Probing Ultra-light Axion Dark Matter from 21cm Tomography (arXiv:2108.07972)

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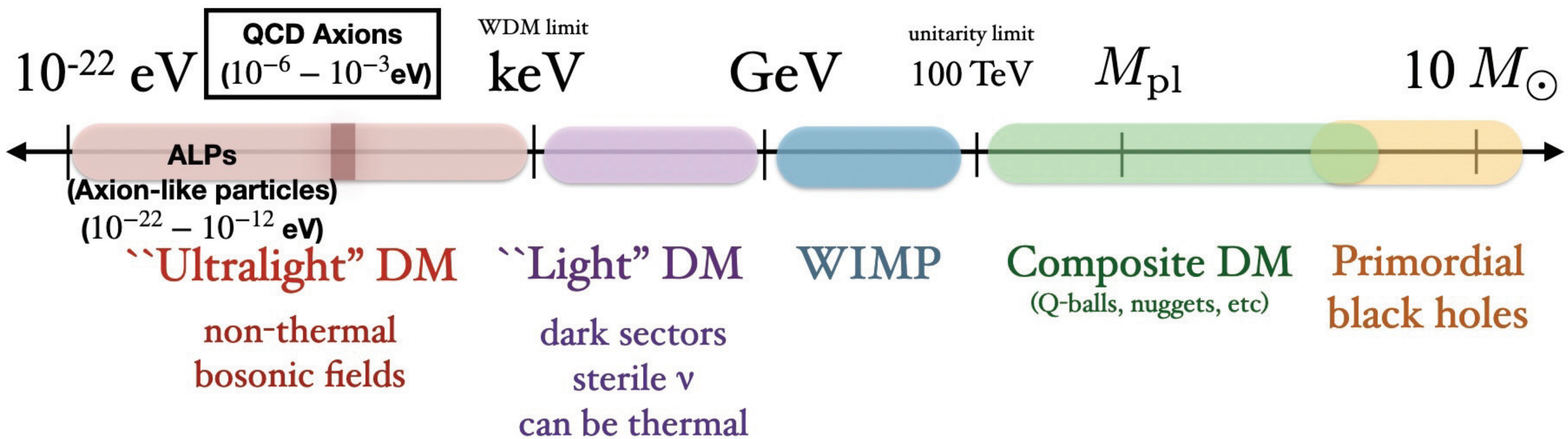
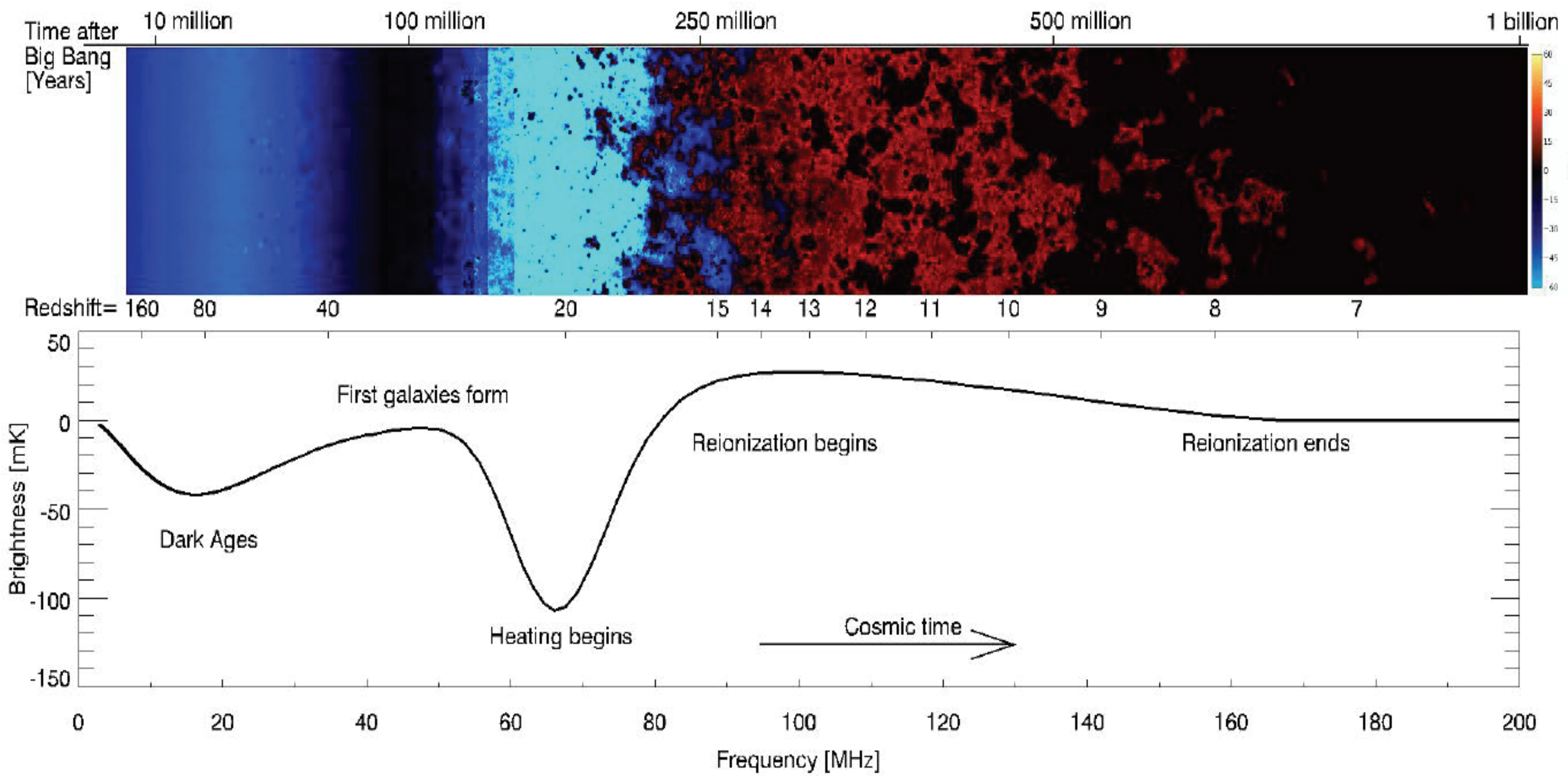


