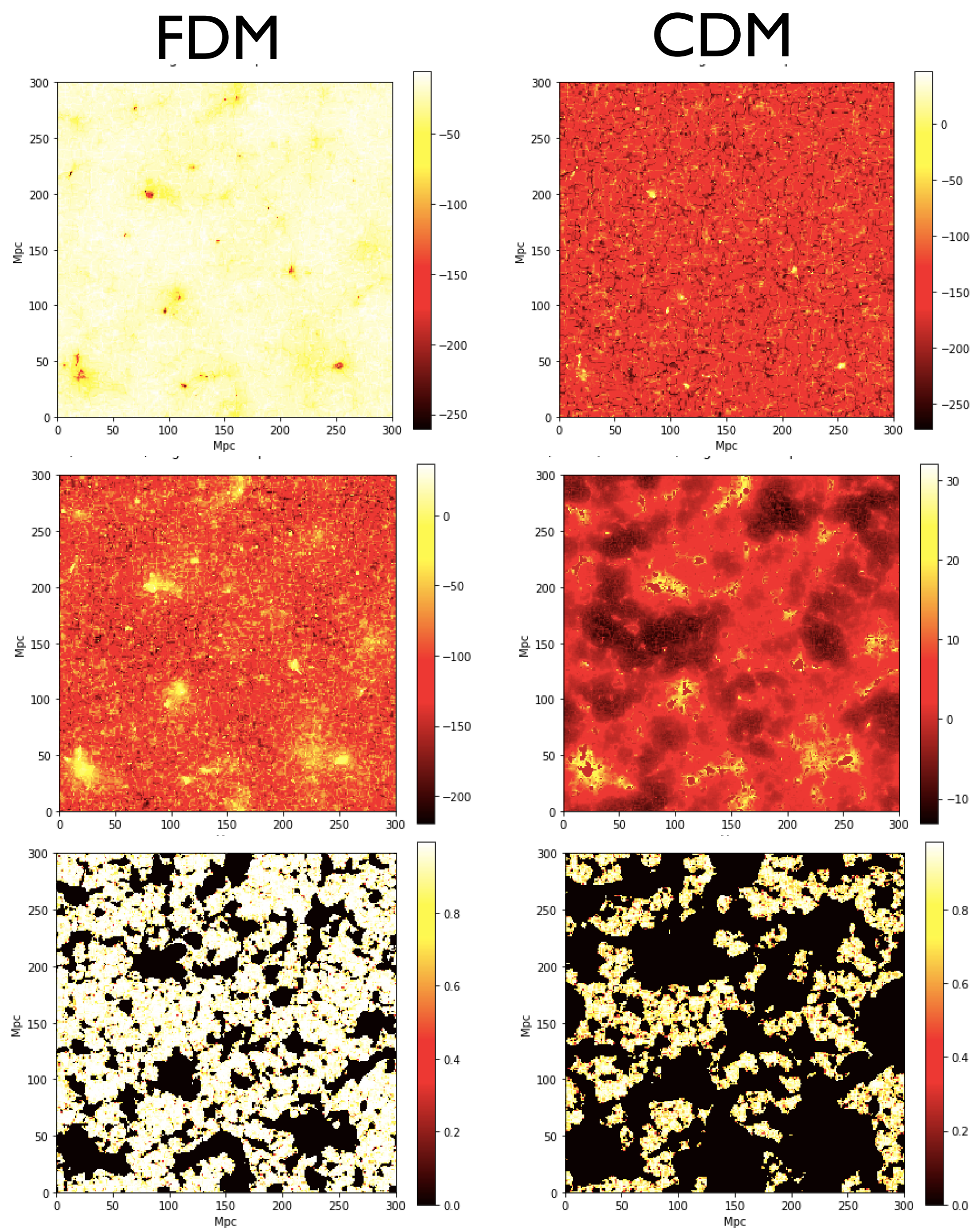
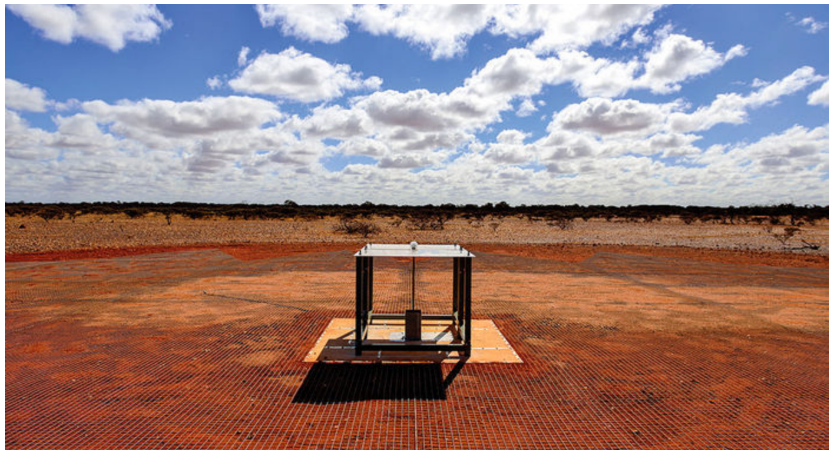
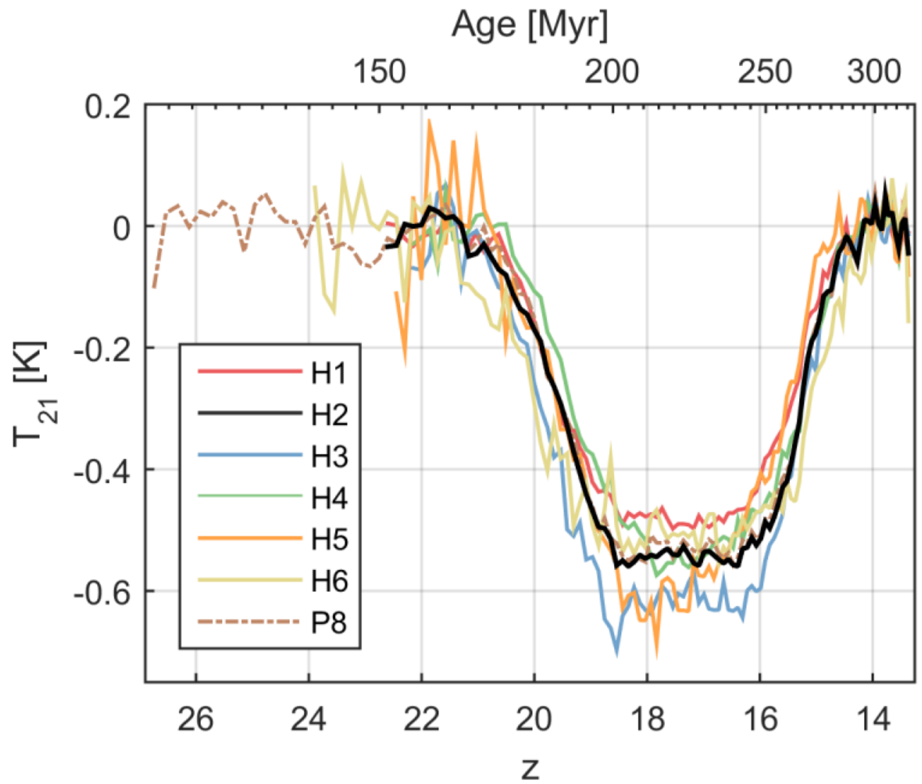






