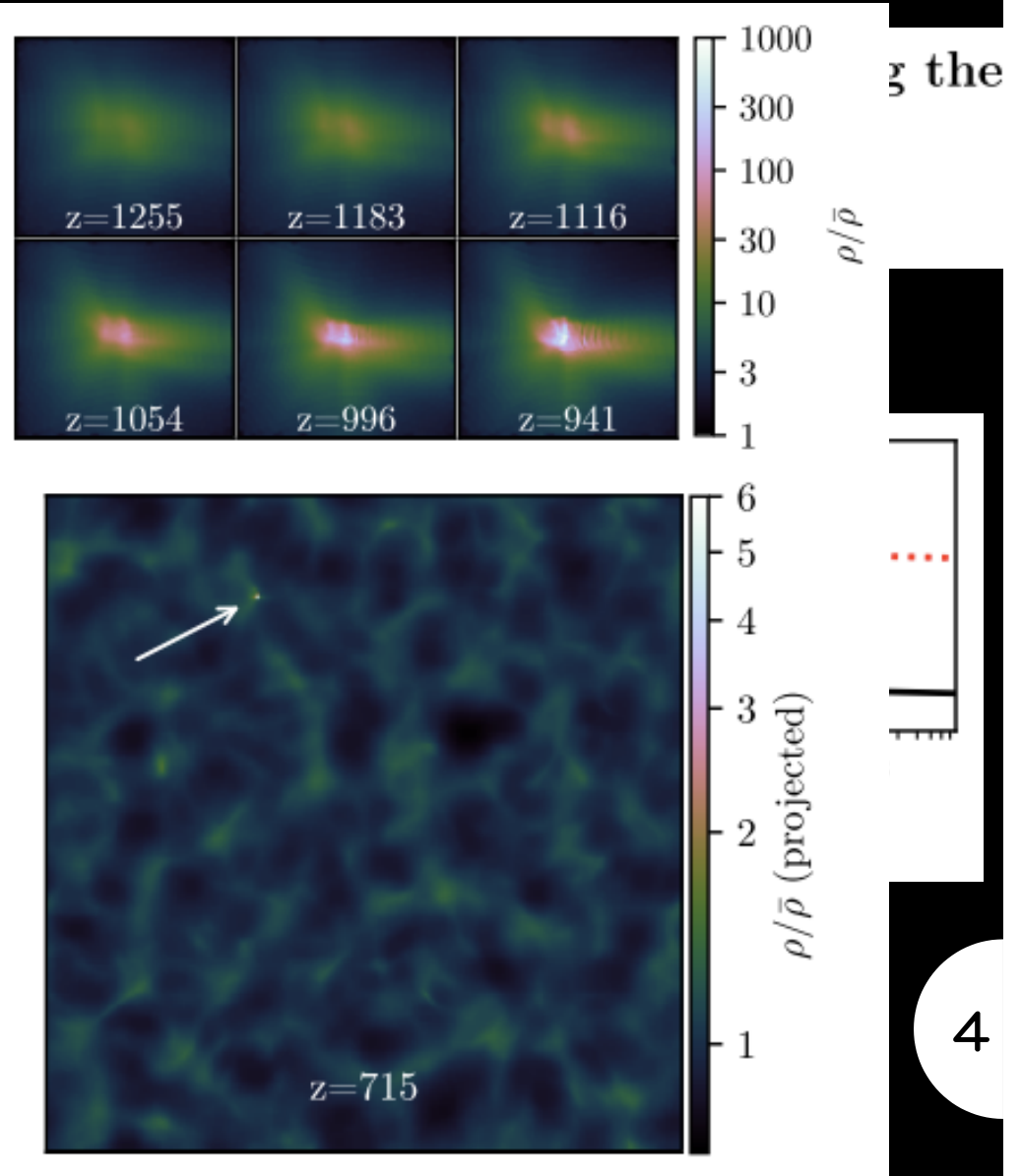
Ultracompact minihalo (UCMH)?

The density profiles of ultracompact minihalo (UCMH) and primordial black holes (PBHs)