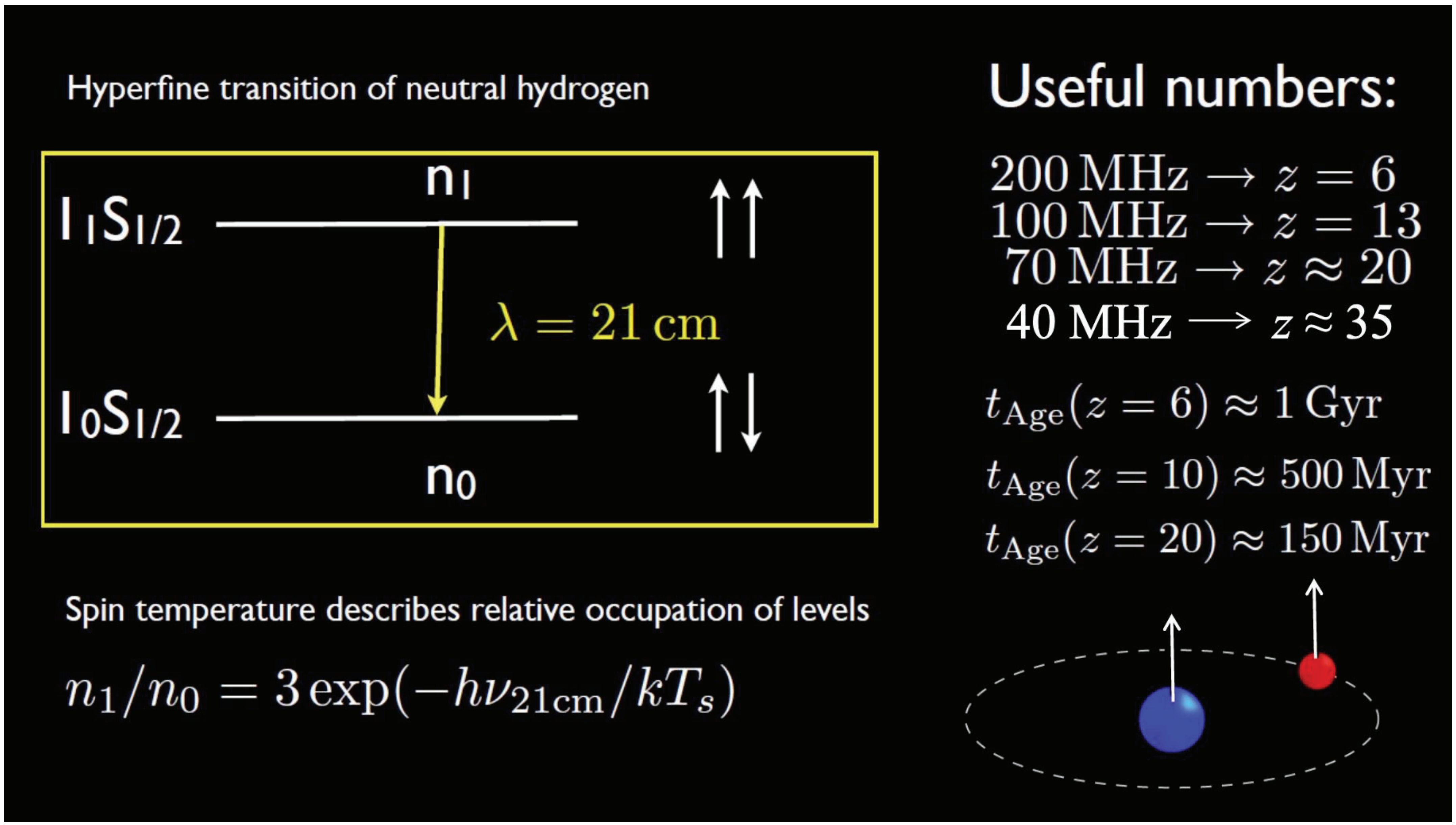
Survey Science Group Meeting
15/02/2022

21cm Intensity Mapping

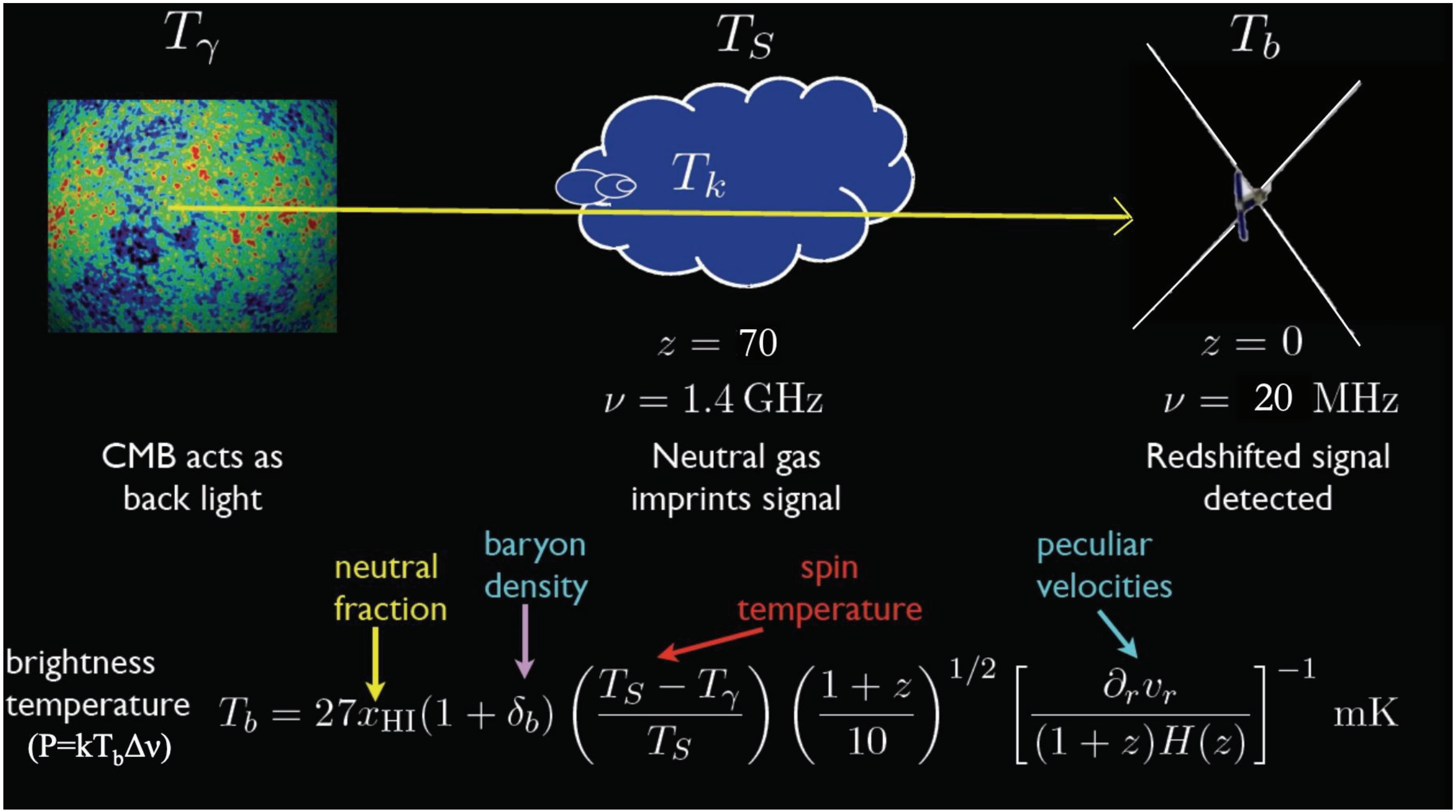
Cosmic Reionization History



21cm Intensity Mapping

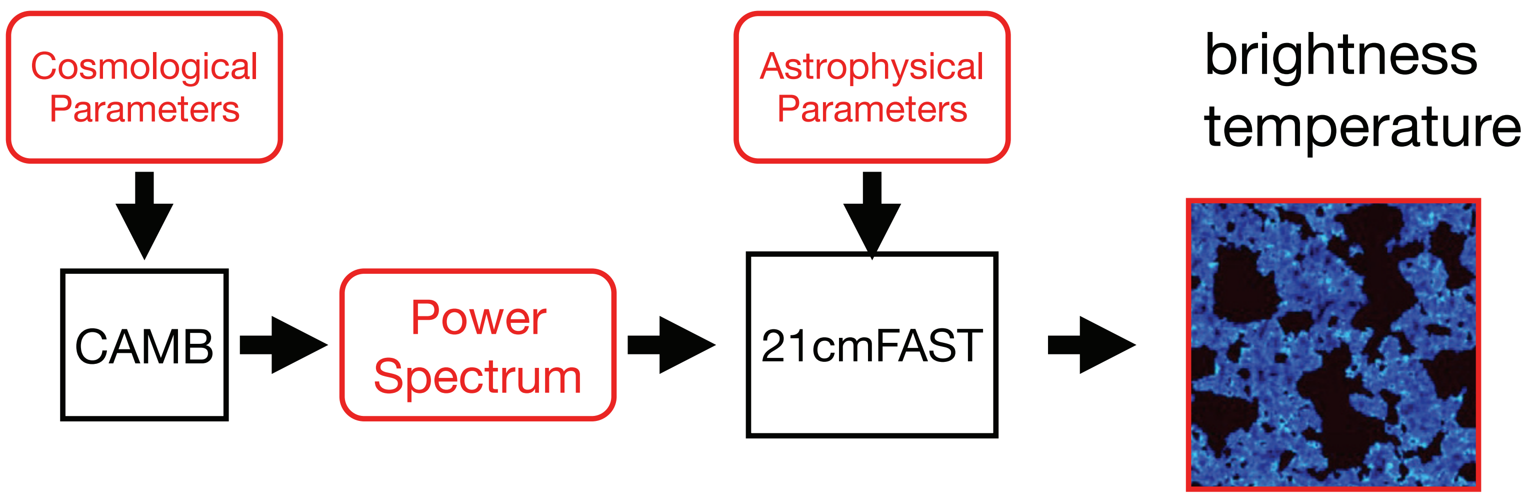


21cm Intensity Mapping



21cm Intensity Mapping

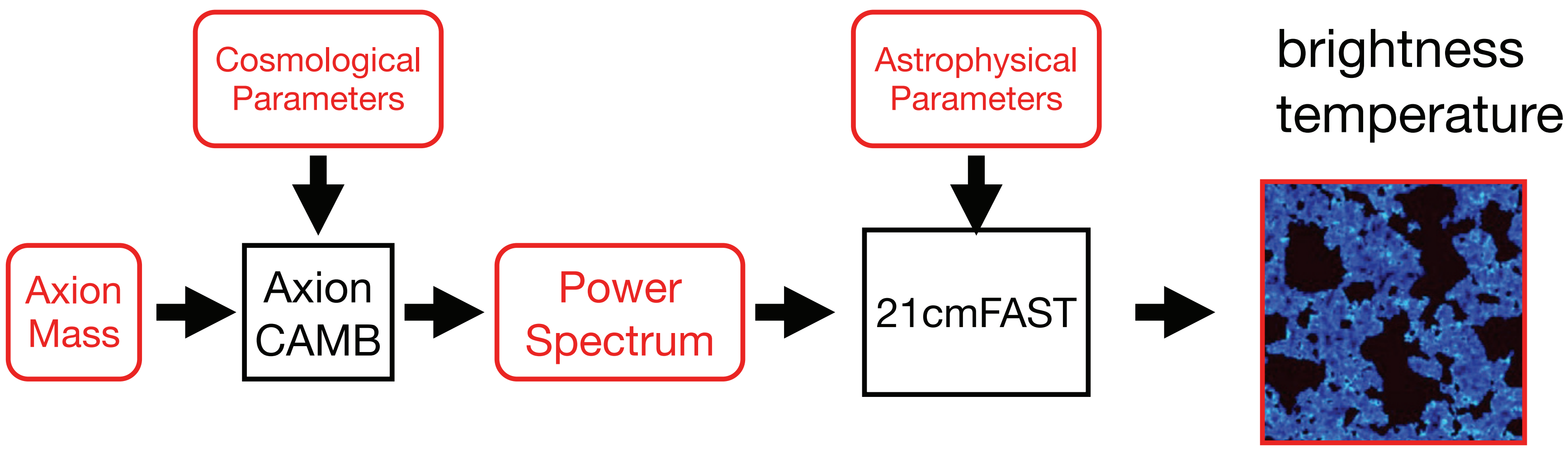
Pipeline



Mesinger & Furlanetto 2007
Mesinger et al. 2011

21cm Intensity Mapping

Pipeline