The 21 cm Signal and Fuzzy Dark Matter

McGill University Global 21 cm Workshop
October 7, 2019

Adam Lidz (University of Pennsylvania)

The Main Point…

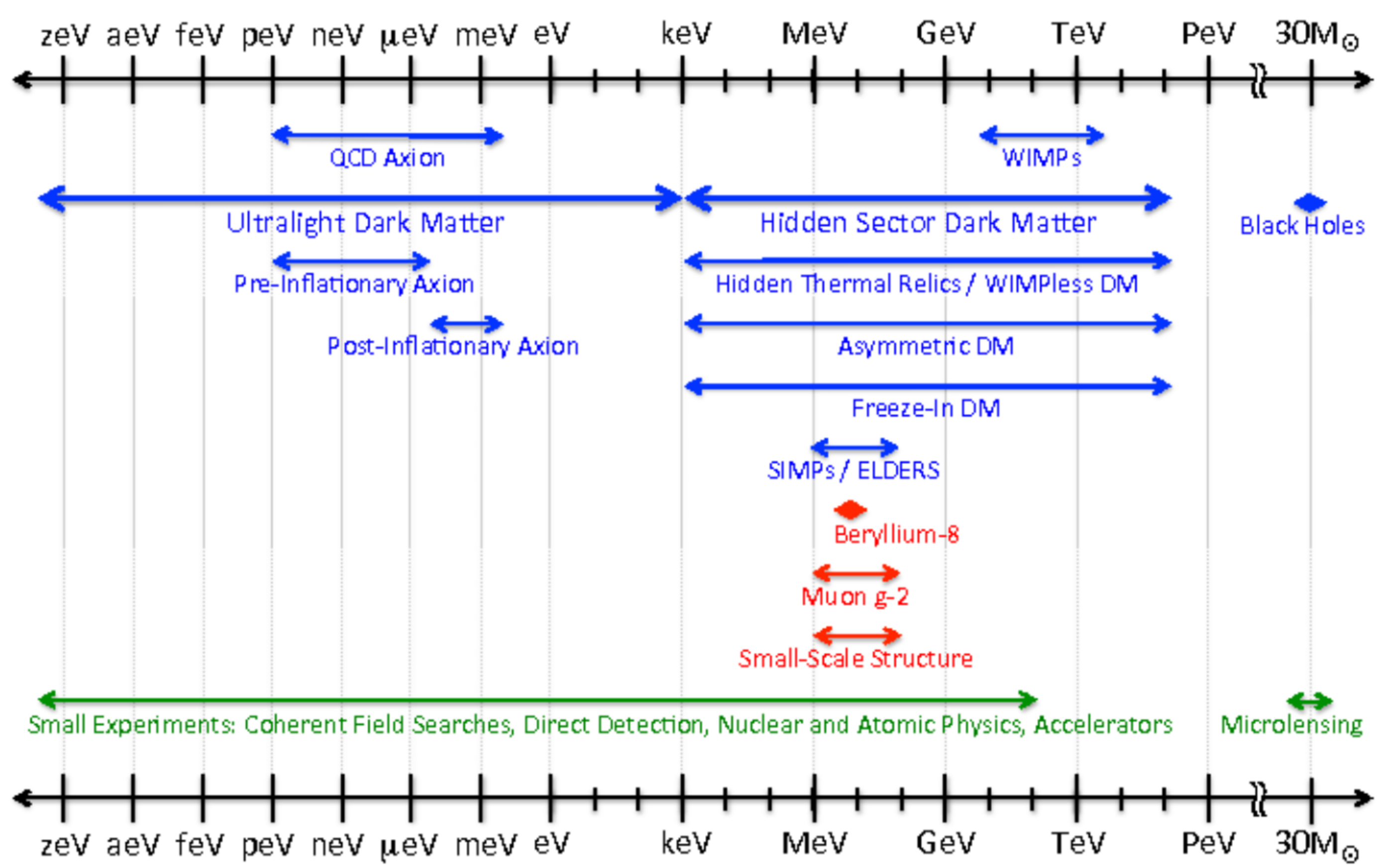
- The 21 cm signal times the onset of Cosmic Dawn and some of the earliest phases of structure formation.

- An early onset redshift yields tight constraints on interesting alternatives to Cold Dark Matter models in which small-scale structure is suppressed.

Dark Matter Candidates

- Current dark matter candidates in the literature span about 88 orders of magnitude in particle mass!
- This talk will focus on Fuzzy Dark Matter (FDM), the lightest candidate in this range with m~10^{-22} eV (e.g. Hu, Barkana, & Gruzinov 2000).

1 zeV = 10^{-21} eV ("zetta-eV")



US Cosmic Visions: Battaglieri+ 2017

FDM gives us another lamppost!

"I'm searching for my keys."

Fuzzy Dark Matter

- Suppose dark matter consists of ultralight bosons with $m \sim 10^{-22}$ eV.
- DeBroglie wavelength is ~ galactic scale.

$$\lambda_D = \frac{\hbar}{mv} \sim 2\,\mathrm{kpc}\frac{10^{-22}\,\mathrm{eV}}{m}\frac{10\,\mathrm{km/s}}{v}$$

- Heisenberg Uncertainty principle prevents confinement on scales smaller than ~ DeBroglie wavelength.
- Prevents dark matter particles from collapsing into small mass halos.
- On large scales (relative to the DeBroglie wavelength) behaves like CDM.

See e.g. Hu+ 2000, Hui + 2017

Motivation

- Ultralight scalar fields arise in many beyond the standard model of particle physics theories, e.g. string theory.

- Can naturally explain relic abundance (e.g. Hui+ 2017):

$$\Omega_{\rm axion} \sim 0.1 \left(\frac{F}{10^{17}\,{\rm GeV}}\right)^2 \left(\frac{m}{10^{-22}\,{\rm eV}}\right)^{1/2} .$$

- Help with small-scale CDM issues (and/or baryonic physics): missing satellites, cuspy halo, too-big-to-fail, etc…?

