Kenji Kadota
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Institute for Basic Science

21cm forest bounds on the ultra-light dark matter

arXiv:1910.XXXXX

In collaboration with: Hayato Shimabukuro (Tsinghua), Kyotomo Ichiki (Nagoya)

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- 21cm forest
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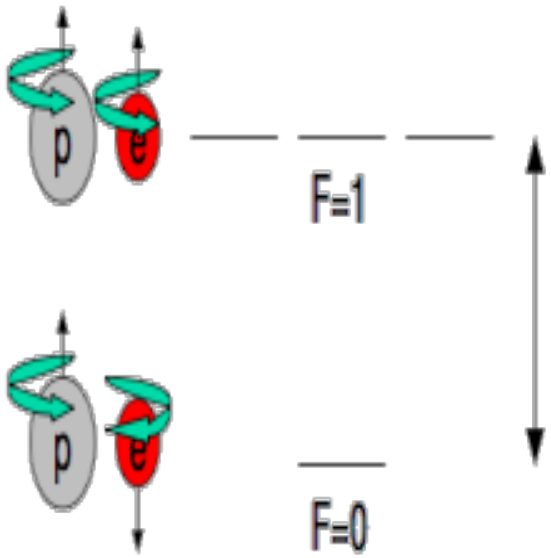
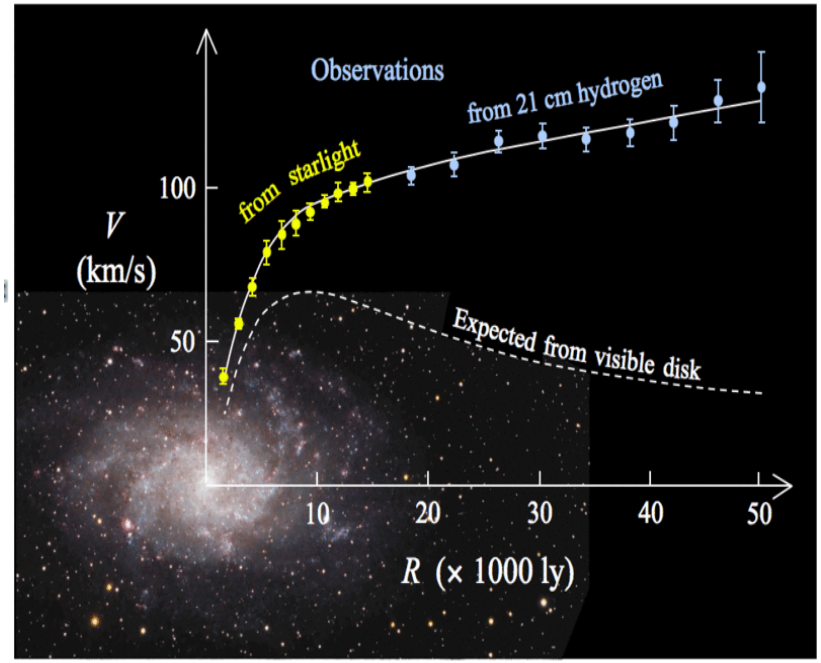
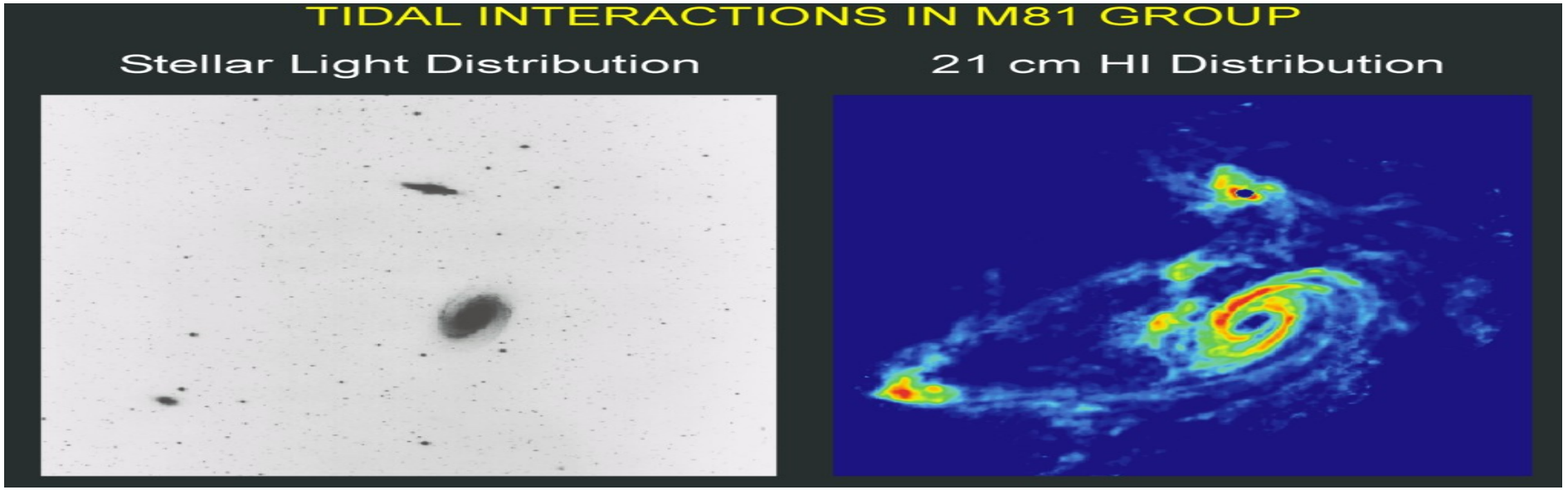
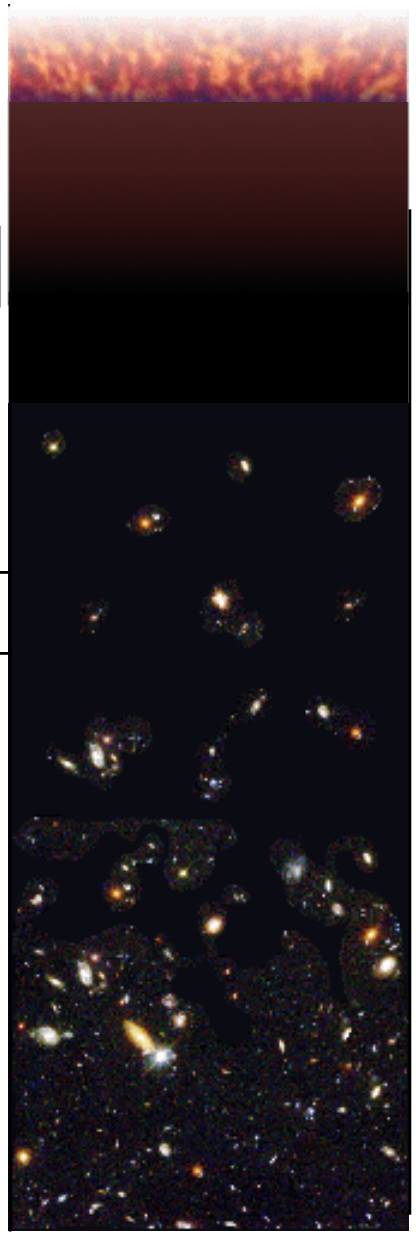


21cm signals
1420MHz





Brief History of the Universe



Years since the Big Bang

~300000 (z~1000)

← Big Bang: the Universe is filled with ionized gas

← Recombination: The gas cools and becomes neutral

Dark Ages

~100 million (z~20-40)

← The first structures begin to form.