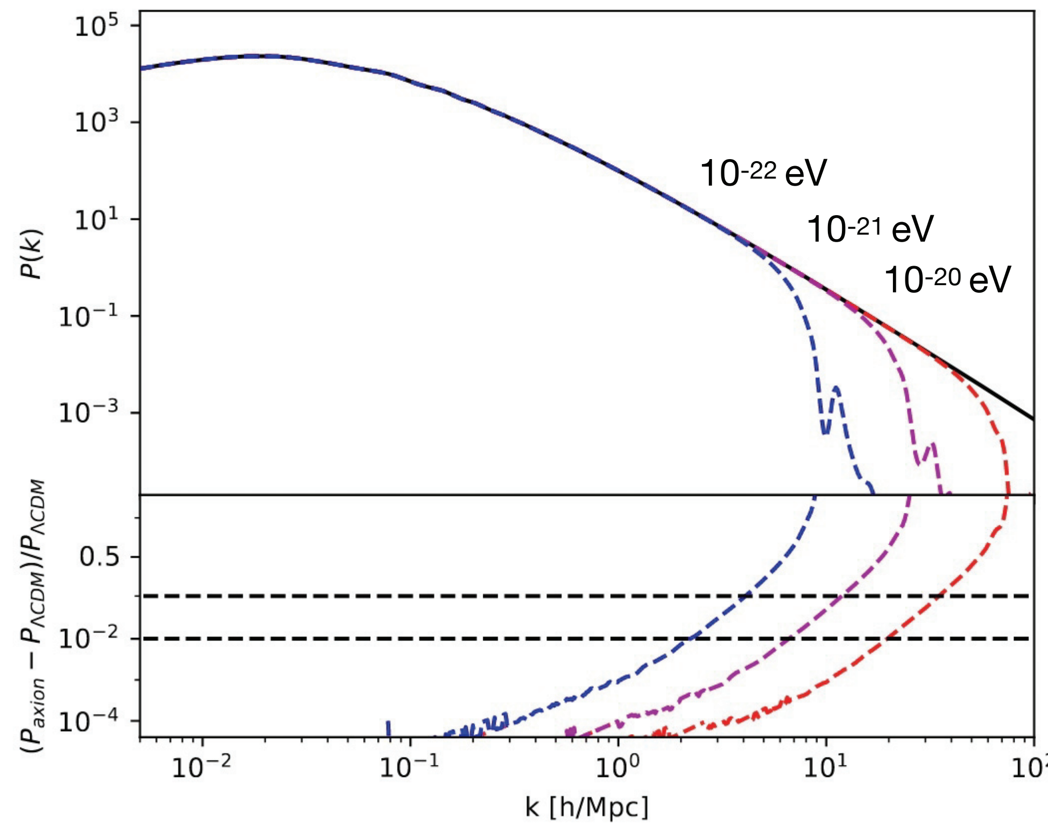
Hlozek et al. 2015

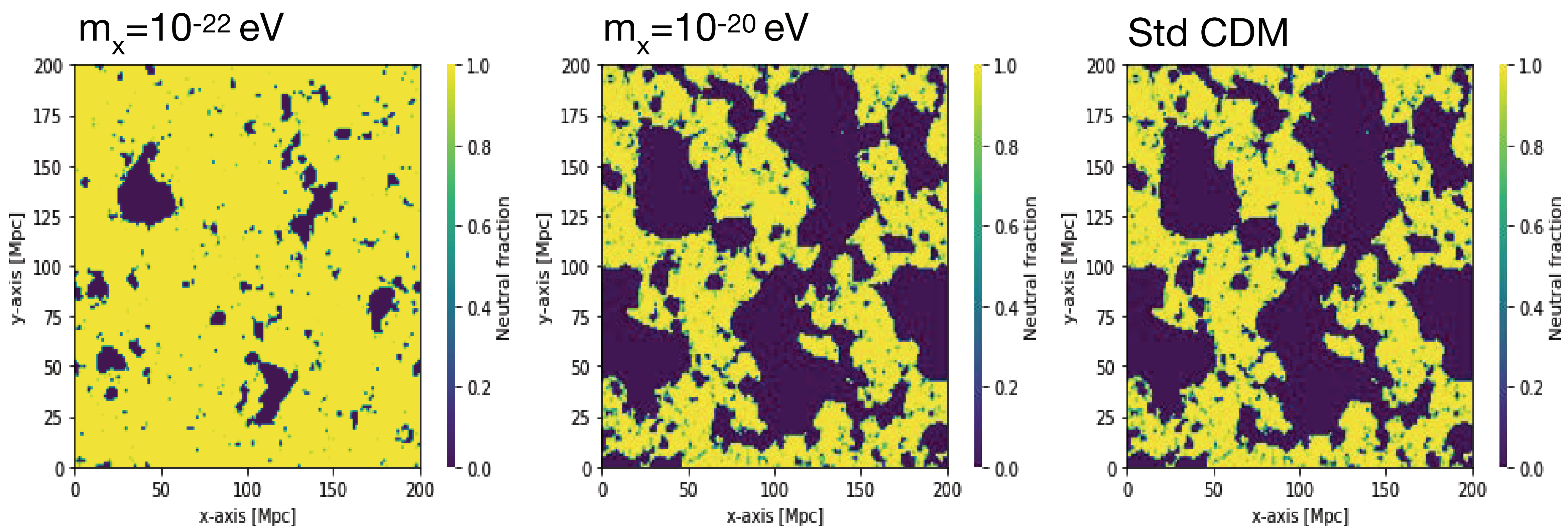
Mesinger & Furlanetto 2007
Mesinger et al. 2011

21cm Intensity Mapping

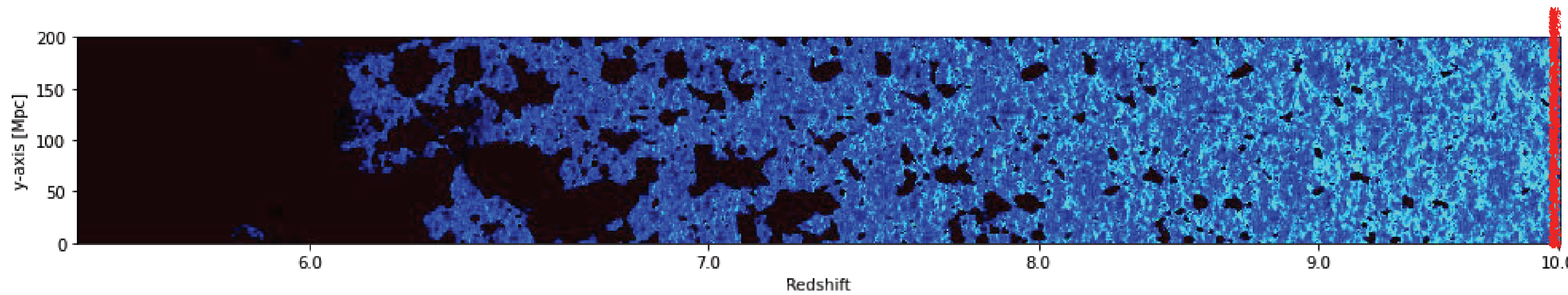
Varying Axion Mass

- ★ The linear power spectrum has a suppression of power at progressively lower k for decreasing axion masses
- ★ This has a significant effect on the collapse fraction of gas
- ★ Delays the onset of reionization compared to Std CDM