- *Makes distinctive testable predictions!*

Fuzzy Dark Matter and Initial Power Spectrum

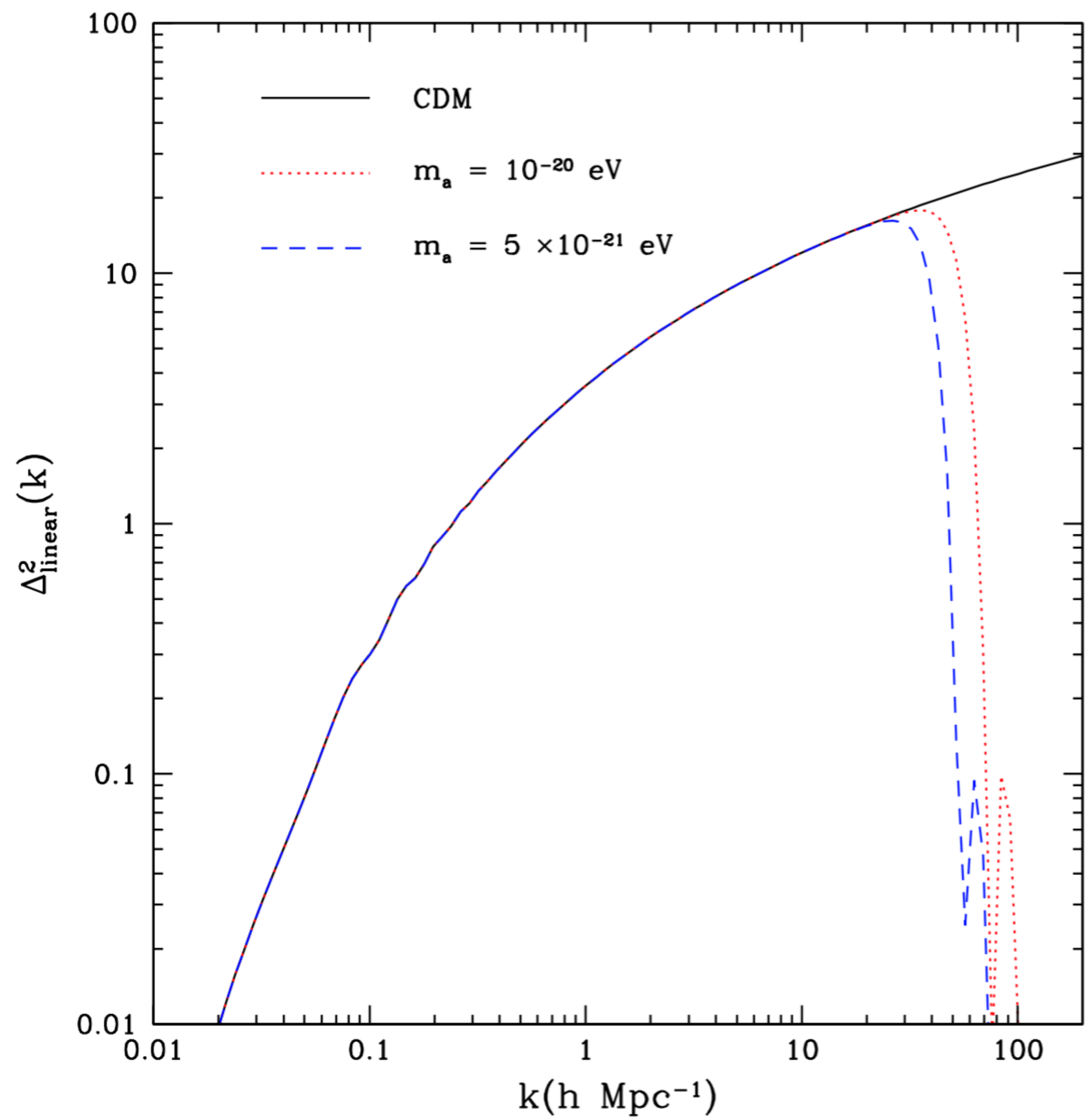
- Macroscopic DeBroglie wavelength leads to suppression of power below a Jeans scale:

$$\lambda_D \sim \lambda_{\rm Jeans} \sim \frac{\hbar}{mv}$$

$$v \sim \frac{\lambda_{\rm Jeans}}{t_{\rm dyn}} \qquad t_{\rm dyn} \sim \frac{1}{\sqrt{G\bar{\rho}}}$$

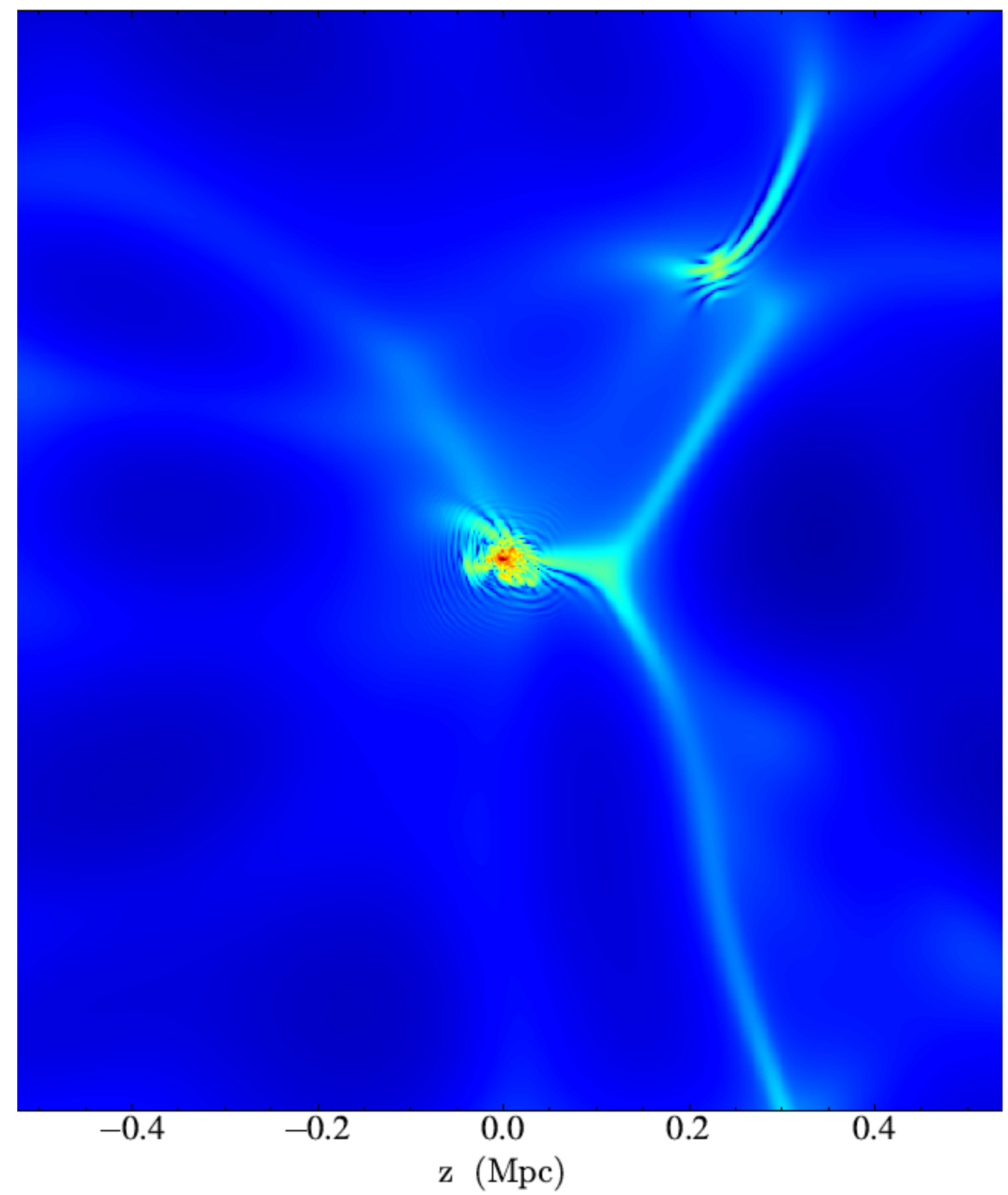
- More precisely, linear P(k) is reduced by a factor of two in FDM at a co-moving wavenumber:

$$k_{1/2} = 26\,{\rm Mpc}^{-1}\left(\frac{m}{5\times10^{-21}\,{\rm eV}}\right)^{4/9}$$



Halo Mass Function in FDM?