Reionization starts (z ~12)

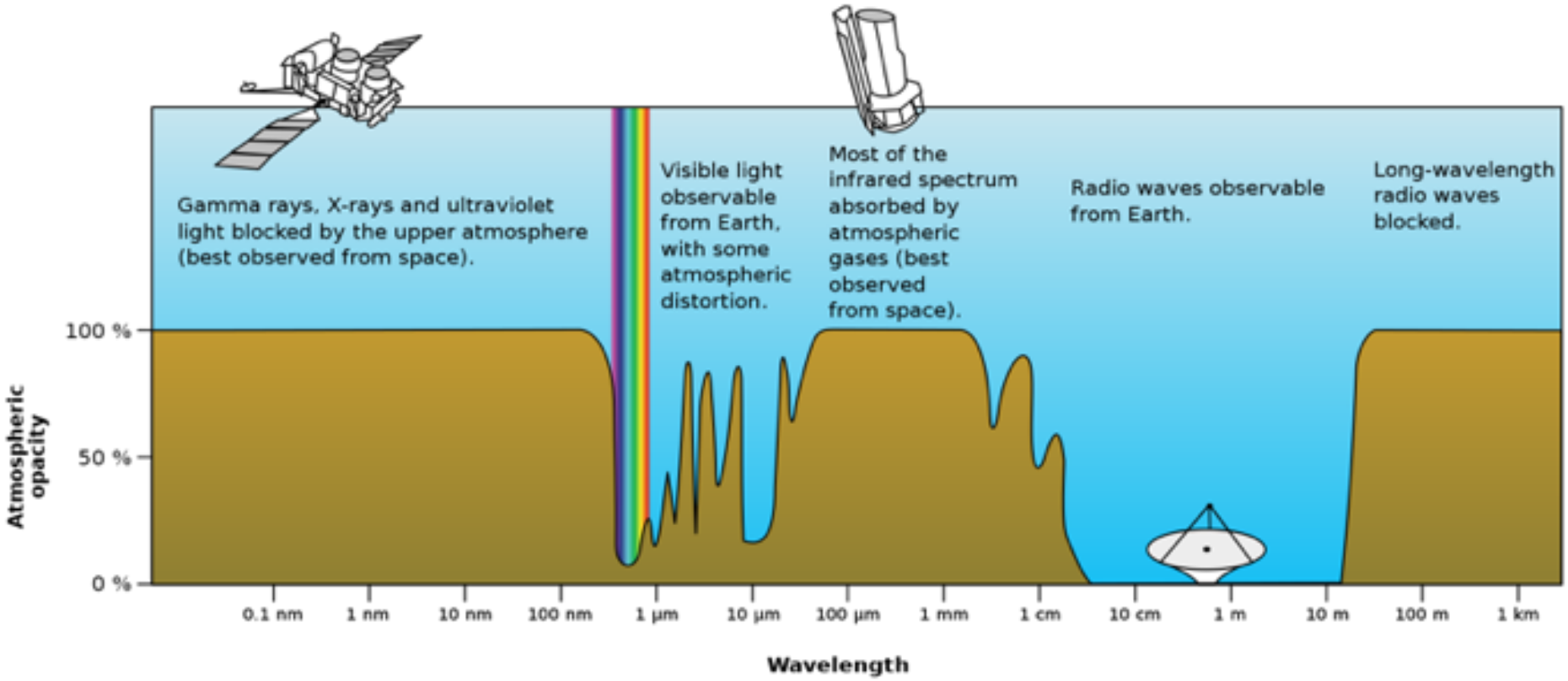
Reionization

~1 billion (z~6)

← Reionization is complete

~13 billion (z=0)

← Today's structures

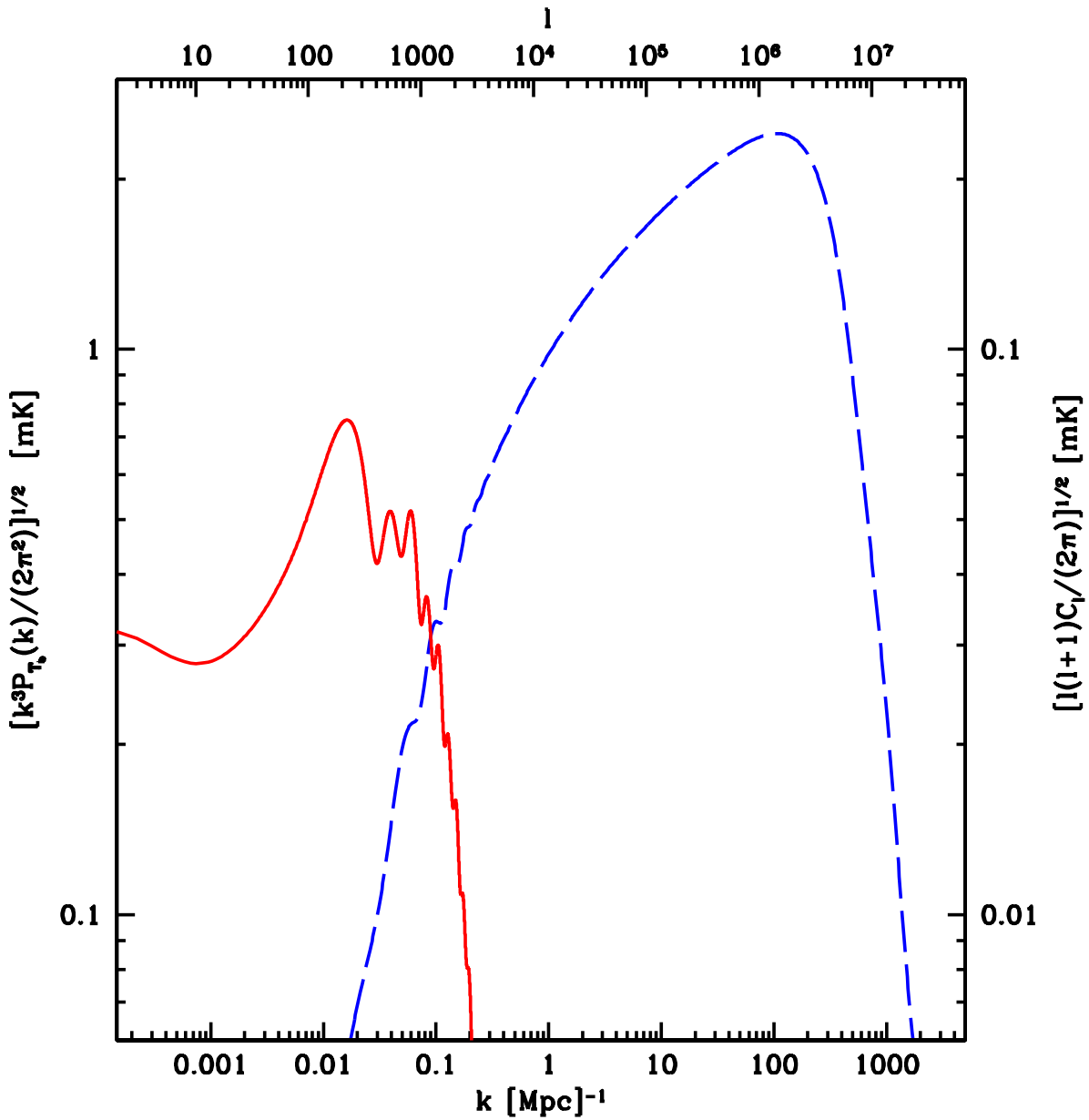


Australia: SKA low: 50-350 MHz

S. Africa: SKA mid: 350 MHz-14GHz

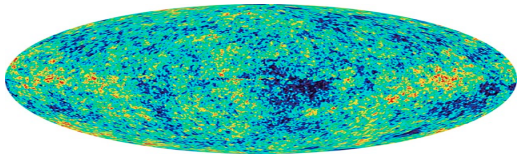
What can we do with 21cm?