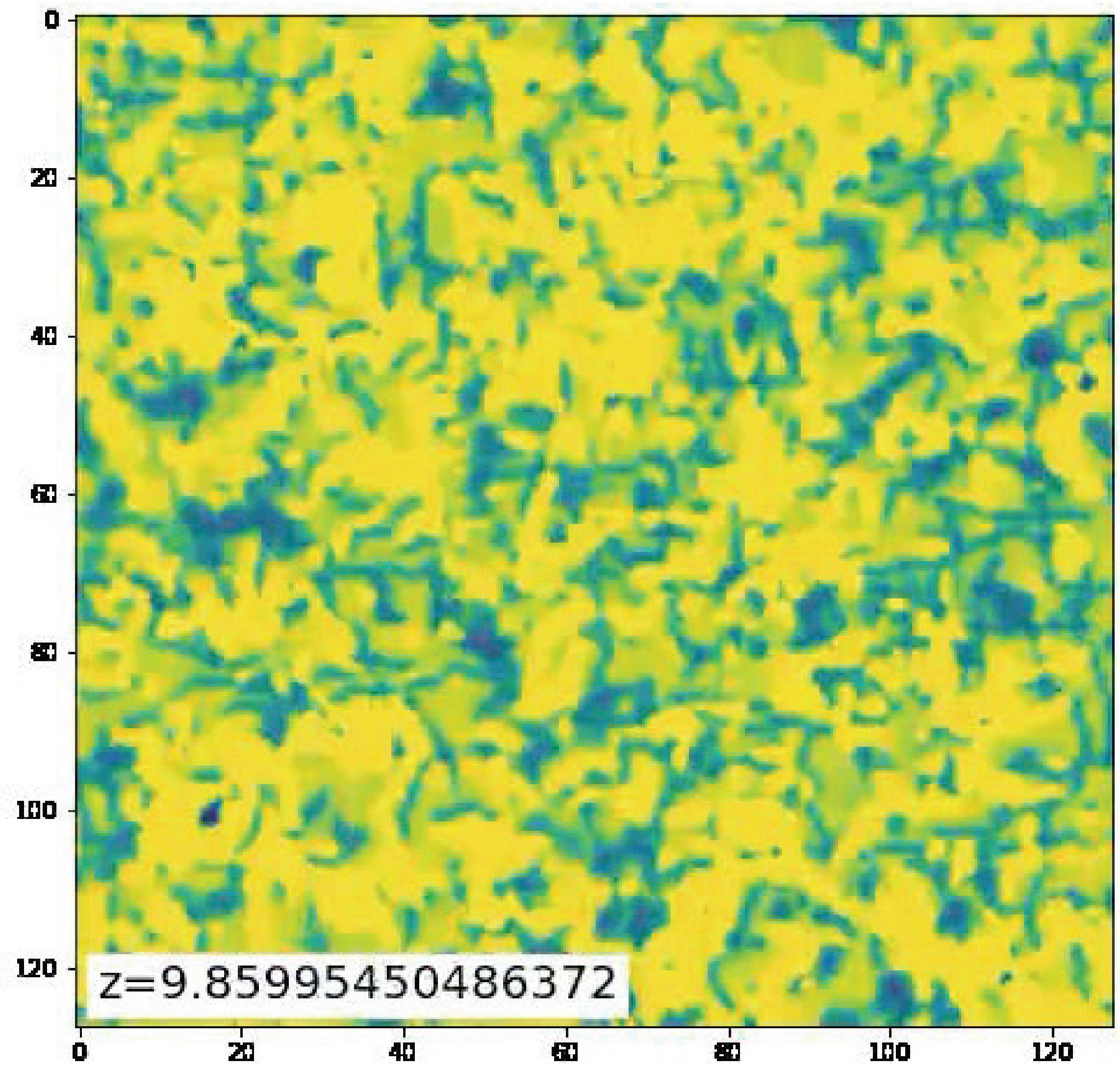




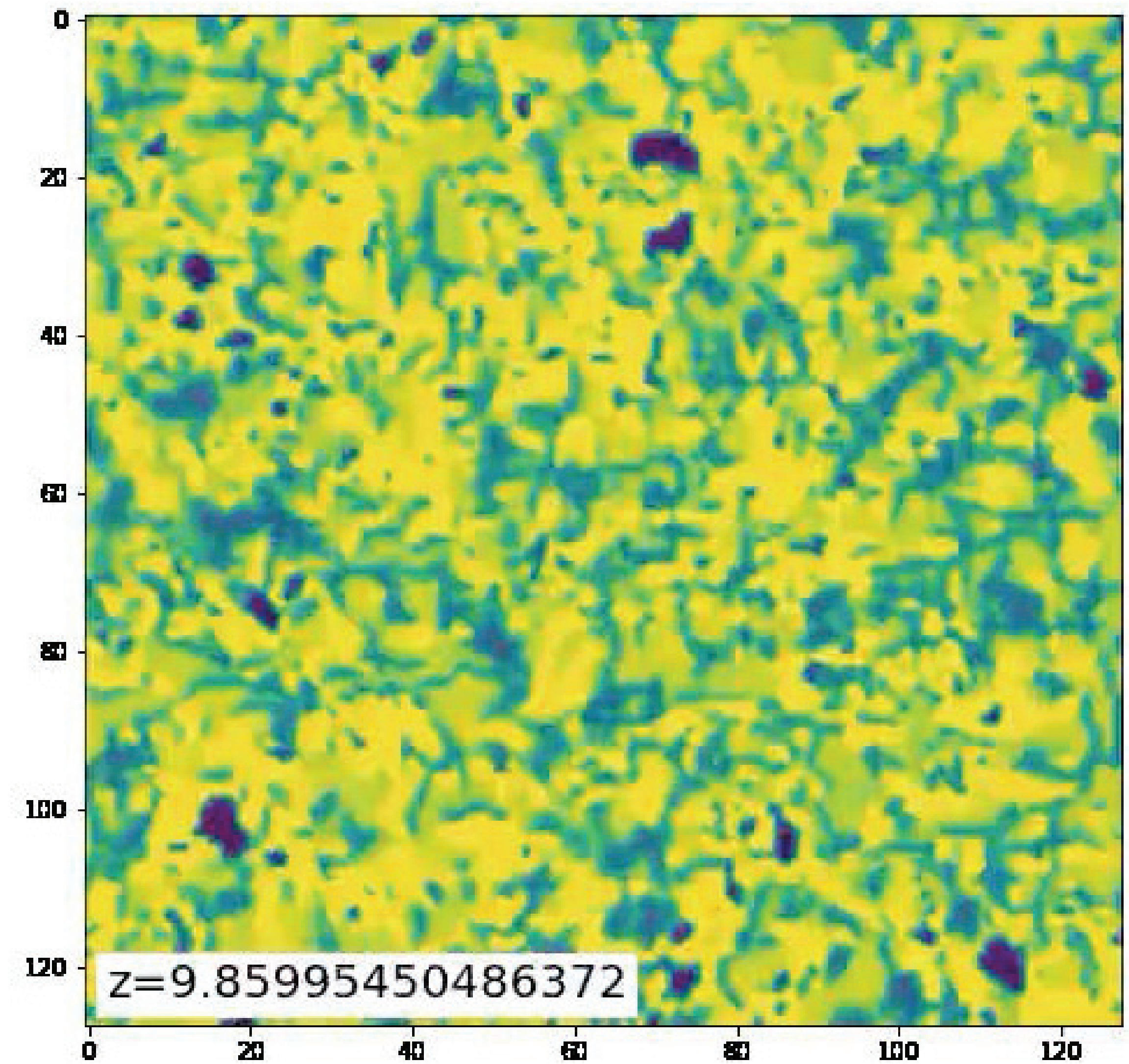
Redshift Evolution of the neutral fraction