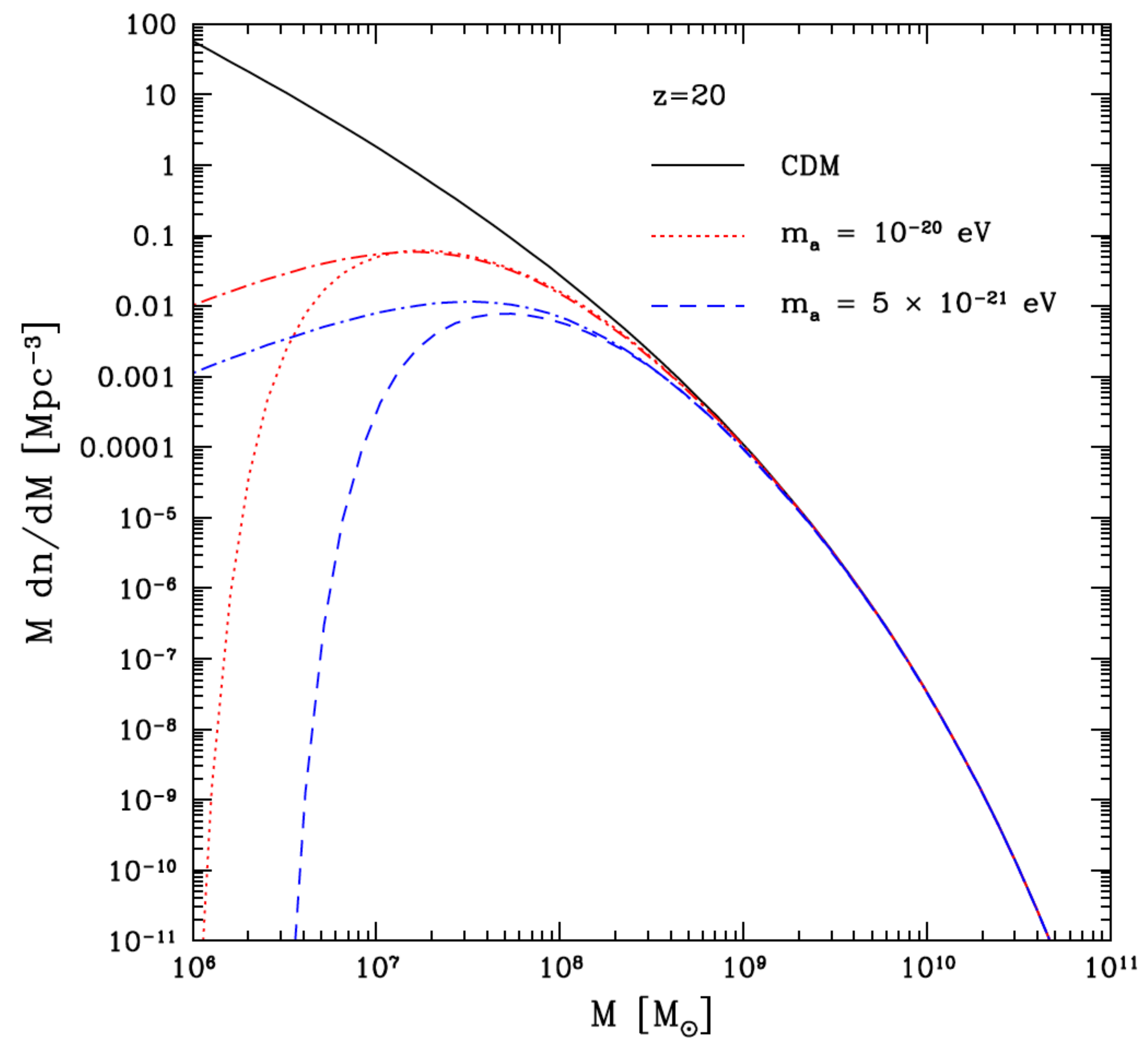
- FDM modifies dark matter dynamics as well as initial conditions.
- Challenging to simulate because one needs to resolve ~ DeBroglie scale everywhere!
- A lot of recent progress, but we don't know exactly what the mass function is in FDM!



Li+ 2018

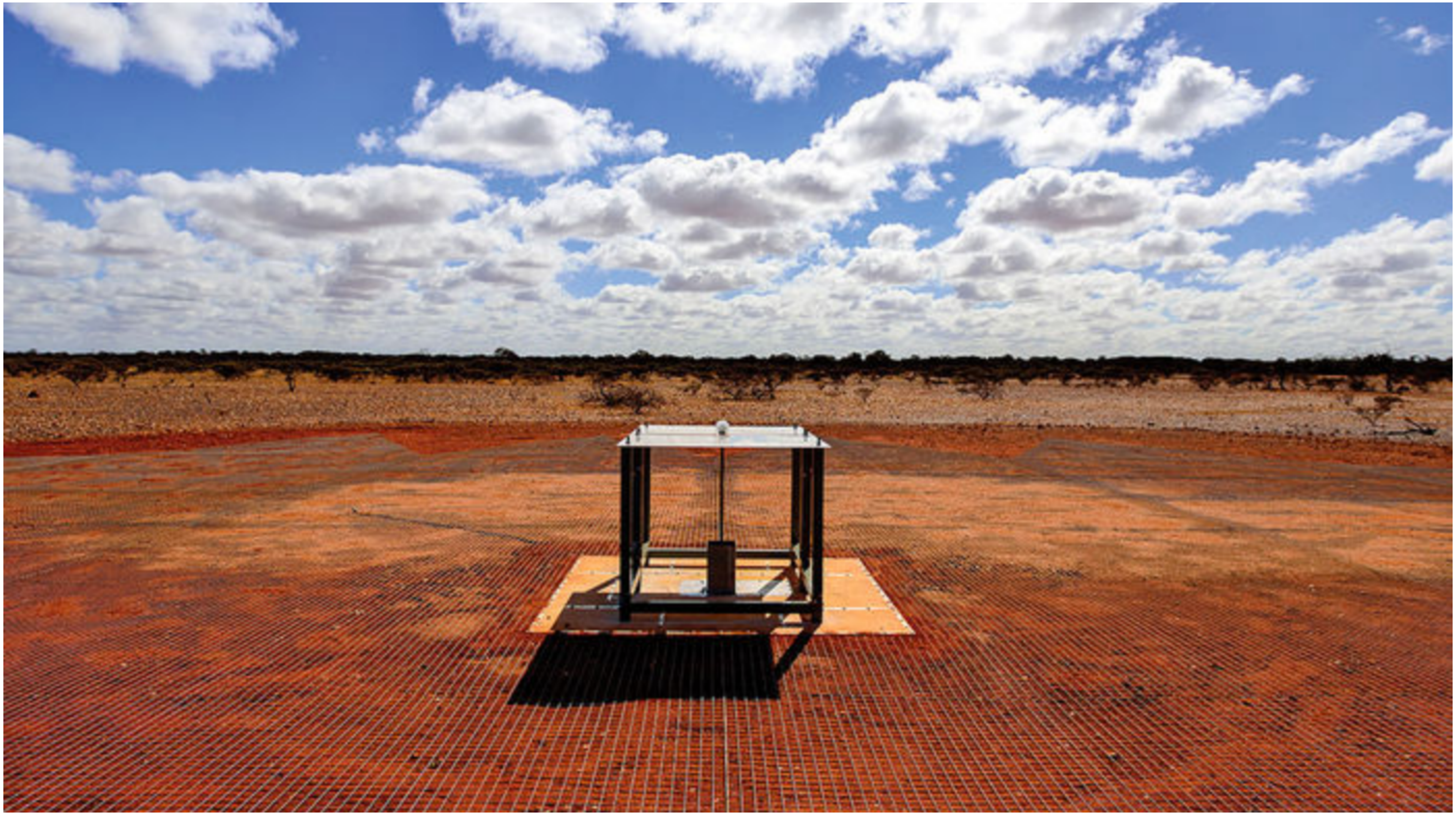
Mass Function Suppression near Cosmic Dawn