$$\Delta P/P \sim 1/\sqrt{N}$$

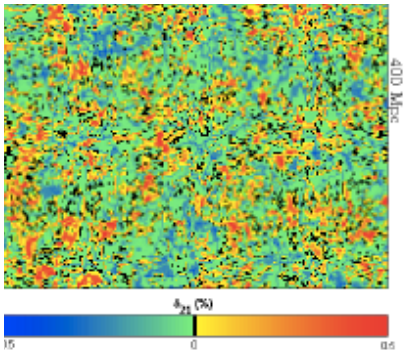


Kleban+(2007)

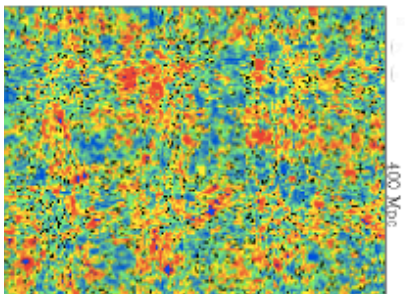
z=1100



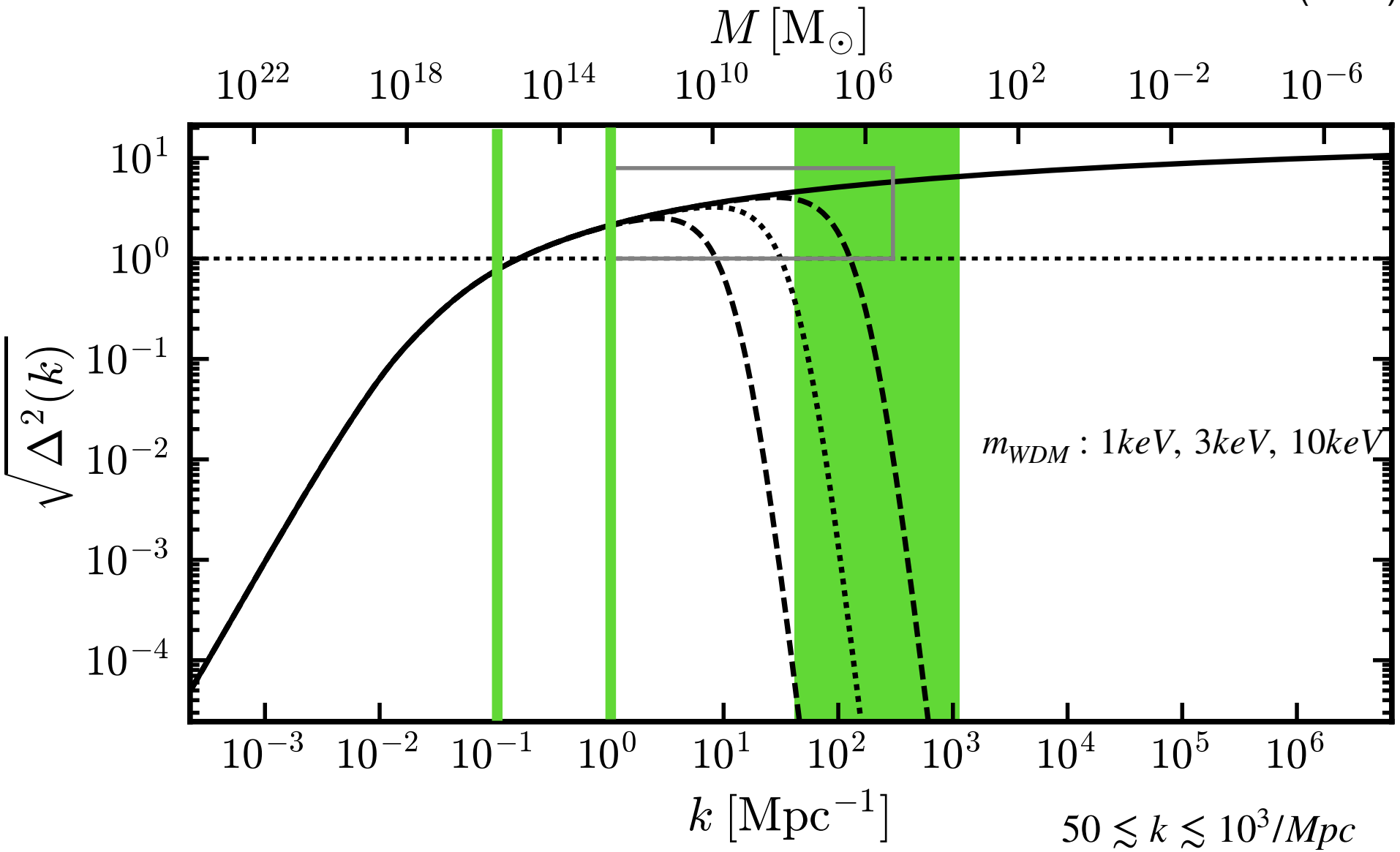
z=25



z=15



Bullock+(2017)



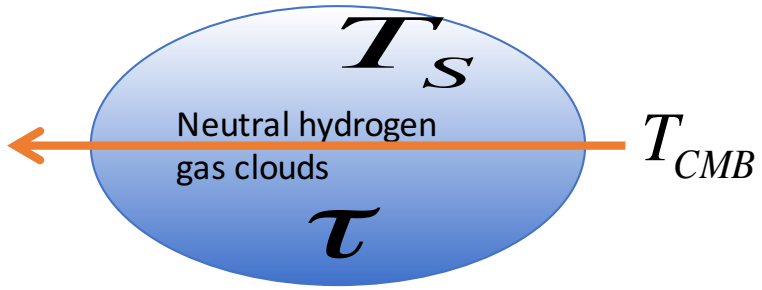
Ly-alpha: $m_{WDM} \gtrsim 5keV$

21cm forest: $m_{WDM} \gtrsim 50keV$

What does the 21cm signal actually measure?