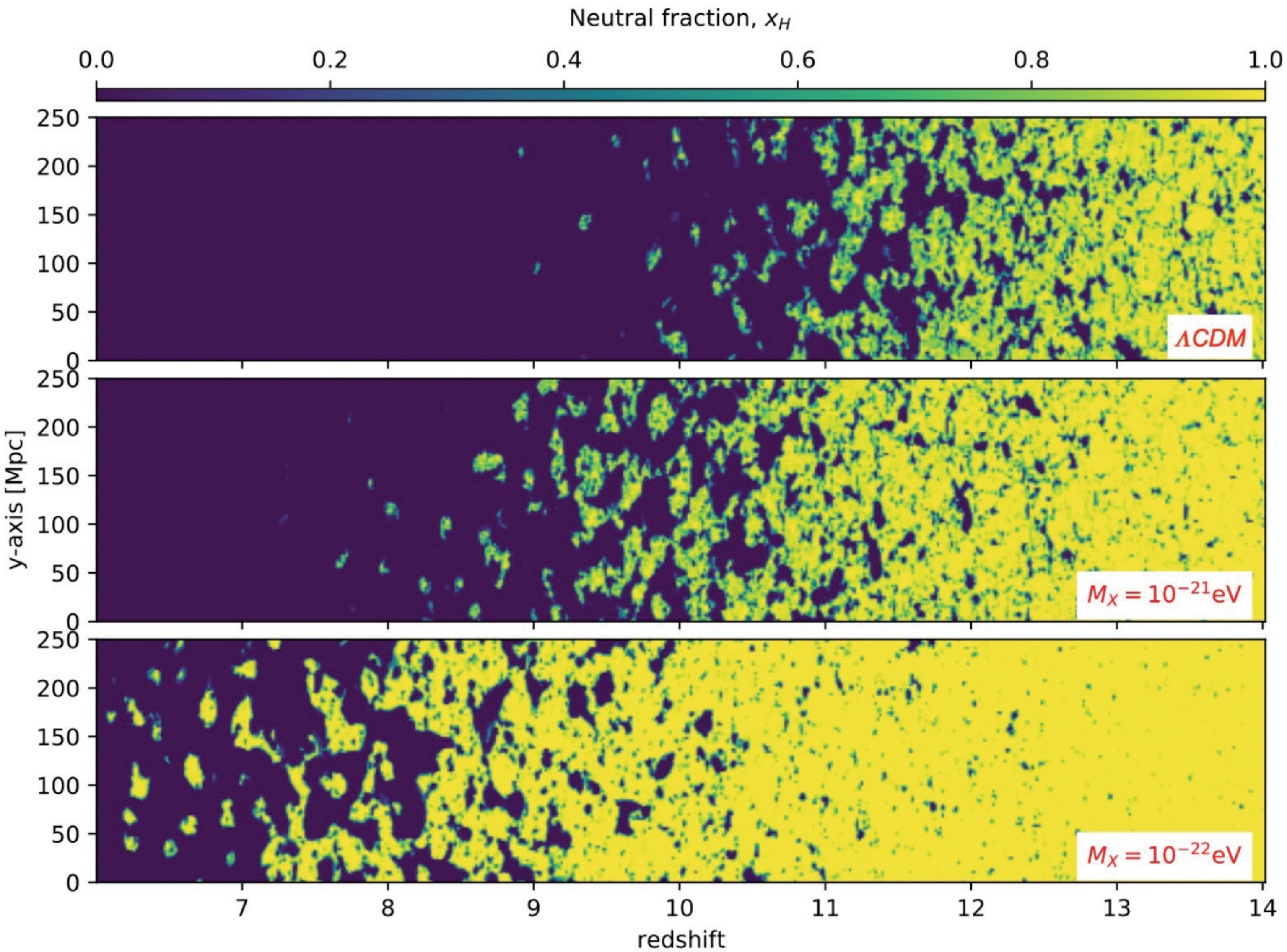
$m_x = 10^{-22}$ eV

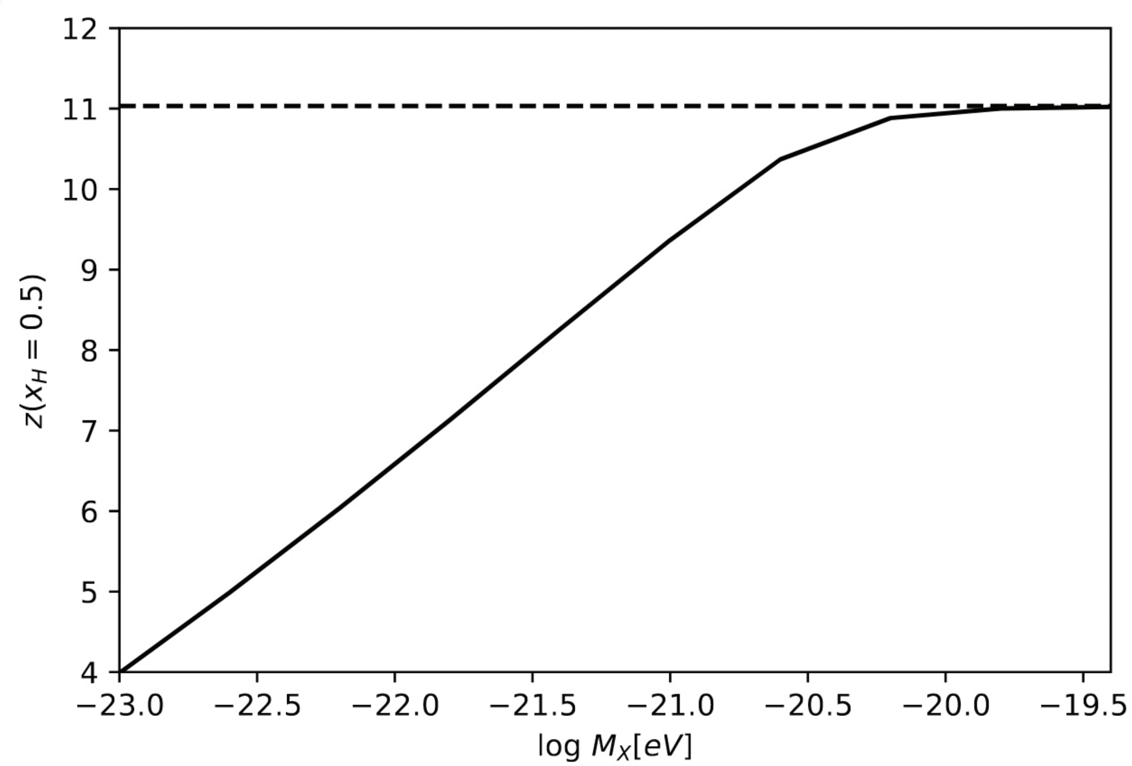


Std CDM



Redshift Evolution of the neutral fraction





★We can look at the redshift when the universe if half ionised as a function of axion mass

21cm Intensity Mapping

Towards Realistic Images

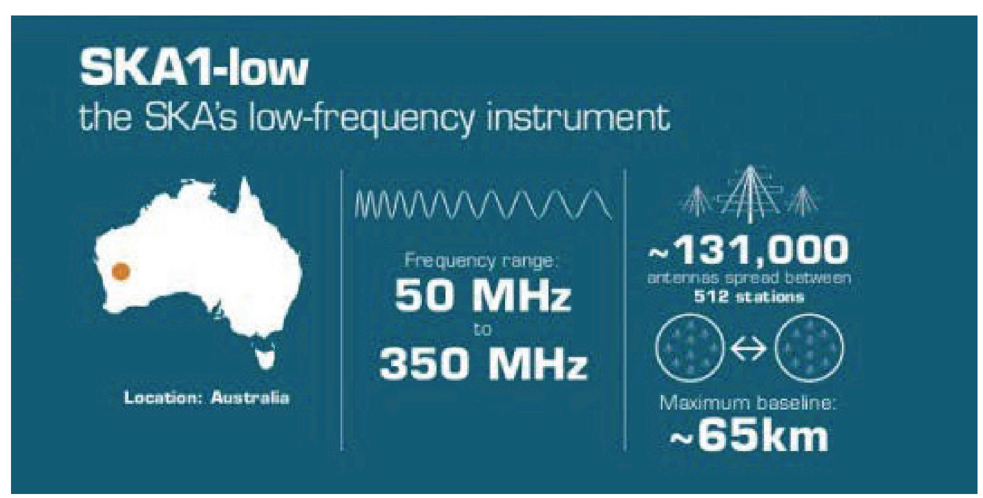
Following the SKA Desgin Plan: https://www.skatelescope.org/wp-content/uploads/2012/07/SKA-TEL-SKO-DD-001-1_BaselineDesign1.pdf

and the methodology of McQuinn, etal 2007

		FAST	MeerKAT	WSRT	Arecibo	ASKAP	SKA1-survey	SKA1-low	SKA-mid
A_{eff}/T_{sys}	m^2/K	1250	321	124	1150	65	391	1000	1630
FoV	deg^2	0.0017	0.86	0.25	0.003	30	18	27	0.49
Receptor Size	m	300	13.5	25	225	12	15	35	15
Fiducial frequency	GHz	1.4	1.4	1.4	1.4	1.4	1.67	0.11	1.67
Survey Speed FoM	$deg^2\ m^4\ K^{-2}$	2.66×10^3	8.86×10^4	3.84×10^3	3.97×10^3	1.27×10^5	2.75×10^6	2.70×10^7	1.30×10^6
Resolution	arcsec	88	11	16	192	7	0.9	11	0.22
Baseline or Size	km	0.5	4	2.7	225	6	50	50	200
Frequency Range	GHz	0.1 – 3	0.7 - 2.5, 0.7 - 10	0.3 – 8.6	0.3 - 10	0.7-1.8	0.65-1.67	0.050 – 0.350	0.35-14
Bandwidth	MHz	800	1000	160	1000	300	500	250	770
Cont. Sensitivity	$\mu Jy\text{-}hr^{-1/2}$	0.92	3.20	20.74	0.89	28.89	3.72	2.06	0.72
Sensitivity, 100 kHz	$\mu Jy\text{-}hr^{-1/2}$	82	320	830	89	1582	263	103	63
SEFD	Jy	2.2	8.6	22.3	2.4	42.5	7.1	2.8	1.7