- Suppression in abundance of dark matter halos near Cosmic Dawn epoch.
- Likely to delay onset redshift.
- Dotted lines: model including only initial condition suppression (Schive+2016).
- Dashed lines : semi-analytic model intended to also roughly account for FDM dynamics (Marsh & Silk 2014)



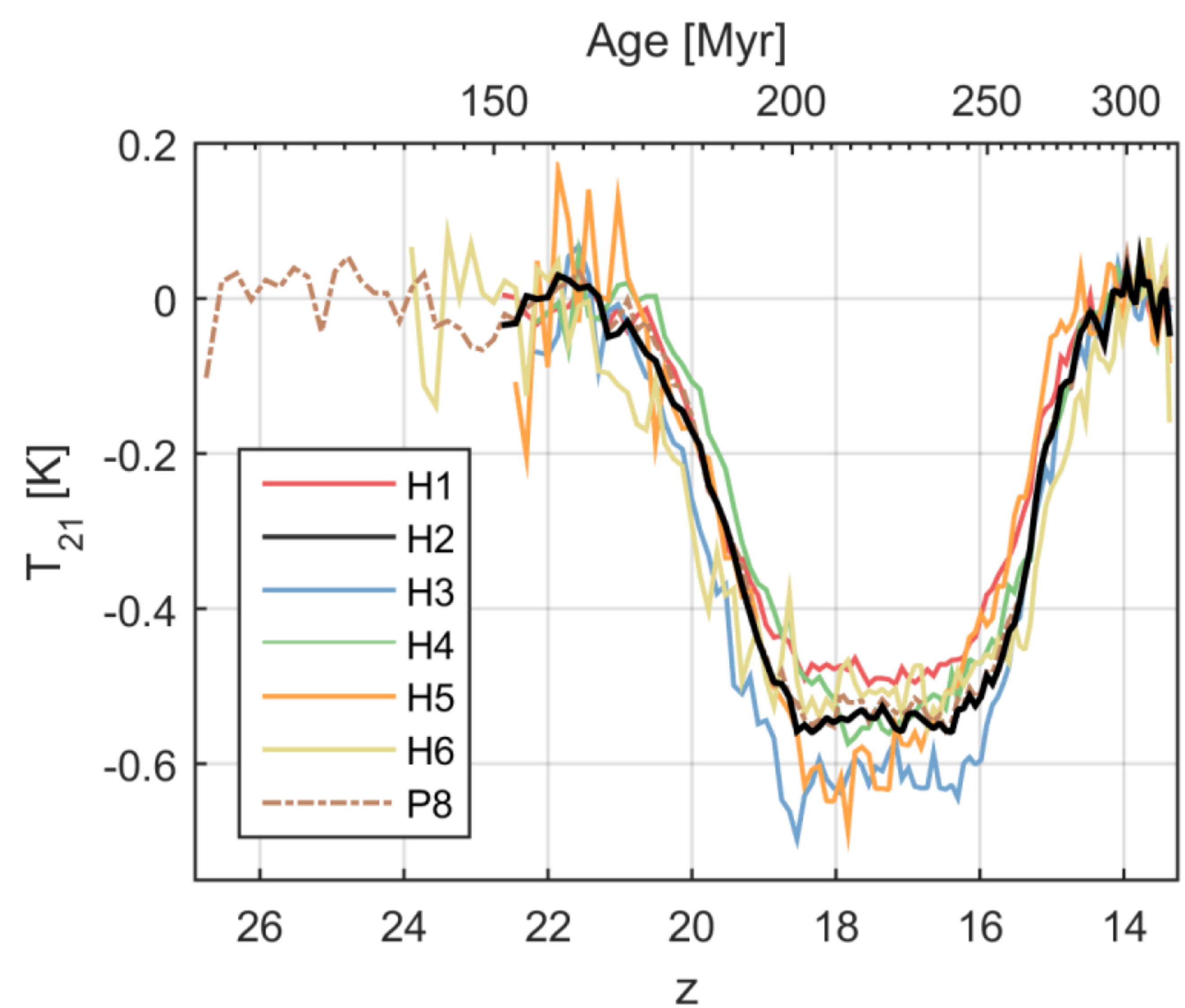
Lidz & Hui 2018

Enter EDGES and the global 21 cm signal



EDGES Absorption Feature

- Claimed absorption feature in sky-averaged radio spectrum!!!
- Attributed to neutral hydrogen absorption at z~15-20.



Bowman+ 2018

EDGES is surprising (if real)…

- Taken at face value, depth requires: mechanism to "super-cool" the gas and/or prominent radio background at z~20.
- A significant Ly-a photon background at z~20 to couple the spin temperature to the gas temperature.
- This requires significant early star-formation, without heat input from early X-rays, cosmic rays, weak shocks, etc..
- The flat bottomed feature requires a delicate balance between heating/cooling over Δz~5.
- Sharp evolution on both sides of the flat-bottom.

Implications for FDM?

- Require ~ 0.1 Ly-alpha photons per hydrogen atom at z~20 to break equilibration of spin temperature to CMB temperature. This is needed to make HI visible against the CMB!
- Need early halo formation, star formation to achieve this Ly-a background! Hard to meet this requirement with FDM!
- We avoid modeling the full shape of the signal and assume that the Wouthuysen-Field coupling $x_\alpha \sim 1$ at z~20.

Lidz & Hui (2018)

Implications for FDM

- Calculate Ly-a specific intensity assuming UV emissivity in CDM/ FDM traces time derivative of halo collapse fraction:

$$\epsilon \propto \frac{df_{\rm coll}(> M_{\rm min}, z)}{dt}$$

- Assume halo-mass independent star-formation efficiency, conservatively $f_* <= 0.05$ in halos above a minimum mass M_{min}.