Brightness temperature T_b

$$T_b \equiv T_{CMB} e^{-\tau} + T_S(1 - e^{-\tau})$$

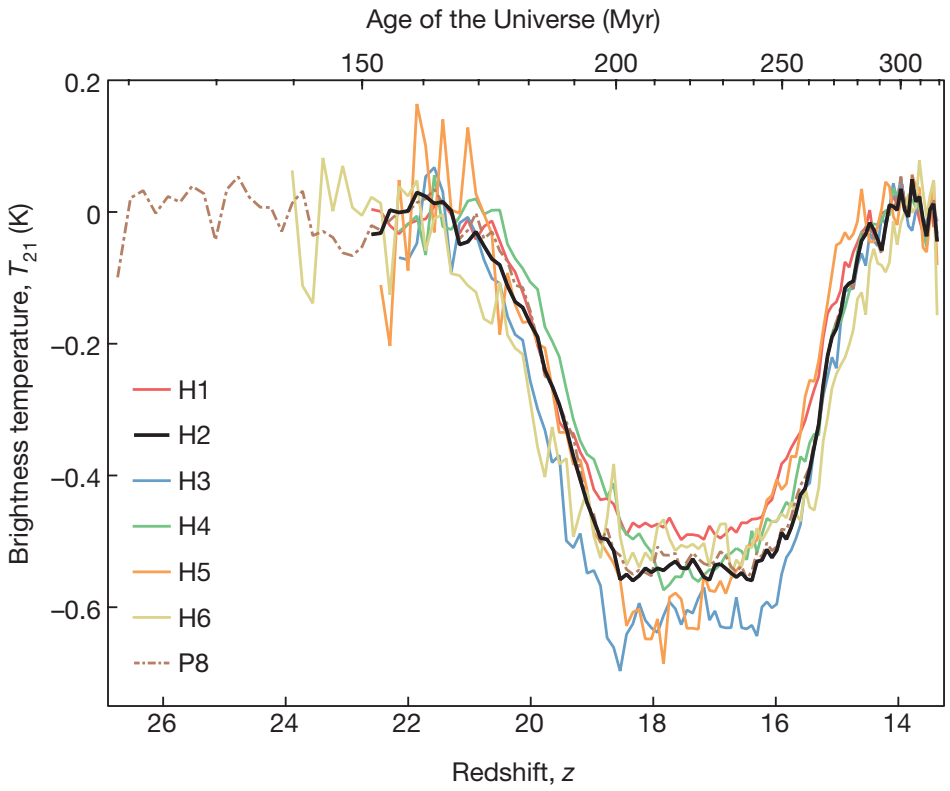


Differential brightness temperature

$$\delta T_b = \frac{T_b - T_{CMB}}{1+z} \approx \frac{T_s - T_{CMB}}{1+z}\tau$$

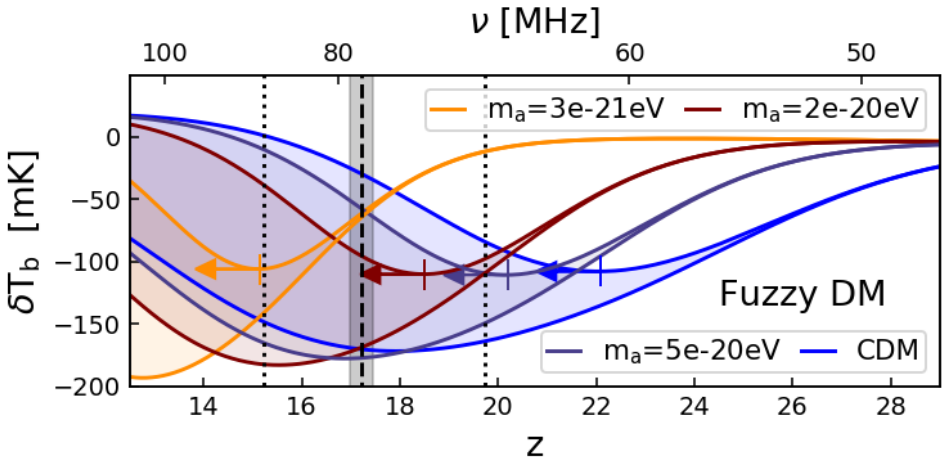
emission (T_s>Tcmb) or absorption (T_s<Tcmb)

Example: global brightness temperature by EDGES

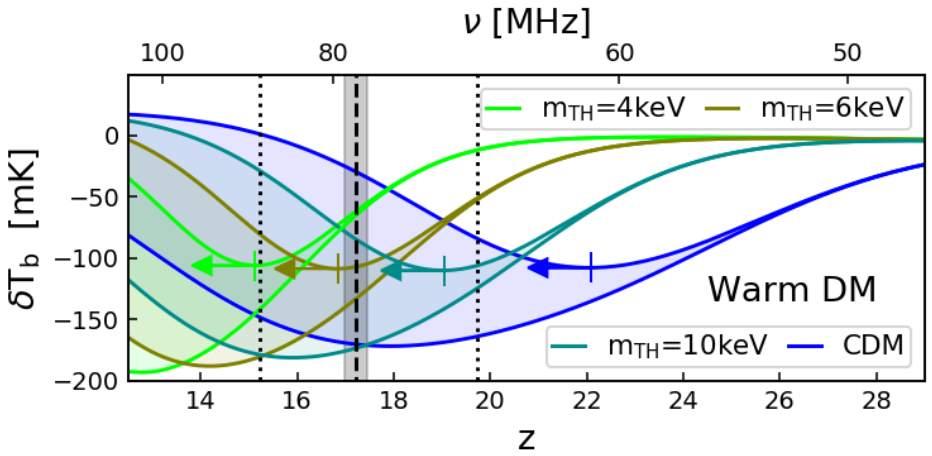


Bowman+(2018)