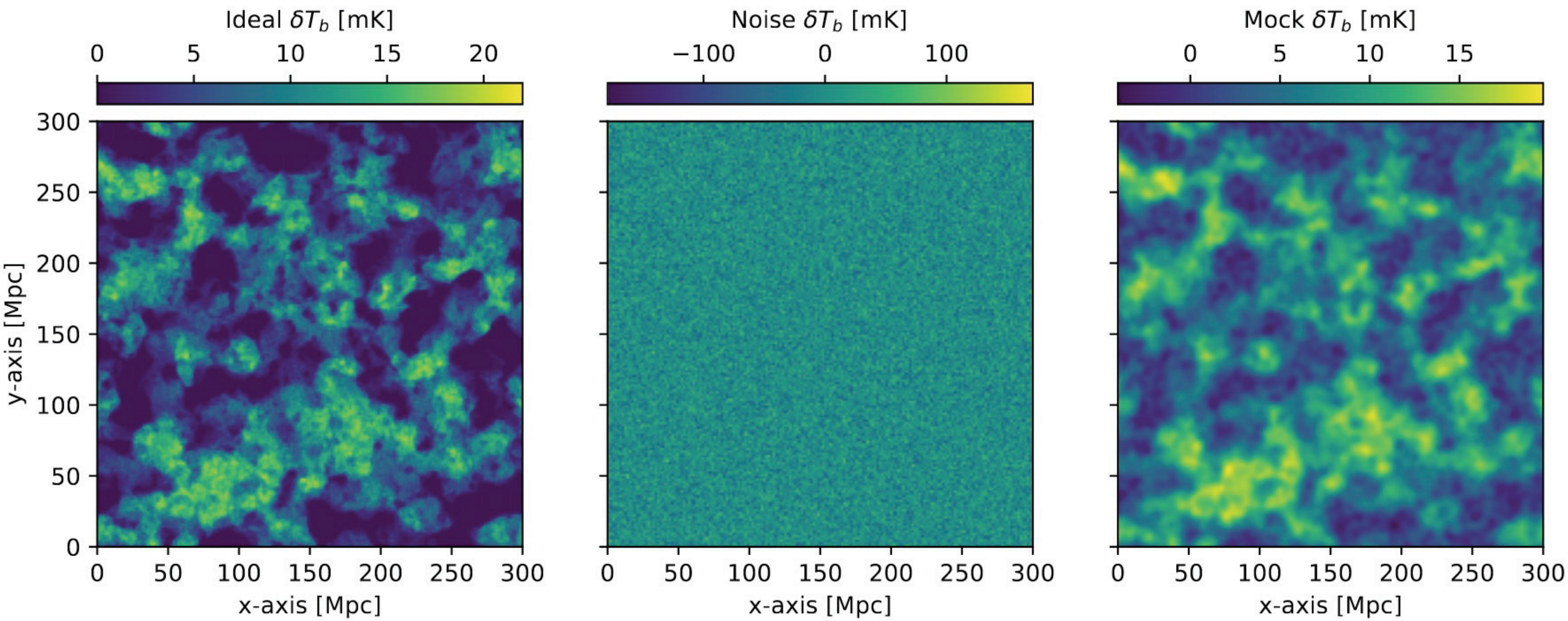
100kpc at z=5

$3 < z_{H1} < 27$



21cm Intensity Mapping

Towards Realistic Images: Noise and Telescope Resolution



Noiseless, Ideal simulation

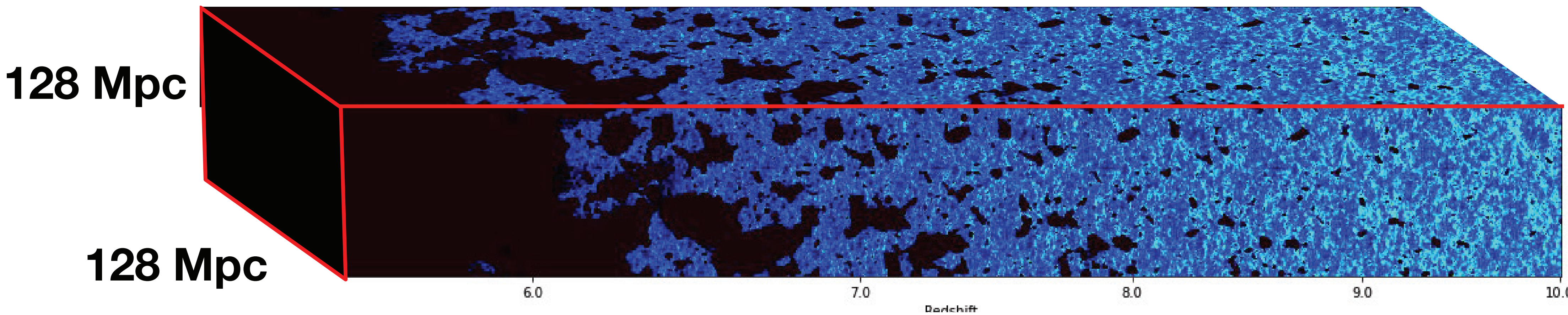
$$\sigma_{noise} = T_{sys}\sqrt{\frac{4\pi f_{sky}}{\Omega_{beam} N_{dish} t_{int} \Delta\nu}}.$$

N_{dish} =is the number of antenna, $\Delta\nu = 1$MHz is the frequency bandwidth, $f_{sky} = 0.02$ is the fraction fo sky observed, $t_{int} = 1{,}000$h is the integration time, and $T_{sys} = T_{rx} + T_{gal}$ the system temperature is composed of $T_{rx} = 0.1 T_{gal} + 40K$ and $T_{gal} = 25\left(\frac{\nu}{408MHz}\right)^{-2.75}$

Radio telescopes have an angular resolution $\Delta\theta \sim \frac{\lambda}{B}$, where B is the baseline which we adopt as 500m for the core antennas of the SKA1-Low design, and since $\lambda = \lambda_{21}(1+z)$, the resolution acquires a mild redshift dependence.

21cm Intensity Mapping

Data structure



64 x 64 x 128 cells of 21cm Brightness temperature
Spanning 2 spatial dimensions and 1 redshift/frequency