- Assume 9690 between Ly-a and the Ly-limit frequency are produced per stellar baryon (e.g. Barkana & Loeb 2005).

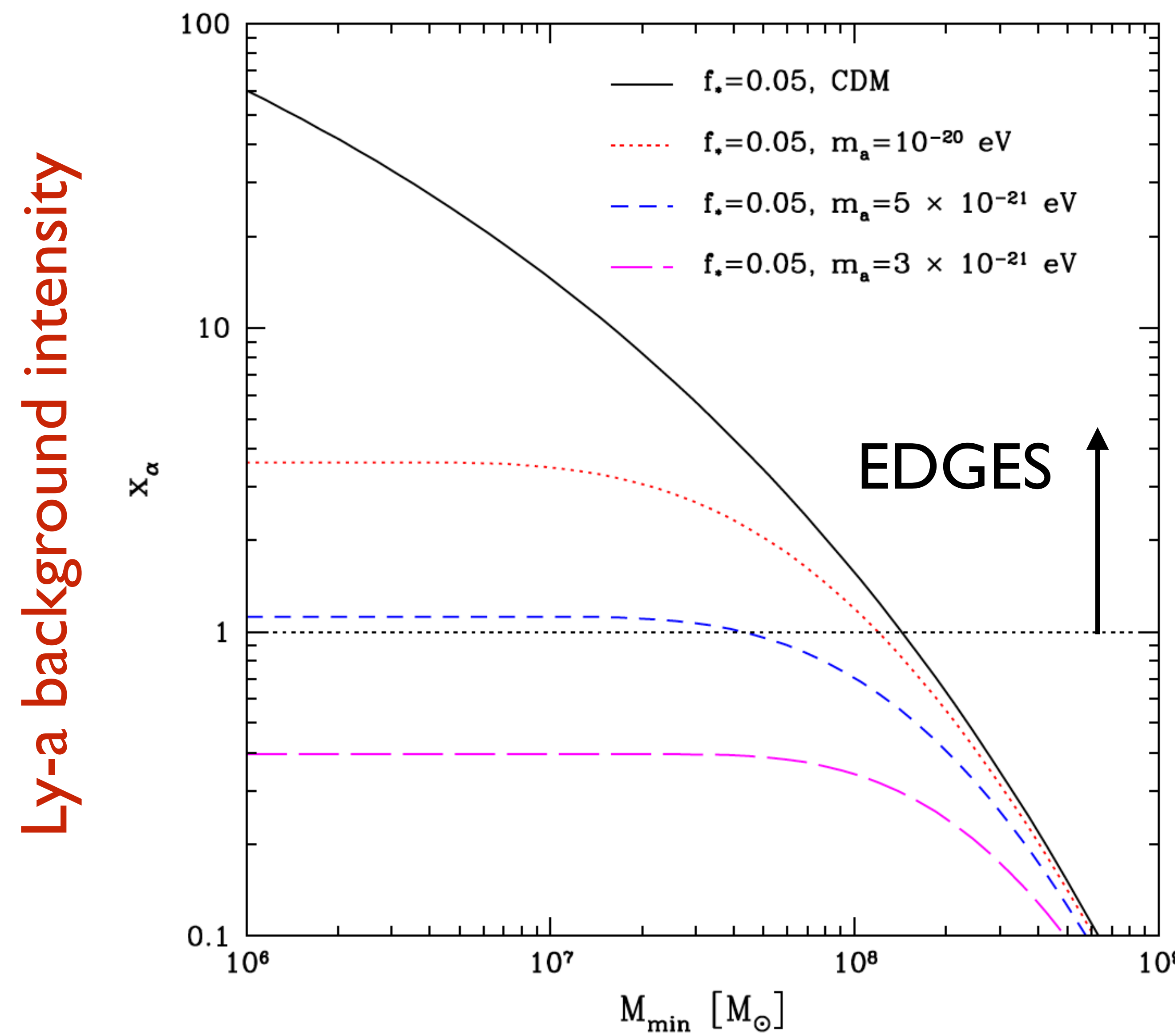
Lidz & Hui (2018)

EDGES and Fuzzy Dark Matter

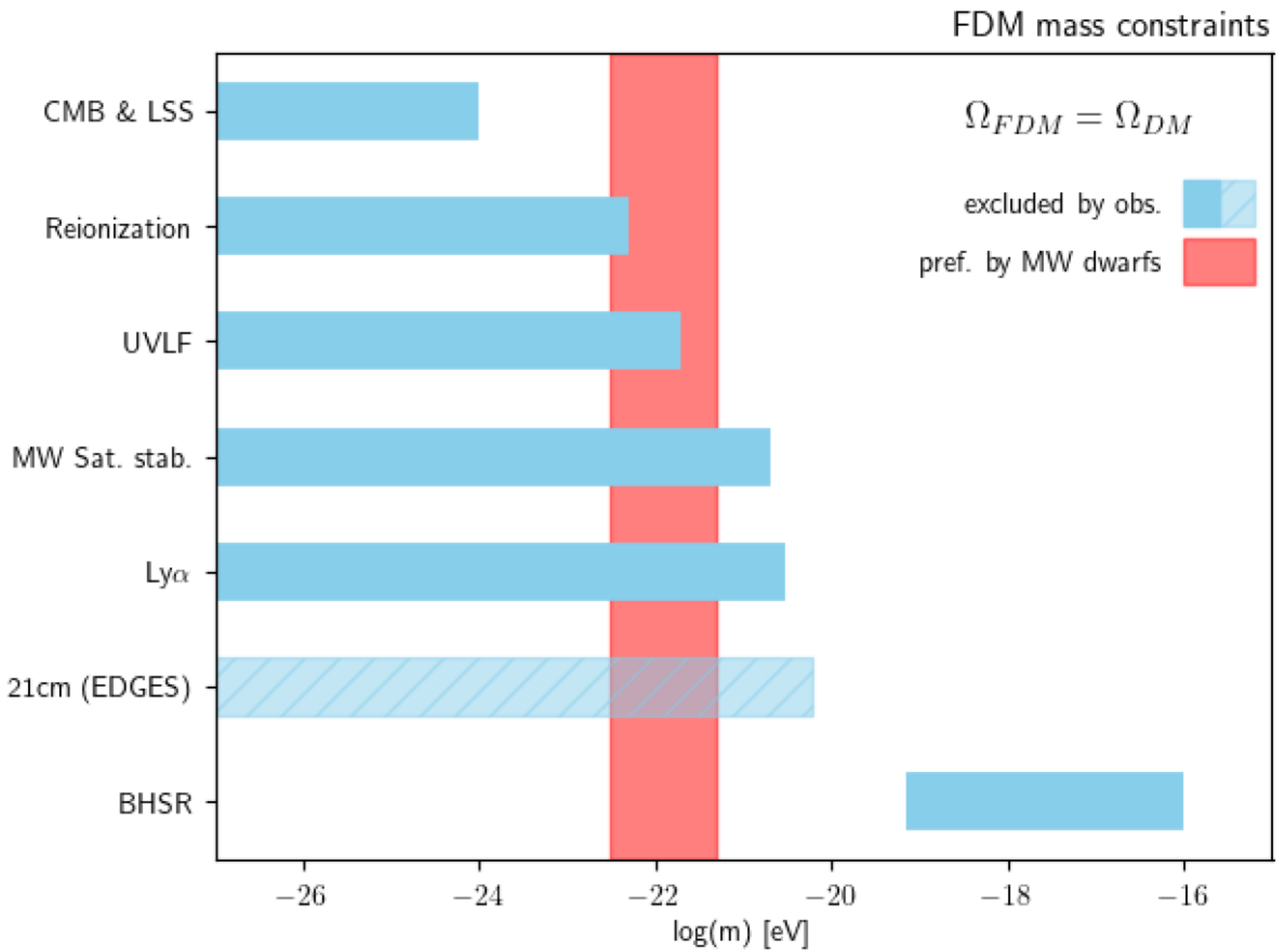
- In order to couple the spin temperature to the gas temperature via WF effect at z~20, require ~0.1 Ly-a photons per hydrogen atom.