M. Sten Delos,^{1,*} Adrienne L. Erickcek,^{1,†}

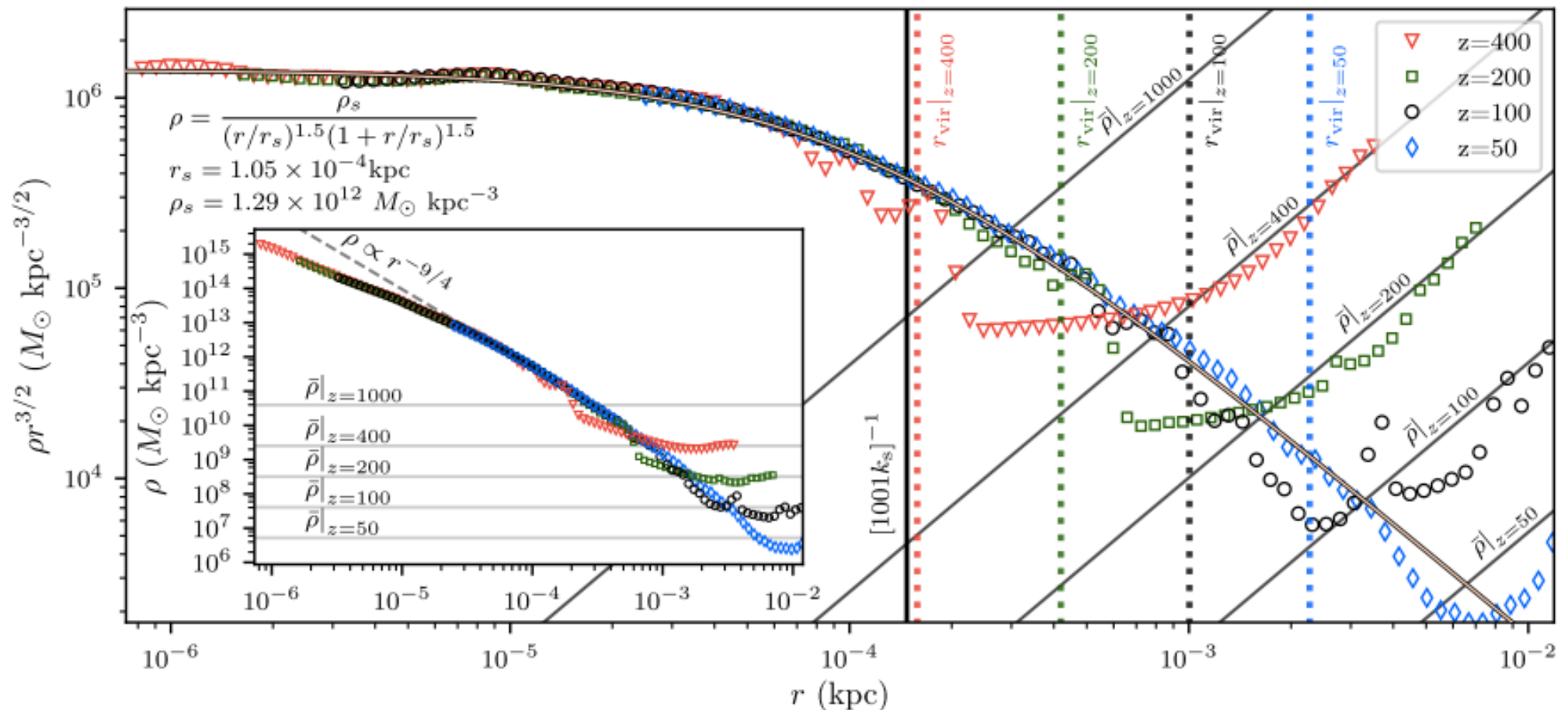
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(Delos et al., 1806.07389)

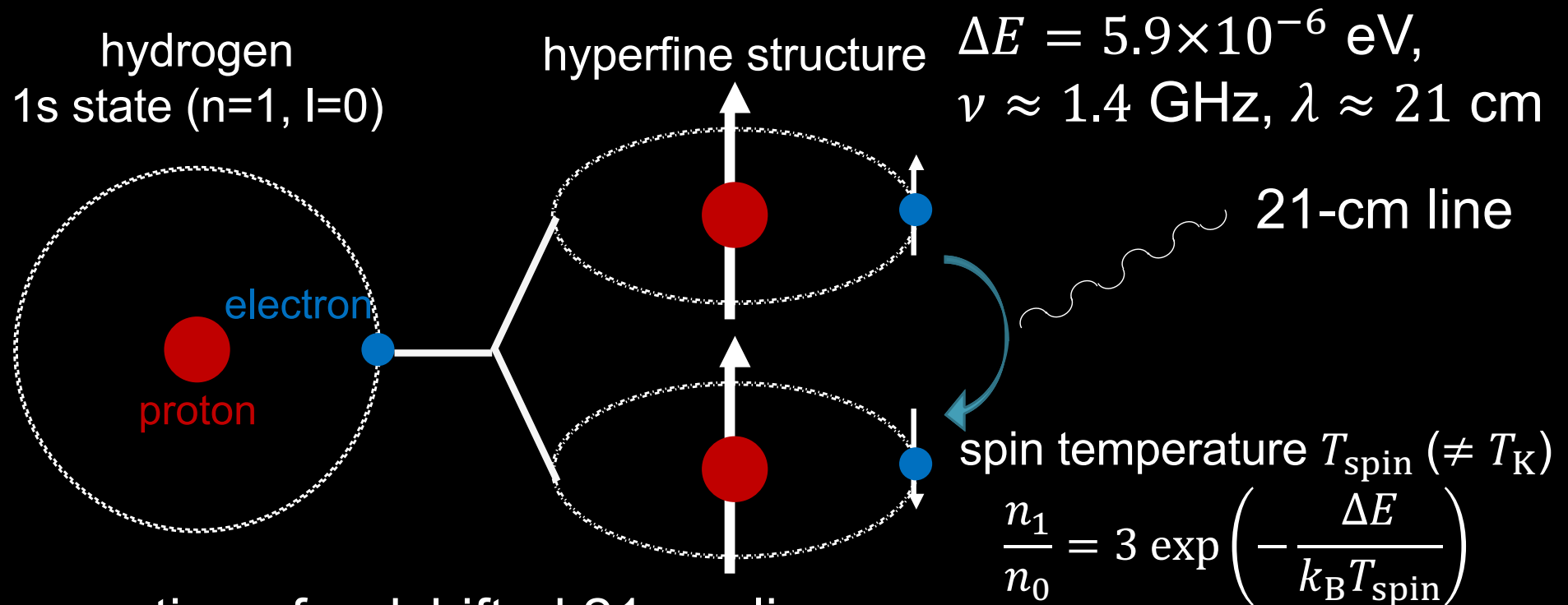
UCMH density profile



Steeper inner profile than NFW, but $\rho \neq r^{-9/4}$

What is 21-cm line?

EM wave due to neutral hydrogen hyperfine structure



observation of redshifted 21-cm line
 => physical history of HI at the redshift
 (matter clustering, IGM thermal history, details of EoR, ...)