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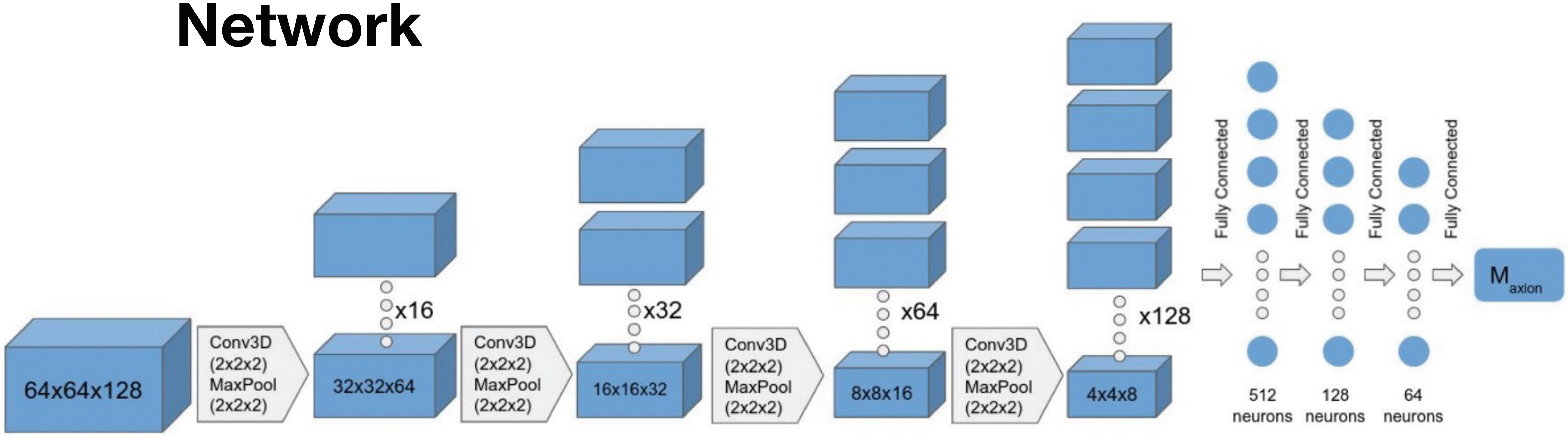
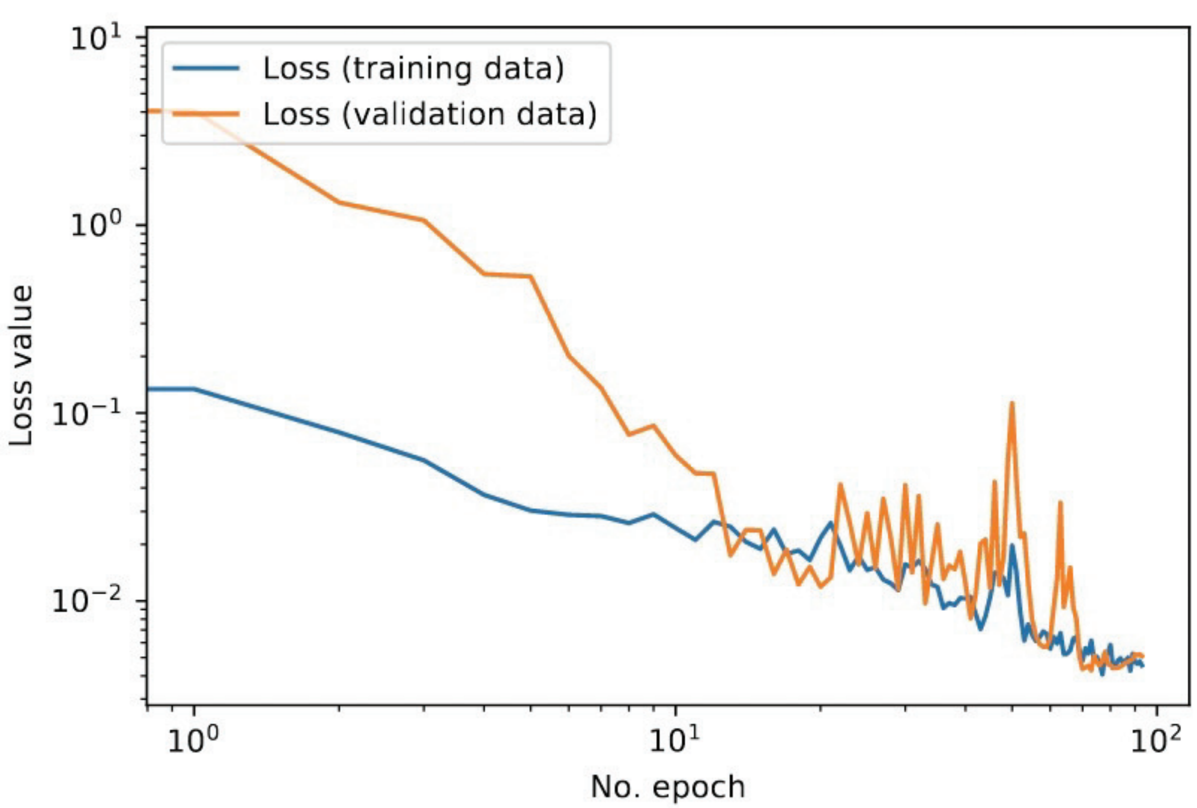
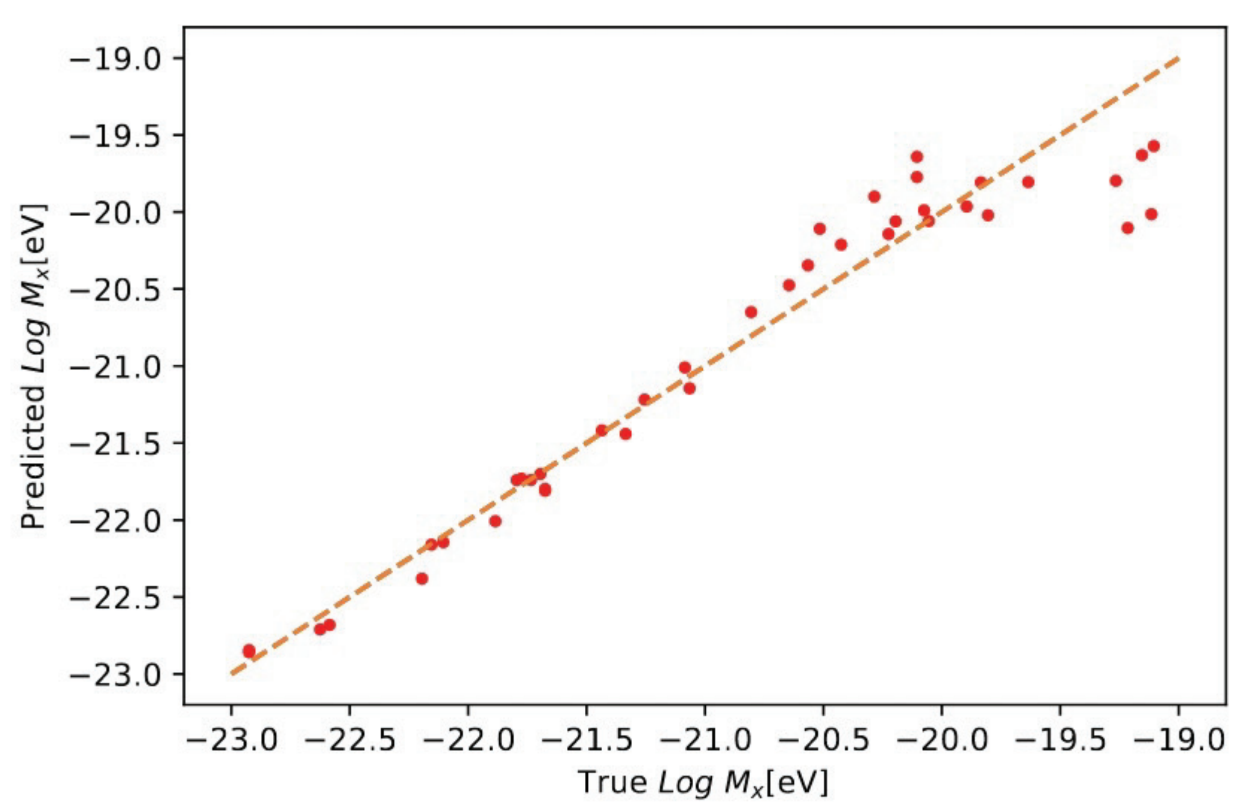
21cm Intensity Mapping

3D Convolutional Neural Network







21cm Intensity Mapping

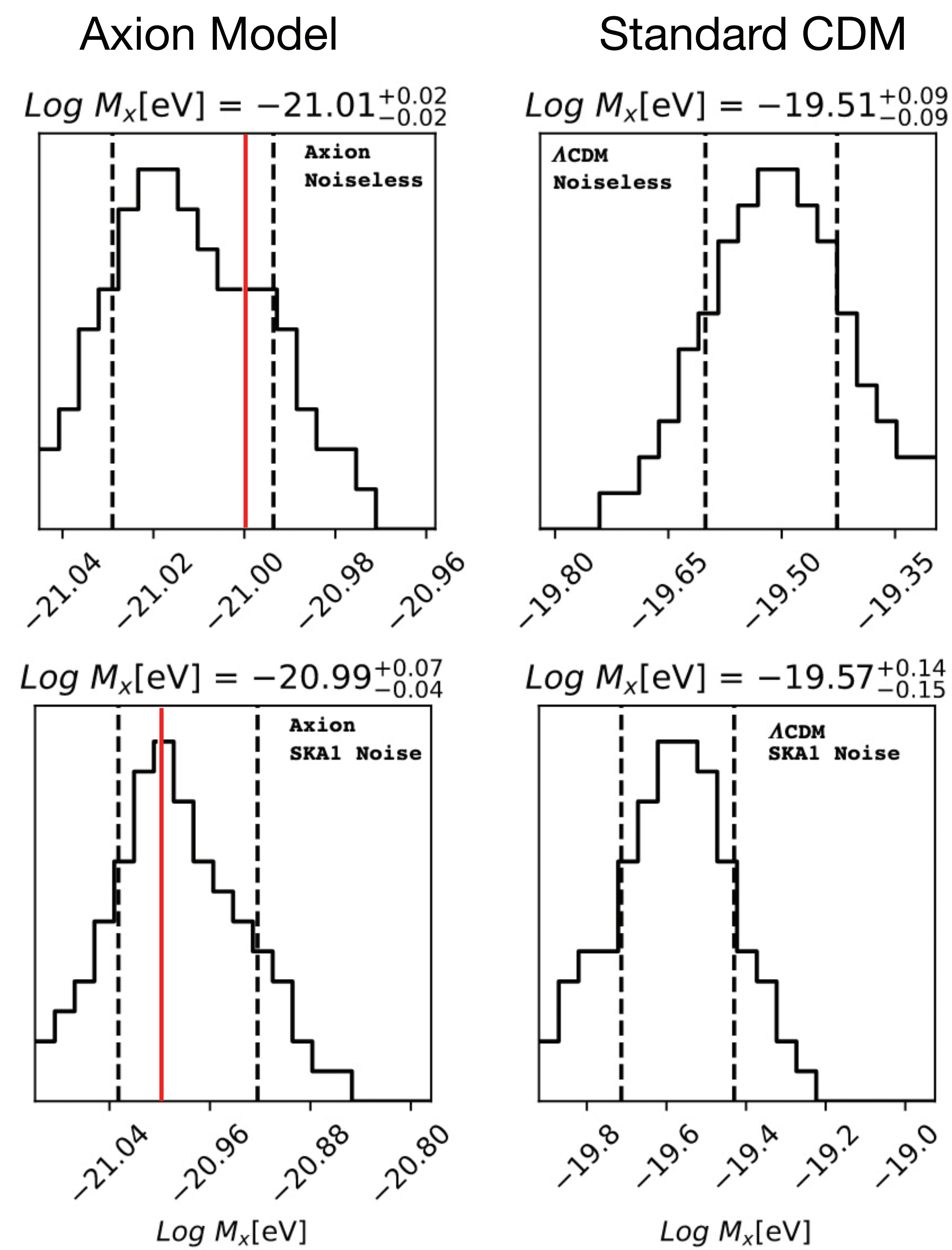
3D Convolutional Neural Network

We trained two CNN networks: one on the ideal noiseless sims and one for the realistic noise simulations.