- Strongly constrains any model where the formation of small mass halos is suppressed such as fuzzy or warm dark matter.

Lidz & Hui 2018



Minimum halo mass hosting star-formation



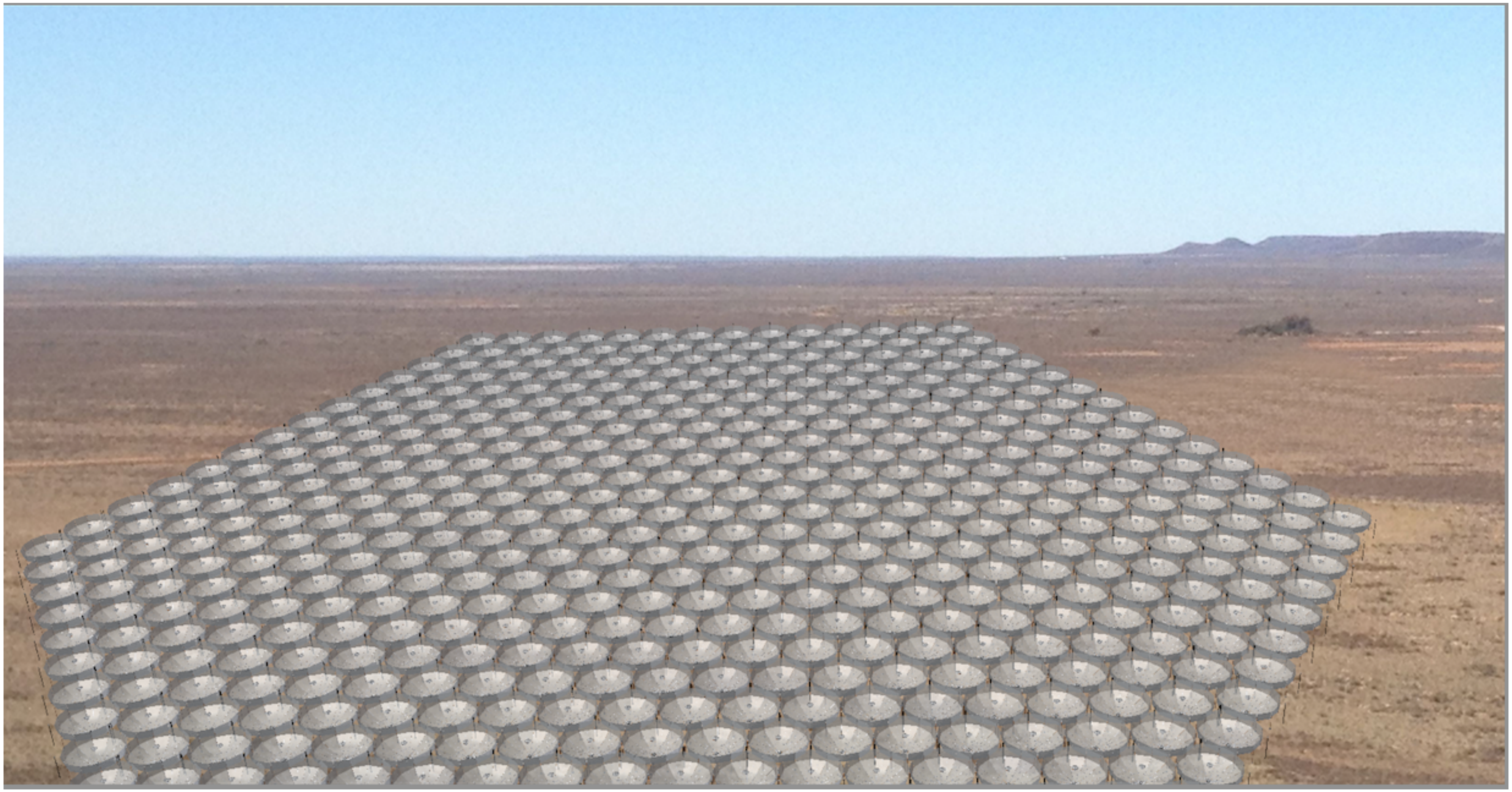
Credit: Schwabe 2018

How about Warm Dark Matter?

- In WDM, free-streaming suppresses small scale structure. By matching suppression scale in linear P(k) we can roughly determine WDM constraint.