21-cm global signal

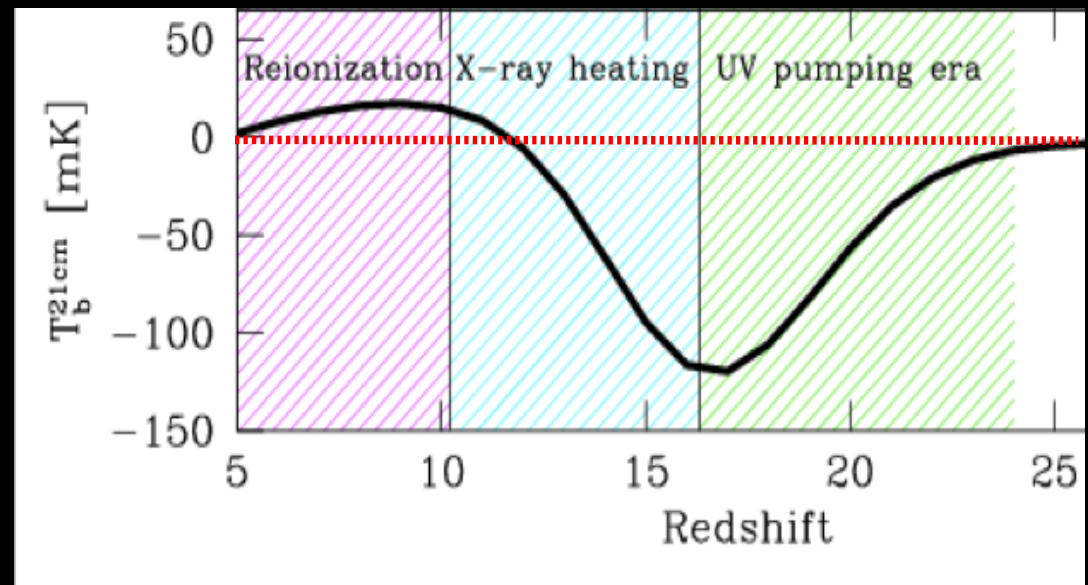
Observable  physical state of HI

Roughly speaking,
emission for

$$T_K \geq T_{\text{spin}} \geq T_\gamma,$$

and absorption for

$$T_K \leq T_{\text{spin}} \leq T_\gamma$$



Theoretical prediction for 21-cm global signal
McQuinn & O'Leary, 2012 (arXiv:1204.1345)

21-cm global signal

Observable  physical state of HI

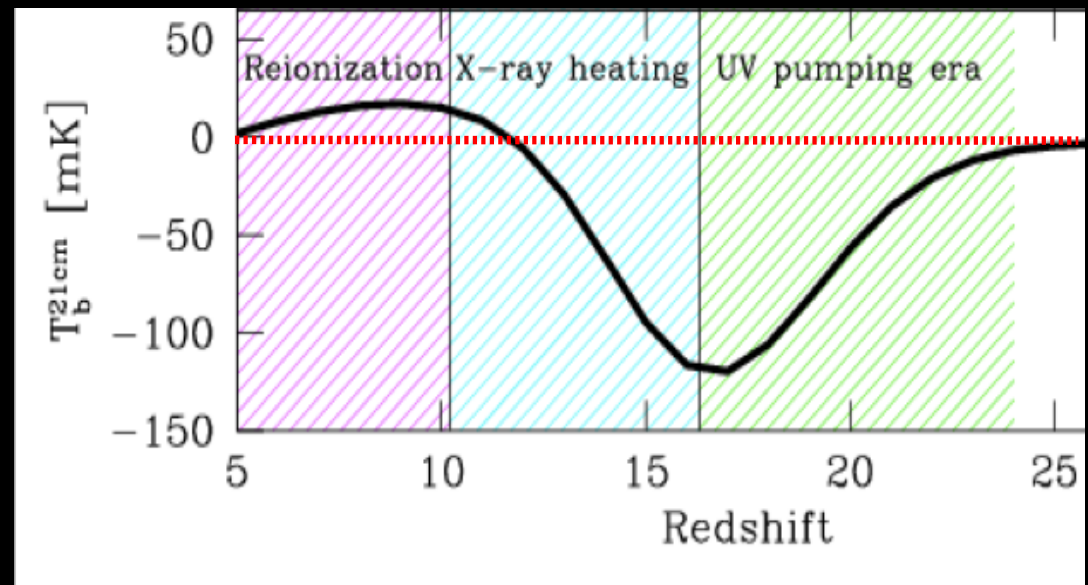
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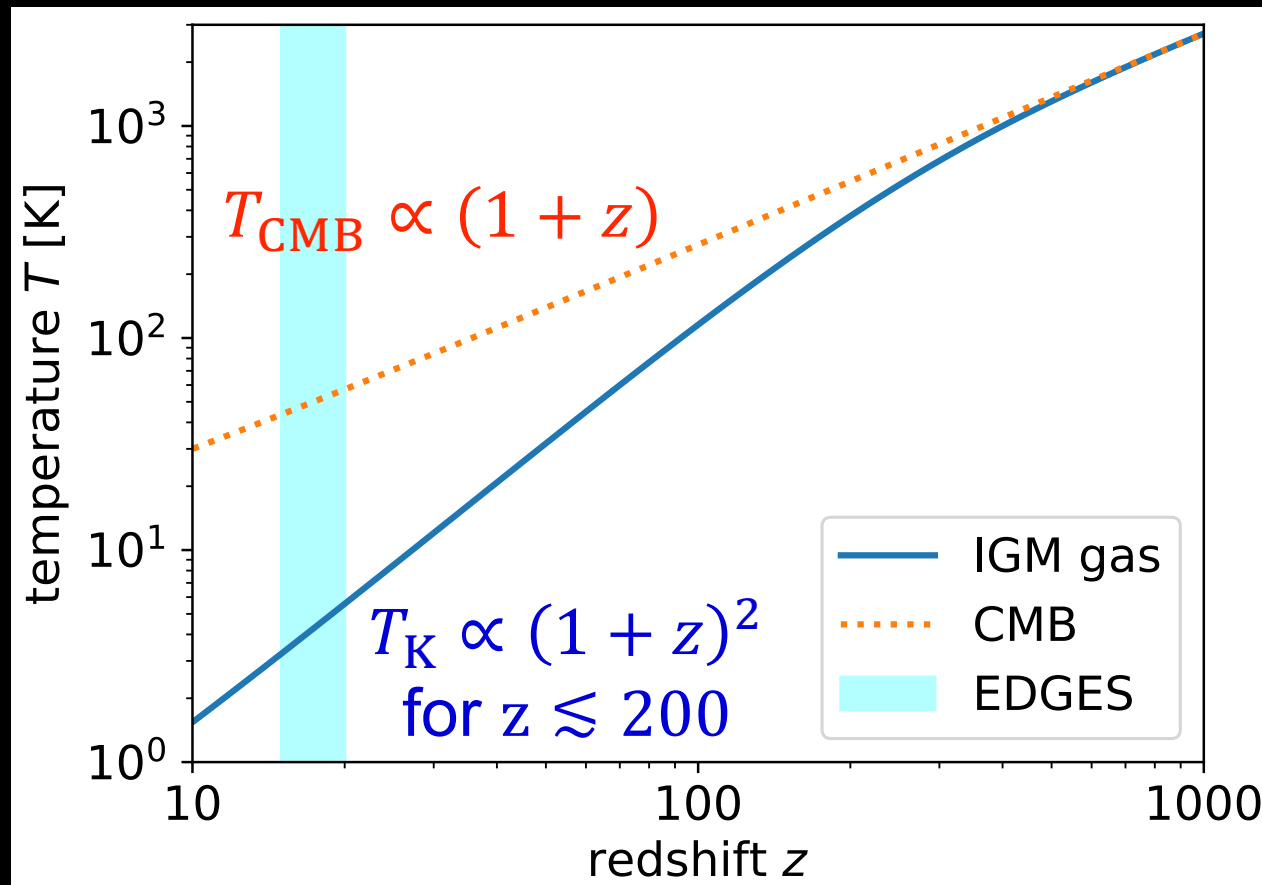
We focus on
absorption signal
during Dark Age ($z \sim 17$)