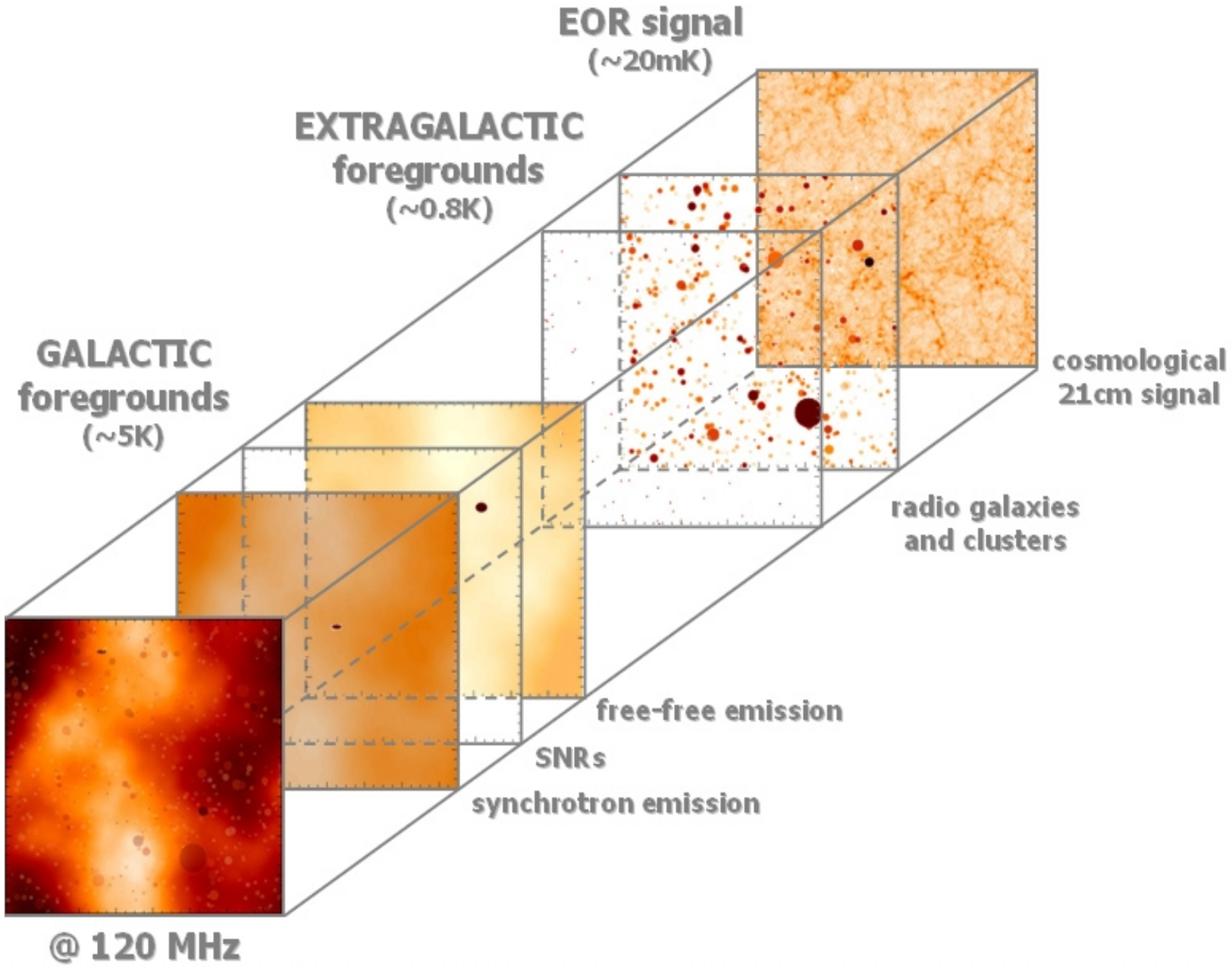
$$m_a \geq 8 \times 10^{-21} eV$$



Schneider (2018)



$$m_{WDM} \geq 6.1 keV$$



Jelic and Zaroubi

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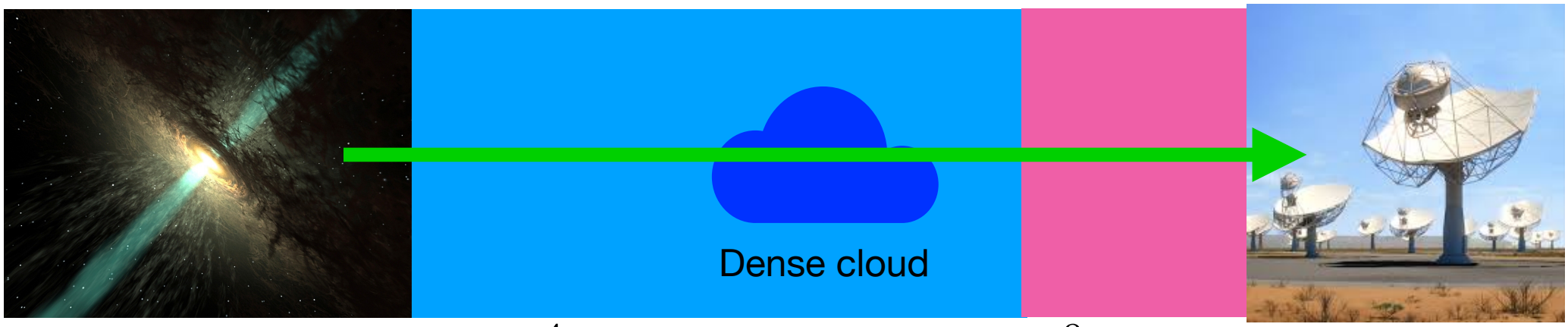
21cm forest