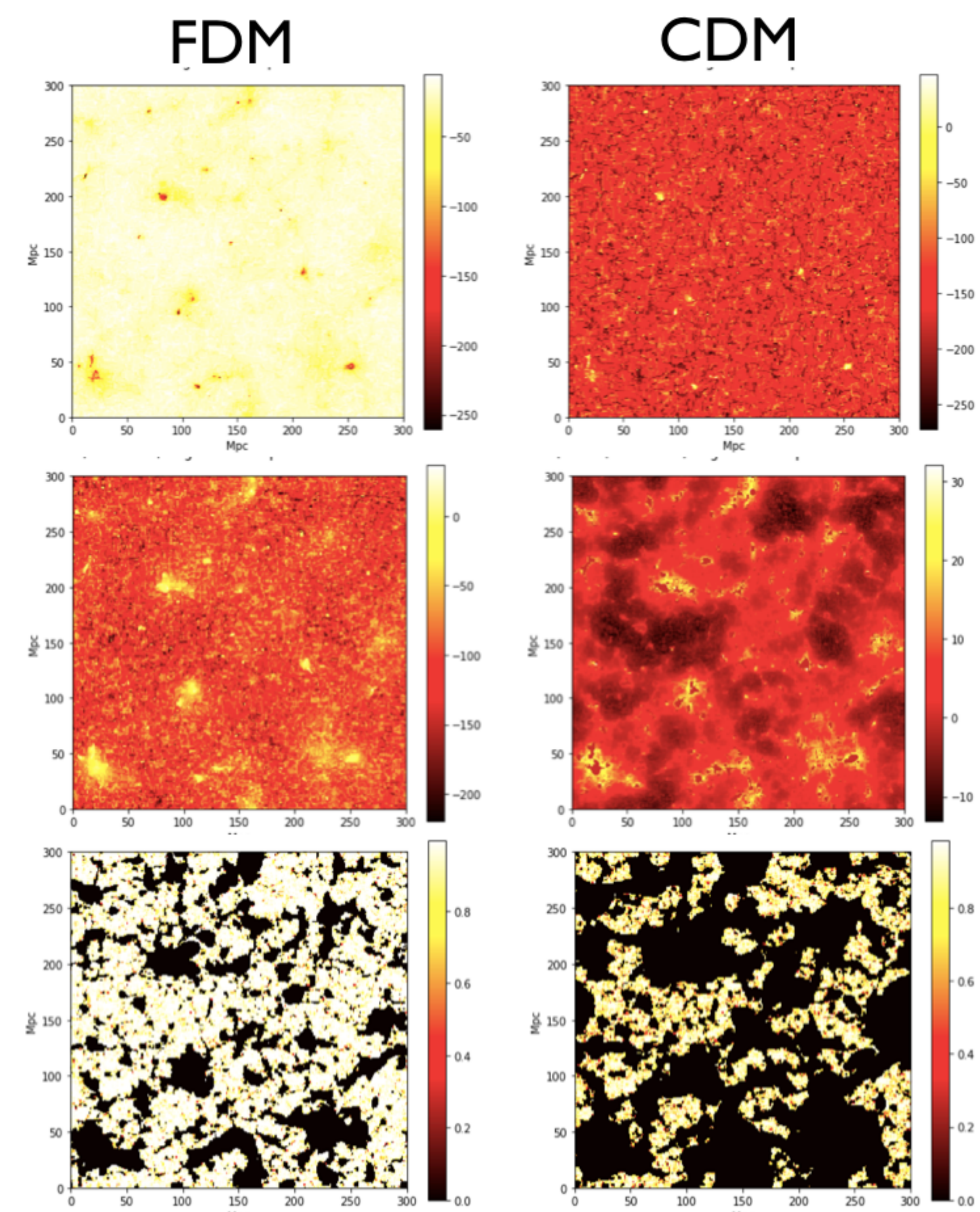
- For thermal relic WDM, the corresponding limit from EDGES is m_{wdm}>= 5 keV (see also e.g. Safarzadeh+ 2018, Schneider 2018).

What about the 21 cm Fluctuation Signal in FDM?



Delay in structure formation leads to interesting signatures in 21 cm fluctuations and power spectra

- Should lead to interesting FDM detections or constraints with HERA (work in progress).
- Different systematics than global 21 cm experiments.
- Help break degeneracies with f_*.



Jones+…,AL (in prep)

Conclusions

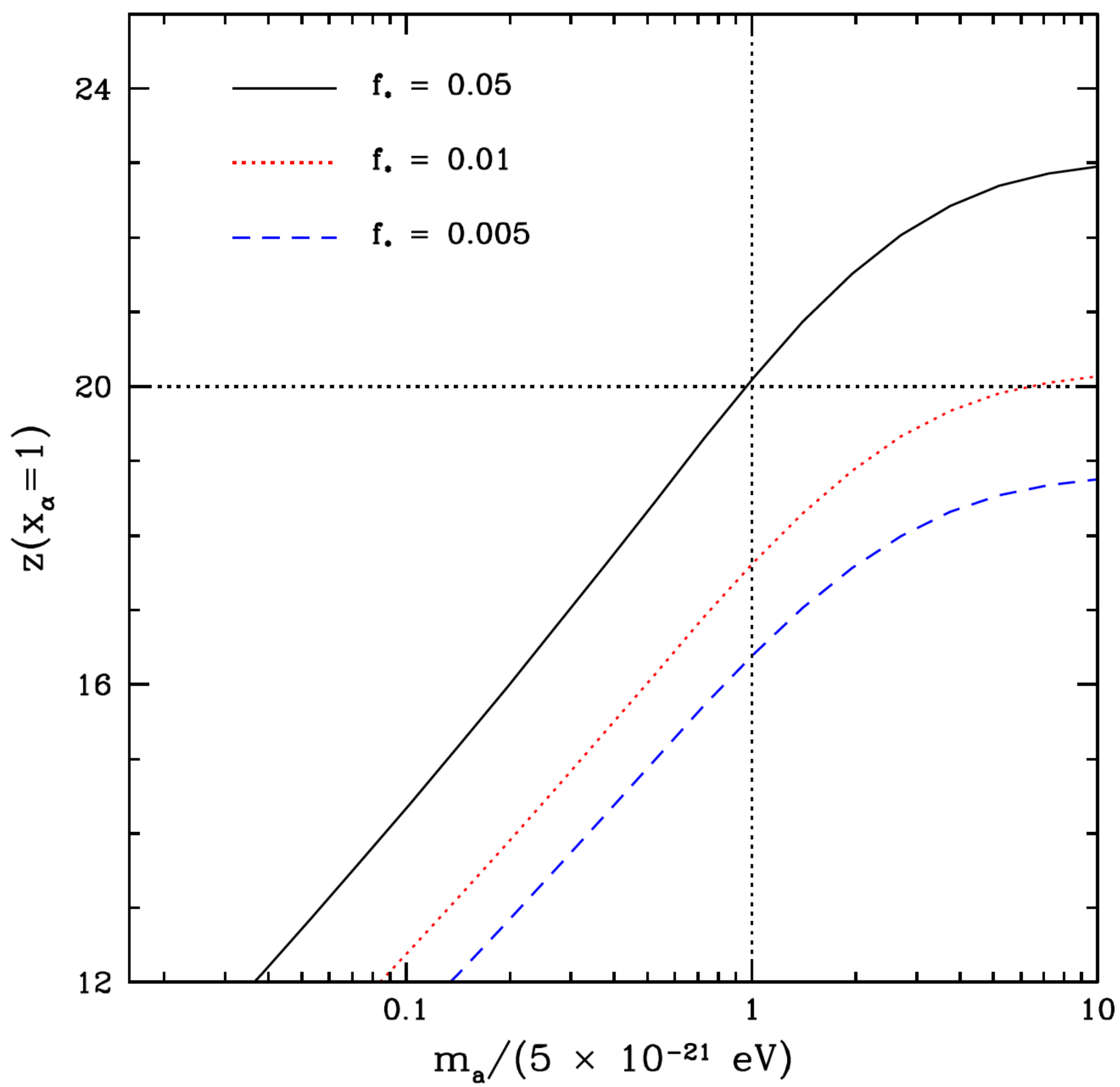
- The 21 cm signal marks the timing of first structure formation, which helps constrain dark matter properties.

- If EDGES is real and the Ly-a background reaches ~0.1 photons/ hydrogen atom by z~20, this implies the tightest constraints to date on Fuzzy Dark Matter.

- Future 21 fluctuation measurements from e.g. HERA provide an interesting cross-check here, and should help in breaking parameter degeneracies.

Sensitivity to Assumptions

- Redshift at which coupling is achieved vs. FDM mass lower limit (for different star formation efficiencies.)
- This shows how the bound would relax if future refined measurements find that WF coupling is achieved at lower redshifts…
- Also how the constraint sharpens if f* is smaller.



Lidz & Hui 2018