Theoretical prediction for 21-cm global signal
McQuinn & O'Leary, 2012 (arXiv:1204.1345)

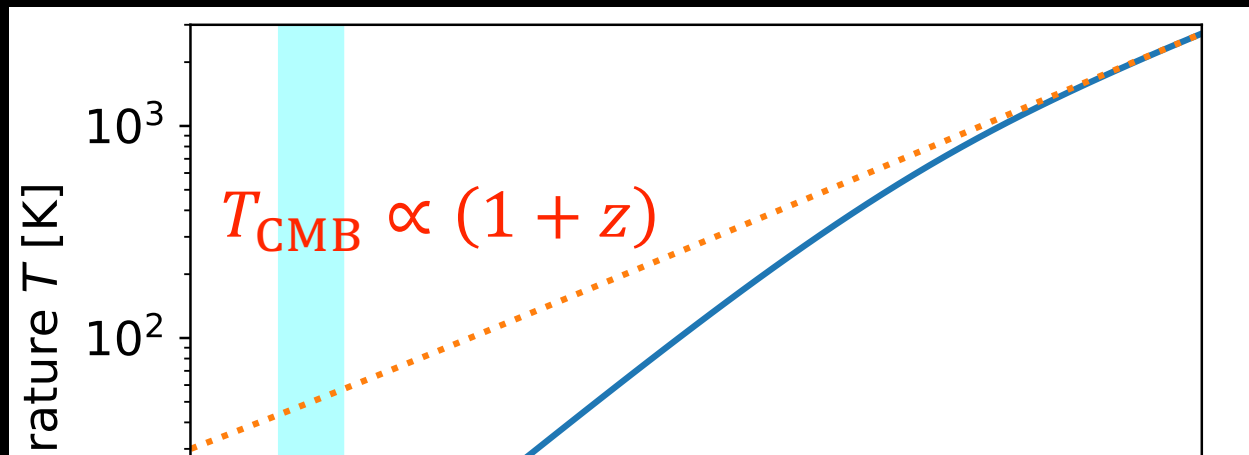
IGM thermal history

Adiabatic calculation $\Rightarrow T_{\text{CMB}} > T_{\text{K}}$ (absorption) around $z \sim 17$



IGM thermal history

Adiabatic calculation $\Rightarrow T_{\text{CMB}} > T_{\text{K}}$ (absorption) around $z \sim 17$



21-cm global absorption signal for $z \sim 17$

$\Rightarrow$ constraint on exotic heating sources for IGM

dark matter annihilation (1803.03629)

primordial black holes (1803.09390)

$\Rightarrow$ gamma-ray emitted by dark matter

annihilation from ultracompact minihalos

Gamma-ray emission due to DM annihilation from UCMH

Gamma-ray luminosity

dark matter mass: $m_x = 1$ (TeV)

annihilation rate: $\langle\sigma v\rangle = 3\times 10^{-26}$ (cm³/s)

$$L_{\text{UCMH}} = \int E \frac{dN}{dE} dE \times \int_0^R 4\pi r^2 \frac{\rho^2}{2m_x^2} \langle\sigma v\rangle dr$$