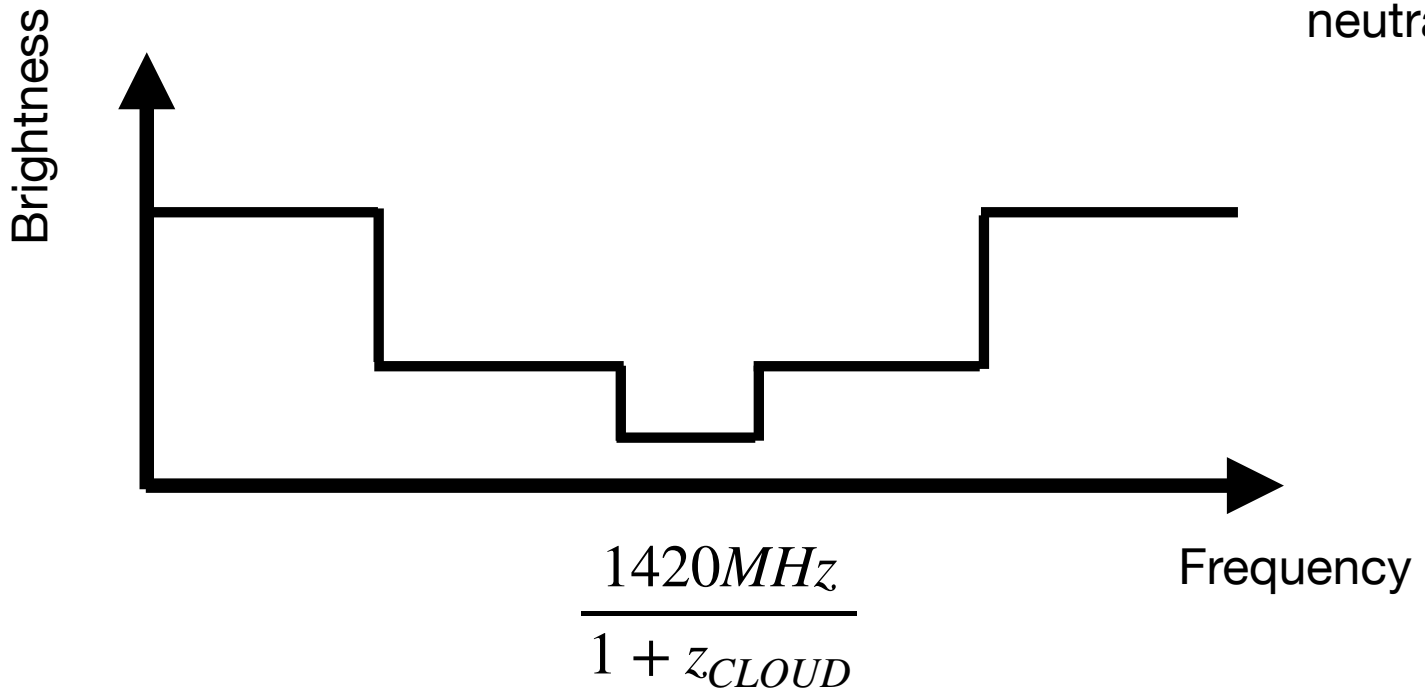
Neutral hydrogen

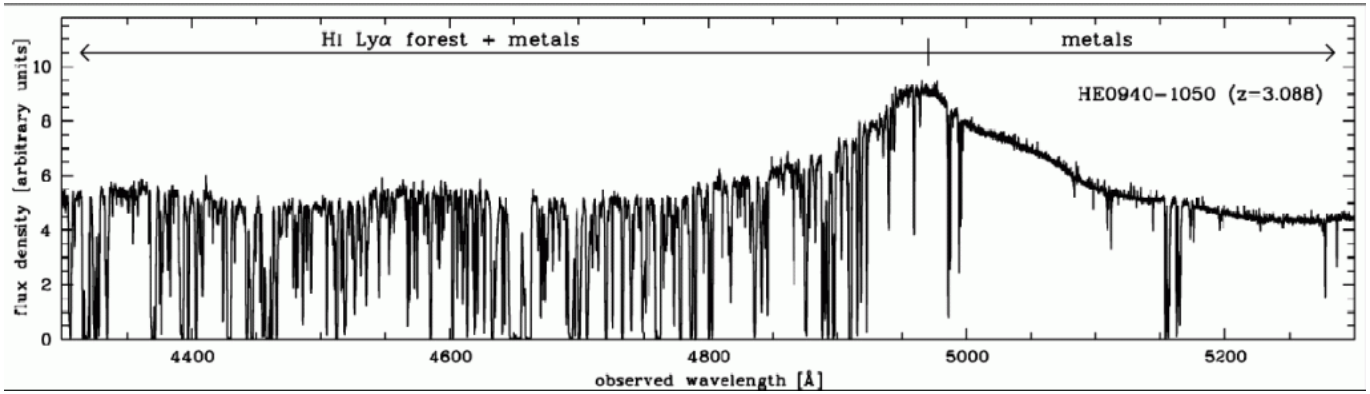
Hydrogen Ionized

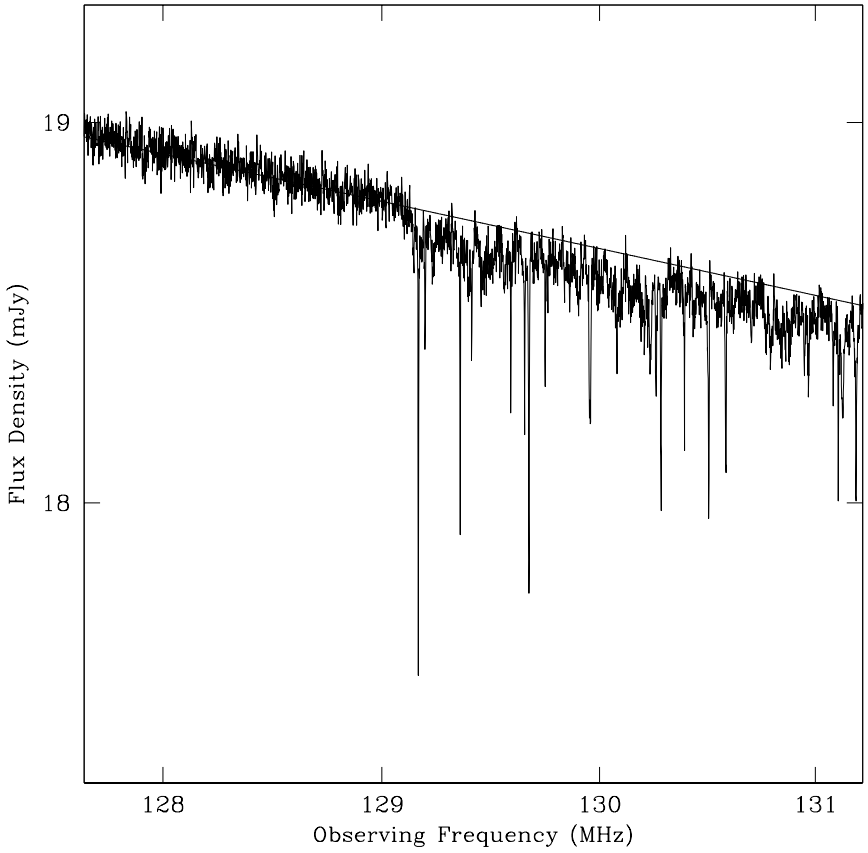


$$10^4 M_{sun} \lesssim M_{MiniHalo} \lesssim 10^8 M_{sun}$$

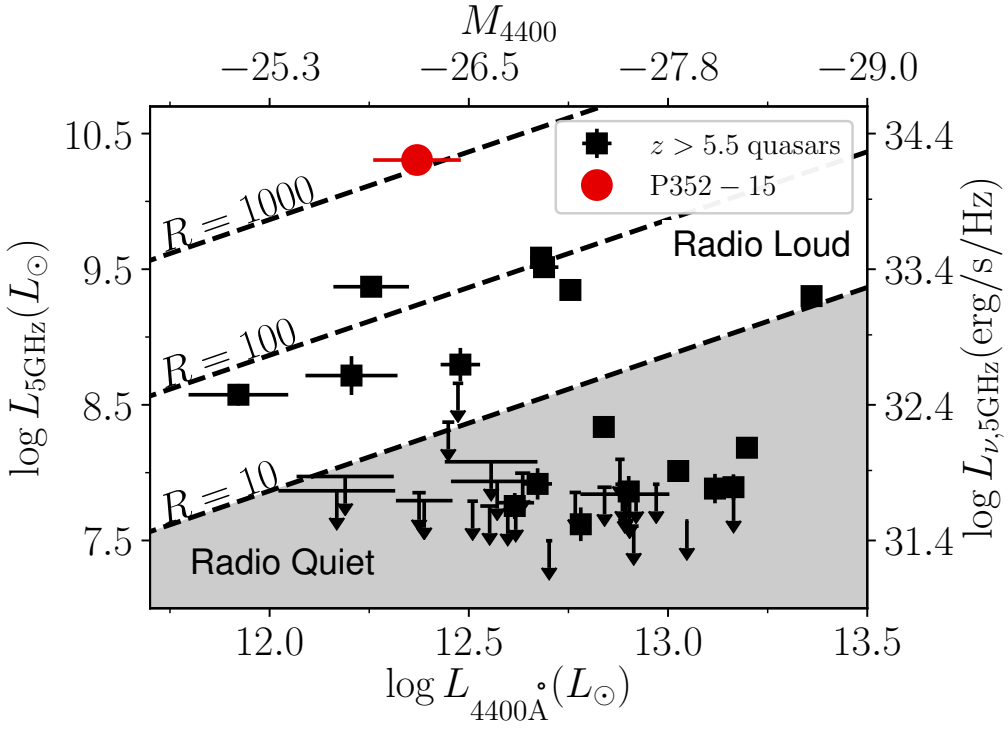
Absorption by neutral hydrogen







Carilli+ 2002



Banados+(2018)

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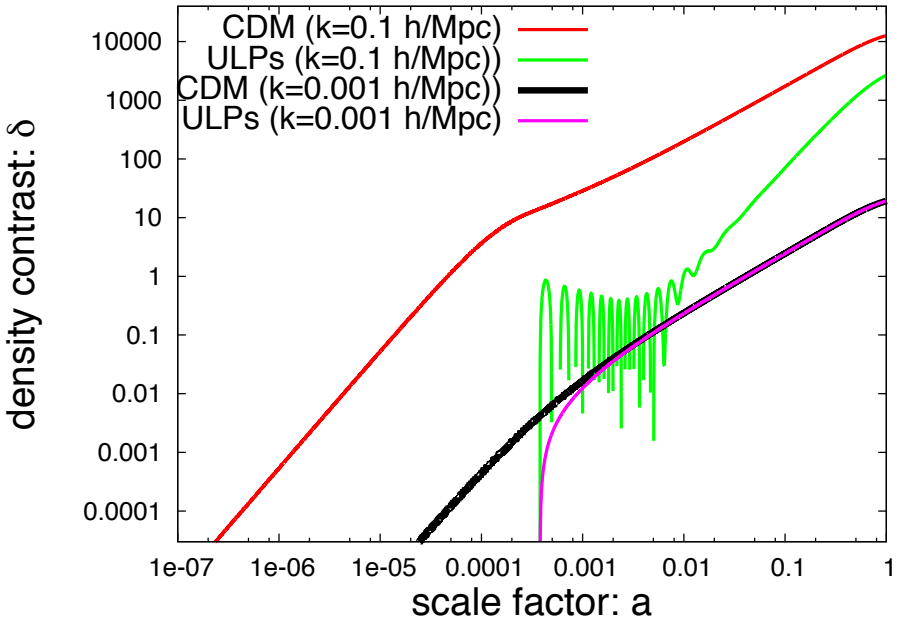
Model: ALP (Axion-like particles)
i.e. Ultra-light scalars

$$m_u : 10^{-10} - 10^{-33} eV$$

(String axiverse (Arvanitaki+(2009),
Fuzzy DM (Hu+(2000)…)

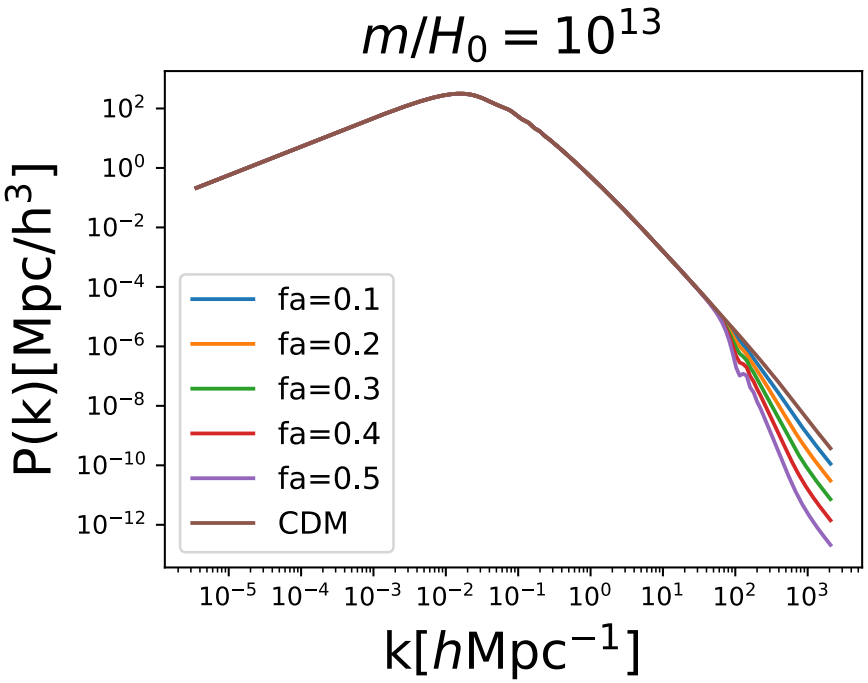
Two free parameters:

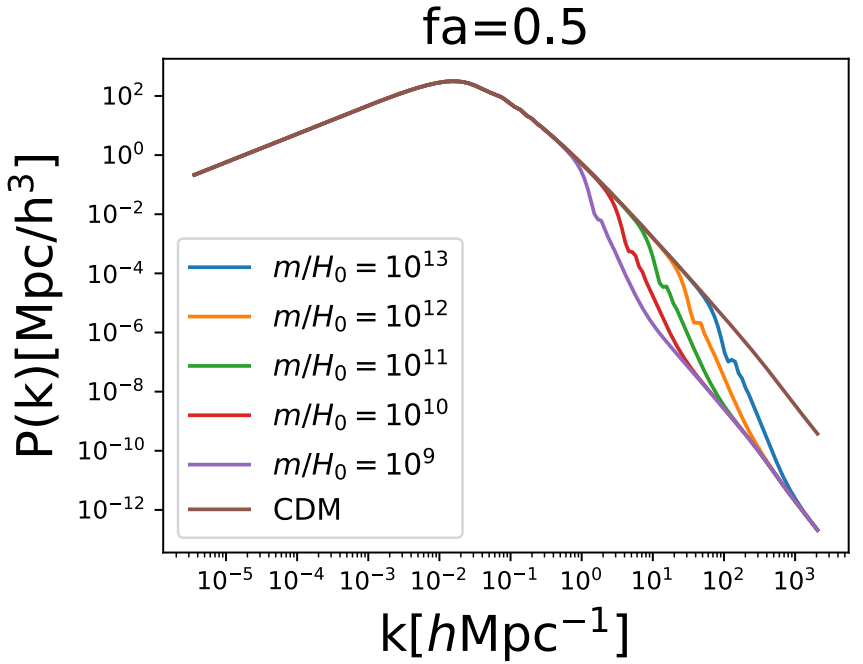
$$m_u, \quad f_u (\equiv \Omega_u / \Omega_{DM})$$



$m/H_0 = 10^5, f_a = 0.05$

KK, Mao, Ichiki, Silk (2013)