Gamma-ray total energy from one DM annihilation

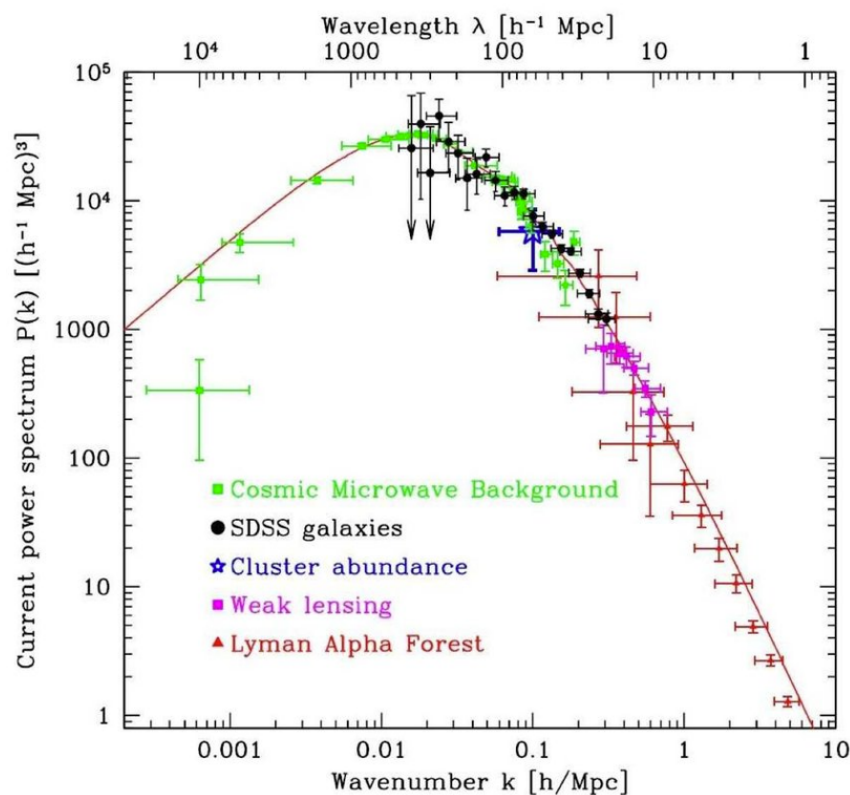
How many DM annihilates inside one UCMH per unit time

UCMH abundance

- UCMH number density from peak theory

$$\frac{dn_{\text{UCMH}}}{da} = \frac{k_s^3}{(2\pi)^2 3^{3/2}} \frac{\nu}{a} e^{-\nu^2} f(\nu)$$

(Bardeen et al., 1986)



peak height: $\nu \equiv \frac{\delta_c}{\sqrt{A_{\text{mat}} a}}$

wave-number of spike: k_s

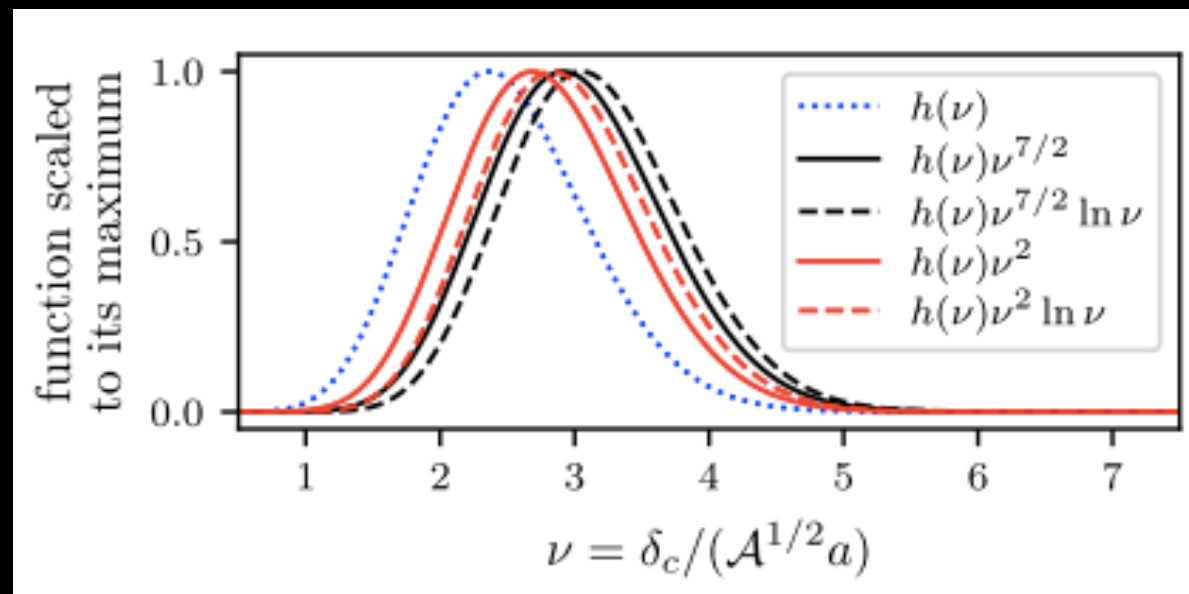
Amplitude of spike: A_{mat}

overdensity threshold: $\delta_c = 1.686$

UCMH abundance

- UCMH number density from peak theory

$$\frac{dn_{\text{UCMH}}}{da} = \frac{k_s^3}{a} h(\nu) \quad (\text{Bardeen et al., 1986})$$



peak height: $\nu \equiv \frac{\delta_c}{\sqrt{A_{\text{mat}} a}}$

wave-number of spike: k_s

IGM thermal history with UCMH

$$\frac{dT_{\text{gas}}}{dt} = \frac{x_e}{1+x_e} \frac{8\rho_{\text{CMB}}\sigma_T}{3m_e c} (T_{\text{CMB}} - T_{\text{gas}}) - 2HT_{\text{gas}}$$