Shimabukuro, Ichiki, KK , to appear

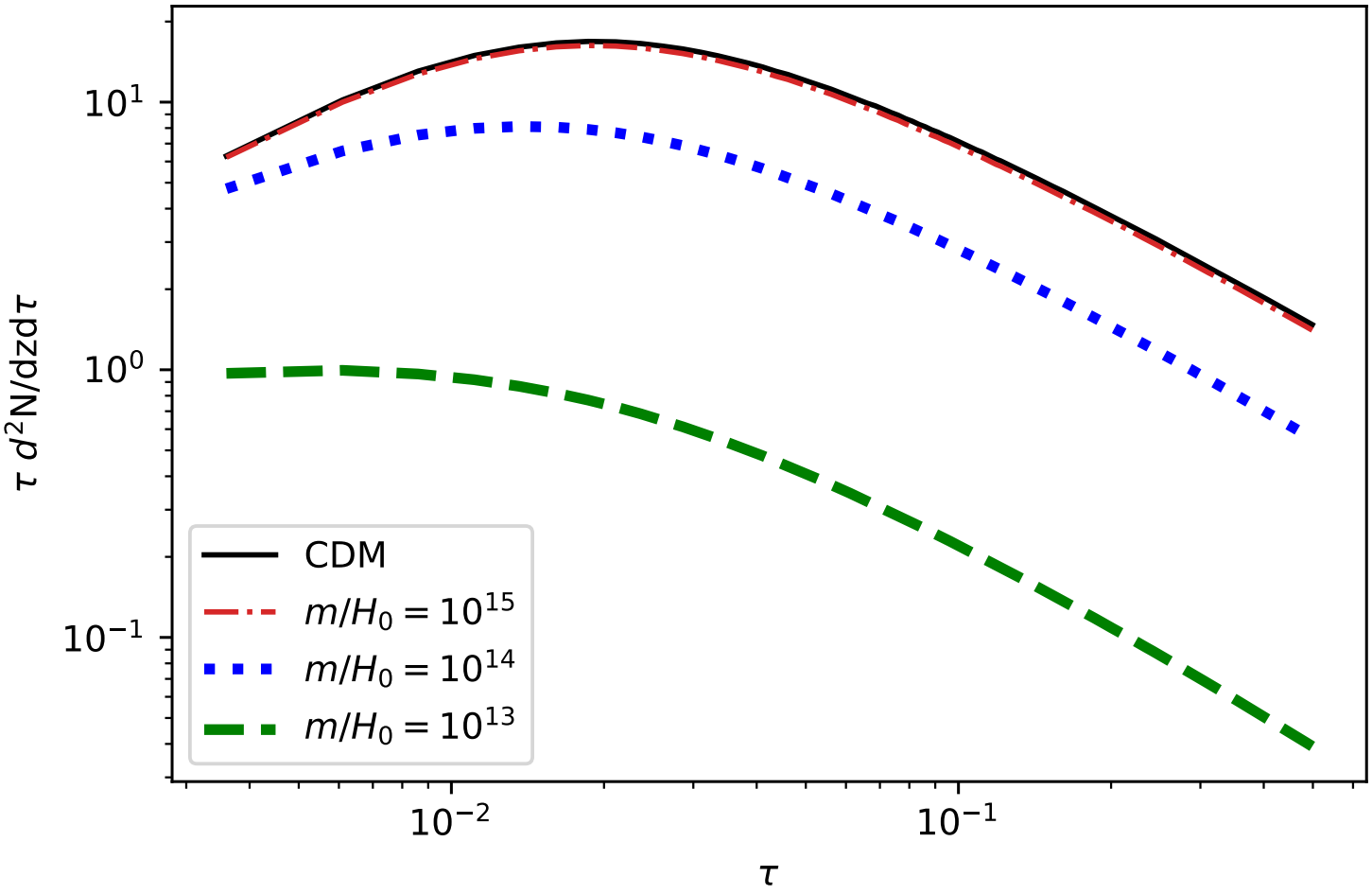
Total number of absorption lines

$$n = \int_{\tau_{min}}^{\infty} \frac{d^2N}{d\tau dz} d\tau \Delta z$$

21cm forest: $m_{FDM} \gtrsim 10^{-18} eV$

Ly-alpha: $m_{FDM} \gtrsim 10^{-21} eV$

Shimabukuro, Ichiki, Kadota (to appear)

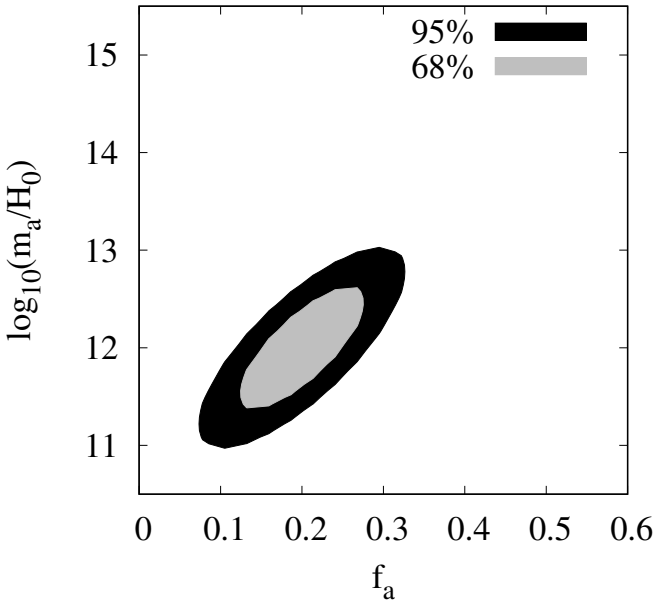


Error minimum at $f_u \sim 0.3$ & $m_u \sim 10^{-20} eV$

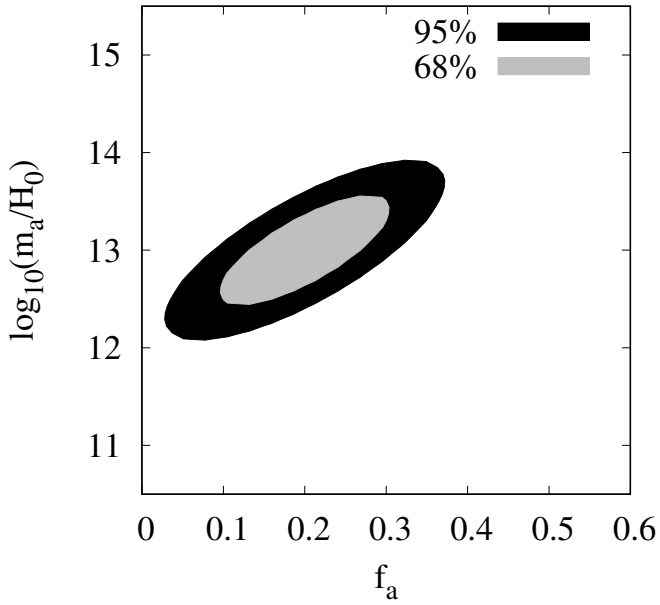
21cm forest can probe $50 \lesssim k \lesssim 10^3 Mpc$

$$k_{\rm J} \sim 3 \times 10^{-5} (m_u/H_0)^{1/2} [h/Mpc]$$

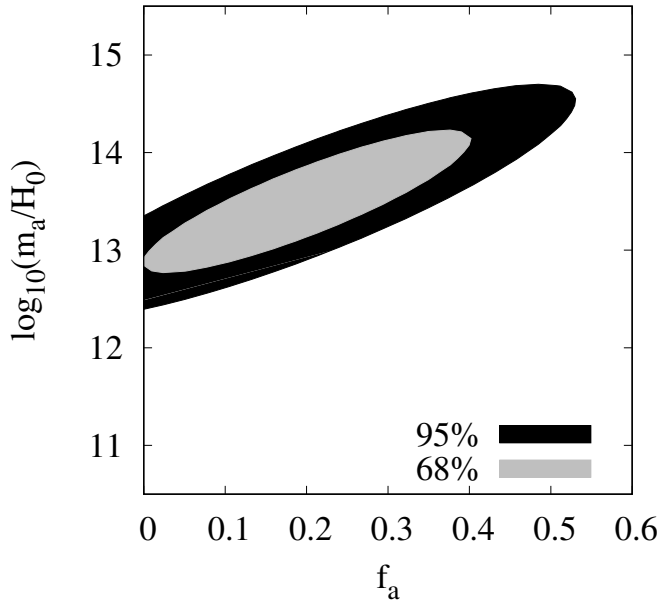
$log(m_a/H_0) = 12$



$log(m_a/H_0) = 13$



$log(m_a/H_0) = 14$



Shimabukuro, Ichiki, KK , to appear

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Summary:

21cm forest $m_{FDM} \gtrsim 10^{-18} eV$

Ly-alpha $m_{FDM} \gtrsim 10^{-21} eV$