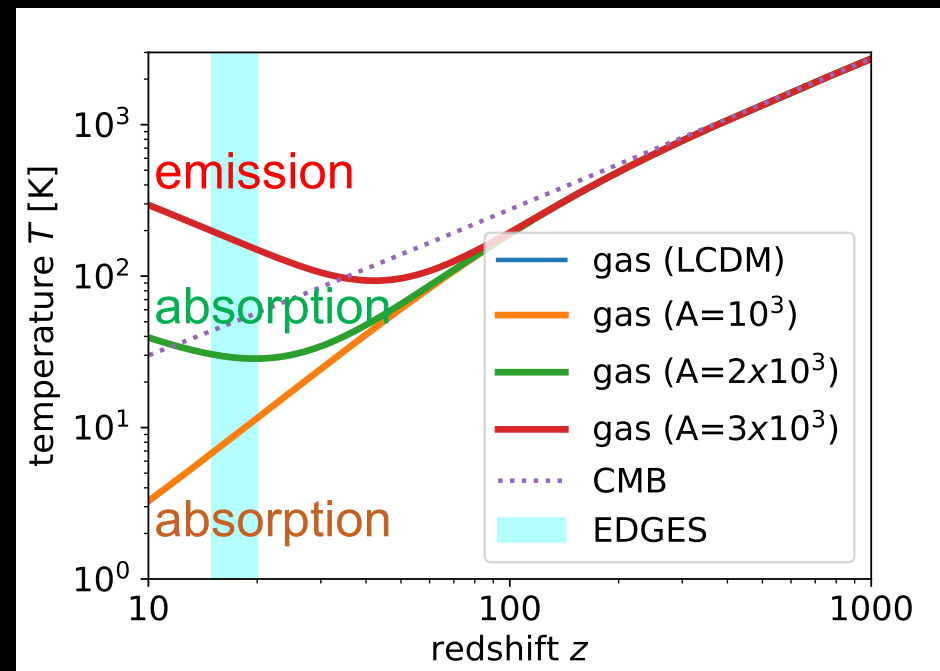
Compton scattering with CMB

cosmic expansion

$$+ \frac{\chi_{\text{heat}}}{1.5n_b k_B} \int L \frac{dn}{da} da$$

DM annihilation
from UCMHs

(+ recombination history)



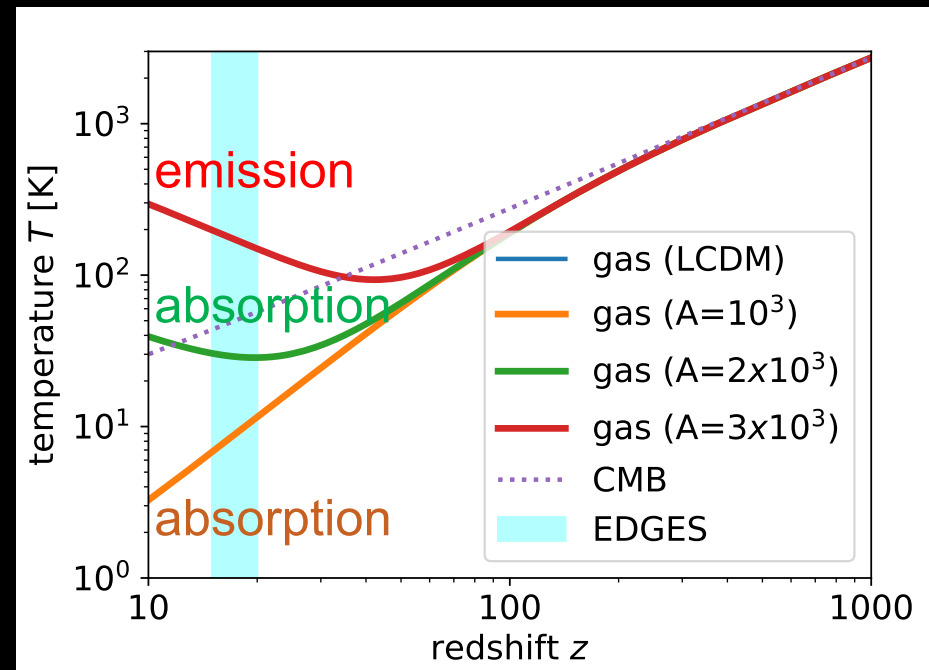
IGM thermal history with UCMH

$$\frac{dT_{\text{gas}}}{dt} = \underbrace{\frac{x_e}{1+x_e} \frac{8\rho_{\text{CMB}}\sigma_T}{3m_e c} (T_{\text{CMB}} - T_{\text{gas}})}_{\text{Compton scattering with CMB}} - \underbrace{2HT_{\text{gas}}}_{\text{cosmic expansion}}$$

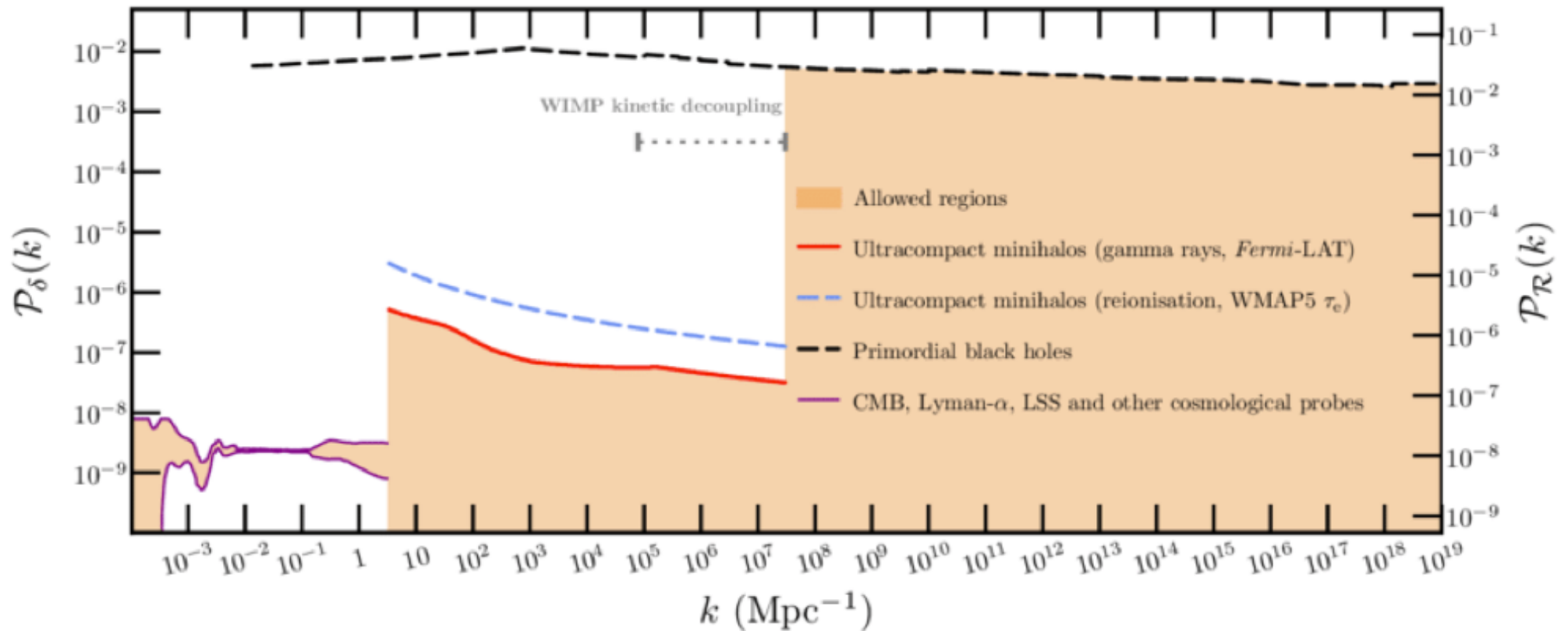
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DM annihilation
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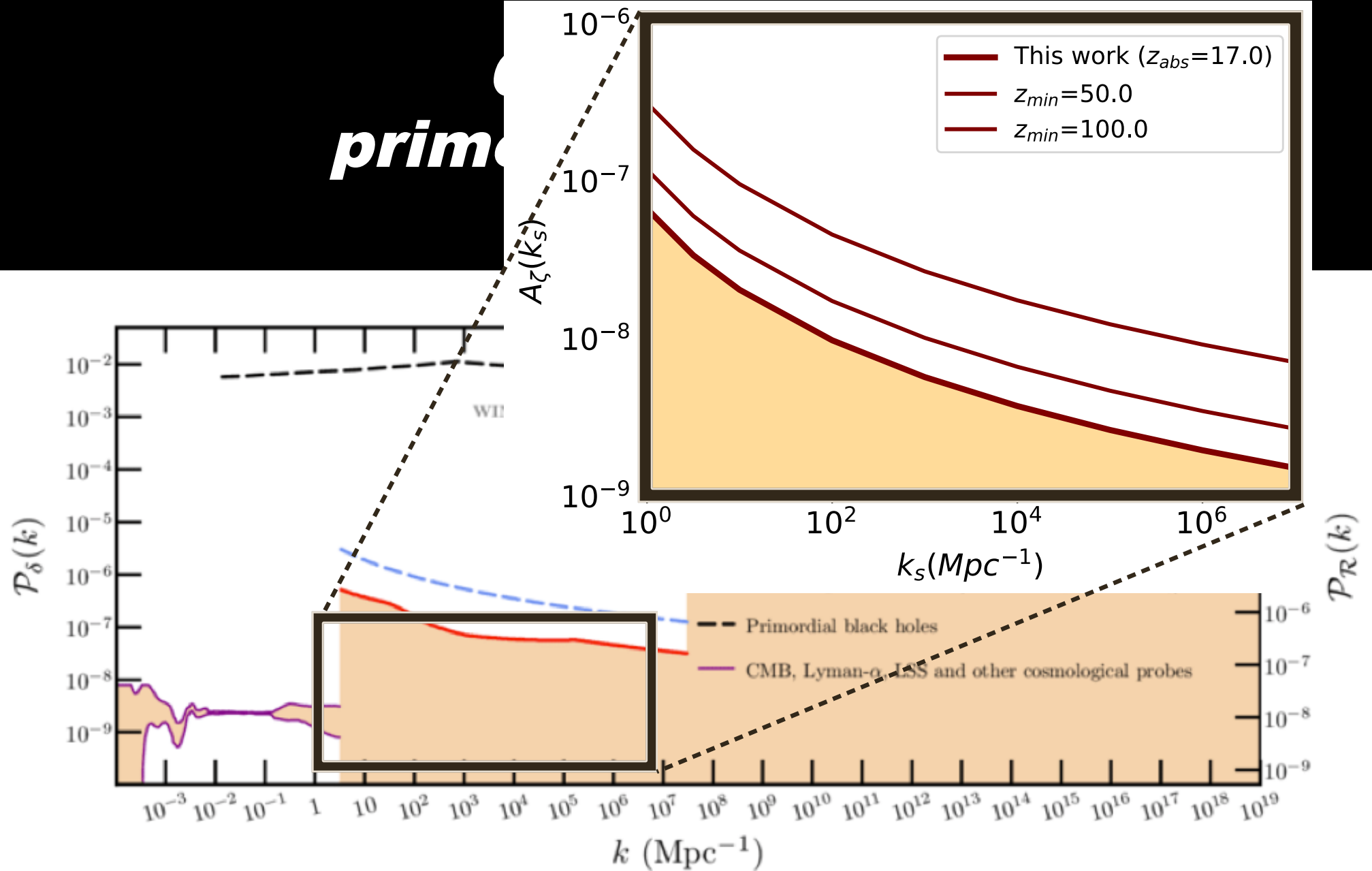
absorption signal for $z \sim 17$
 $\Rightarrow A_{\text{mat}} \lesssim 2.3 \times 10^3$



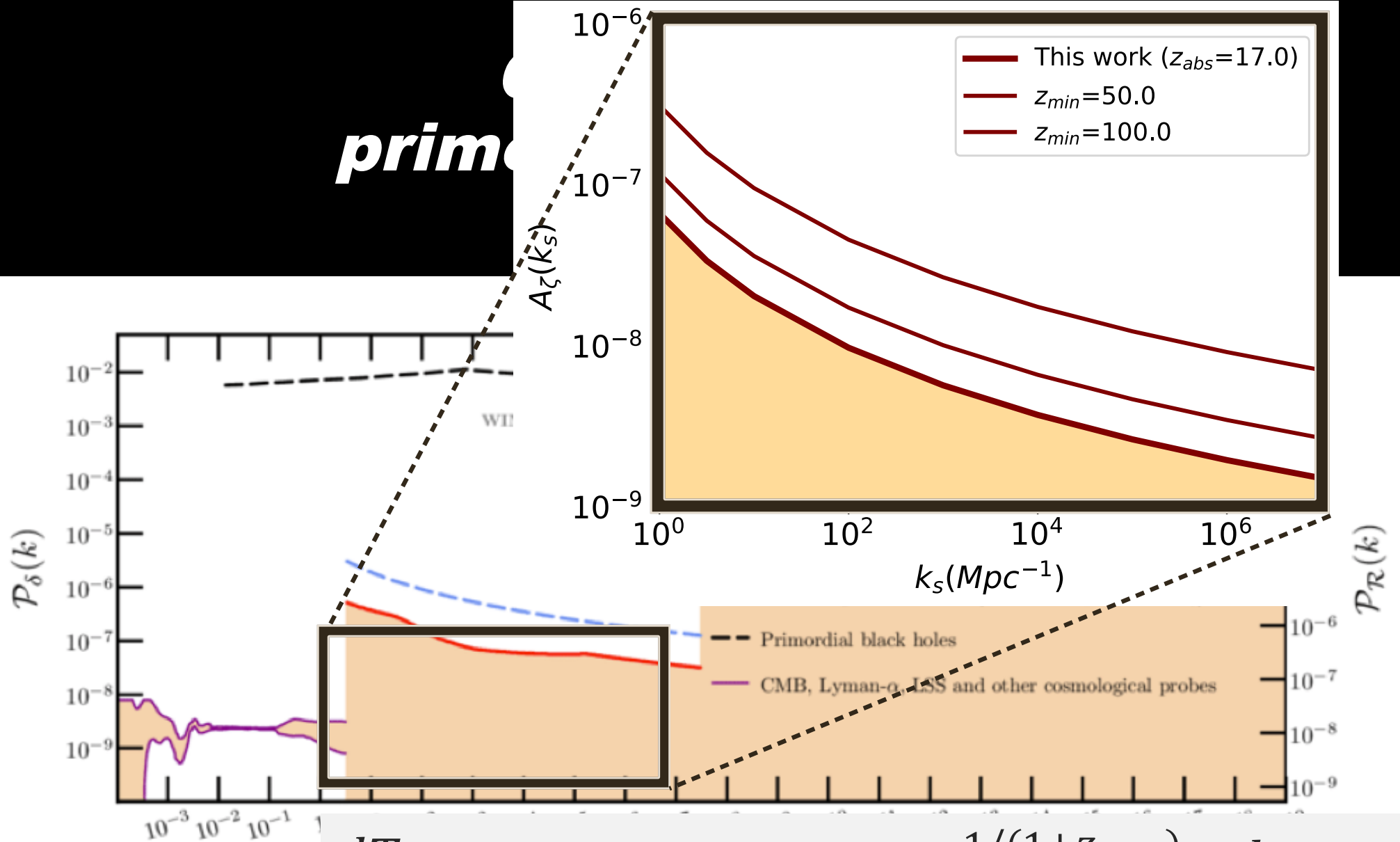
Current constraints on primordial power spectrum



primordial



primordial



$$\frac{dT_{\text{gas}}}{dt} = (\dots) + \frac{\chi_{\text{heat}}}{1.5n_{\text{b}}k_{\text{B}}} \int_0^{1/(1+z_{\text{min}})} L \frac{dn}{da} da$$

Summary

- ✓ Constrained primordial power spectrum on small-scales from 21-cm global absorption signal
- ✓ Calculated IGM thermal history during Dark Ages with DM annihilation from UCMHs
- ✓ absorption signal at redshift $z \sim 17$

$$\Rightarrow P_{\zeta} < 10^{-7} \text{ at } k_s < 10^0 \text{ Mpc}^{-1},$$

$$P_{\zeta} < 10^{-9} \text{ at } k_s < 10^7 \text{ Mpc}^{-1}.$$

Backup