We now probe those two trained networks.

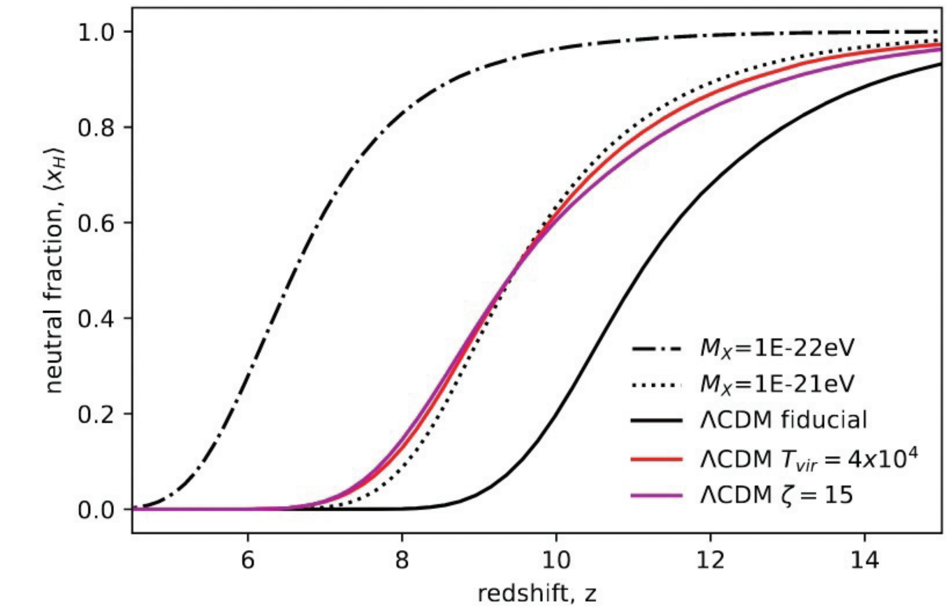
We create 200 mock observations each for the standard DM and an ultra light axion dark matter of fixed mass logM=-21

We add analyses each in the ideal no noise case and for realistic SKA1-Low noise



21cm Intensity Mapping

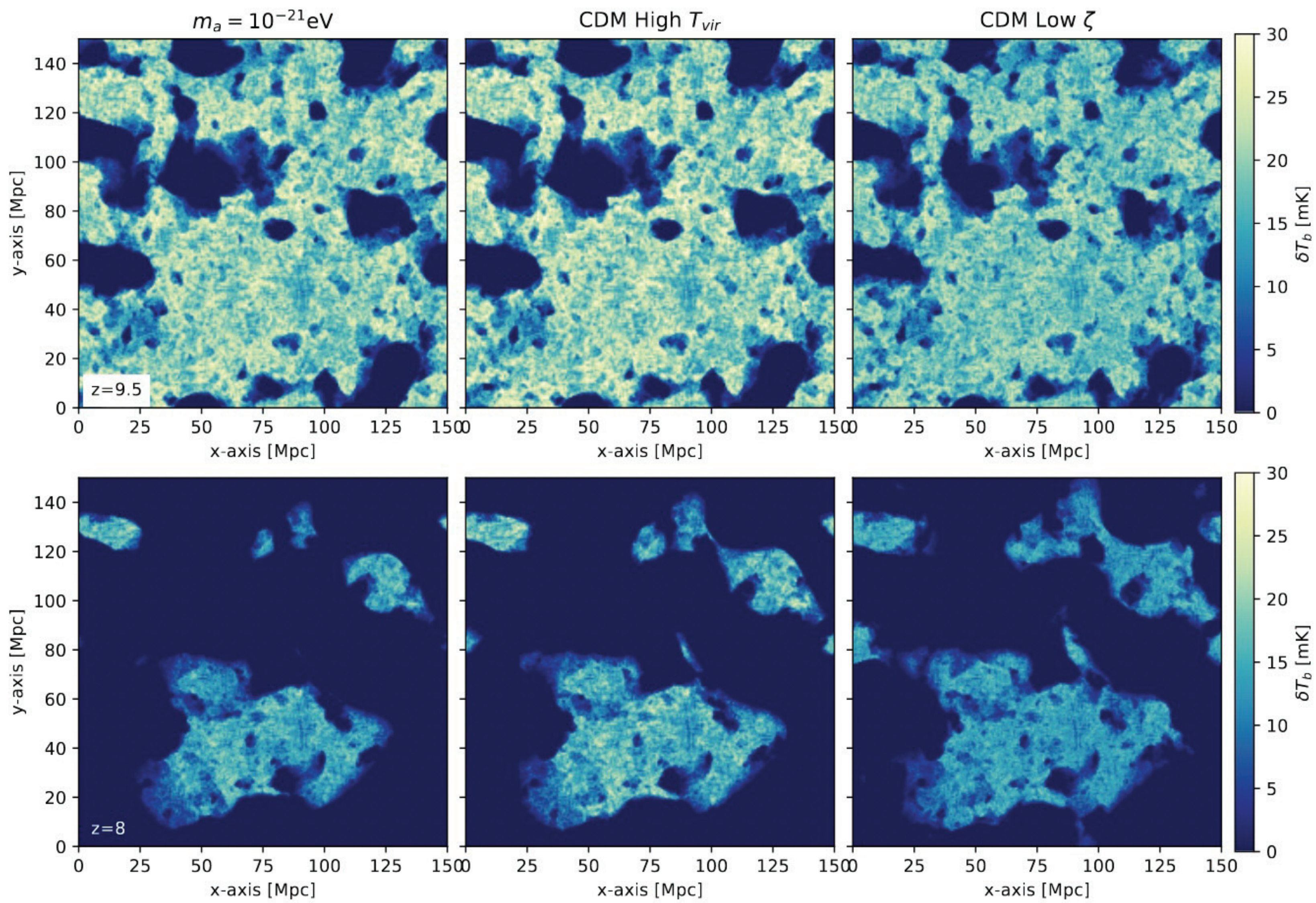
Breaking Degeneracy between Axion Mass and Astrophysical parameters

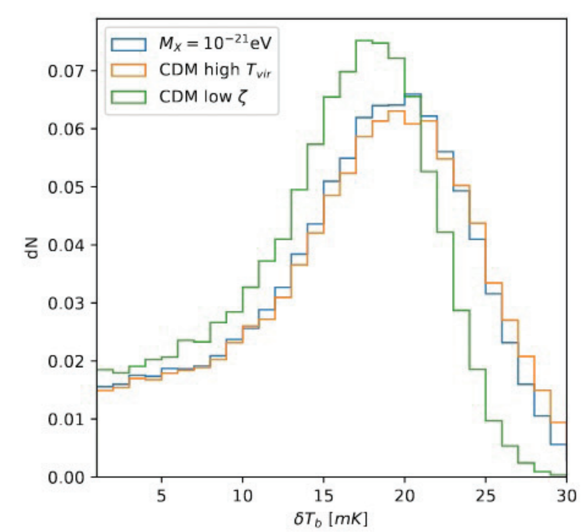


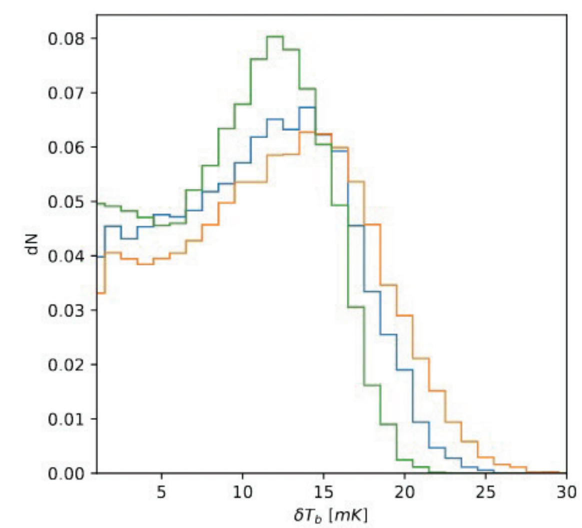
Fid astro params
Axion

High Tvir
Std CDM

Low efficiency
Std CDM

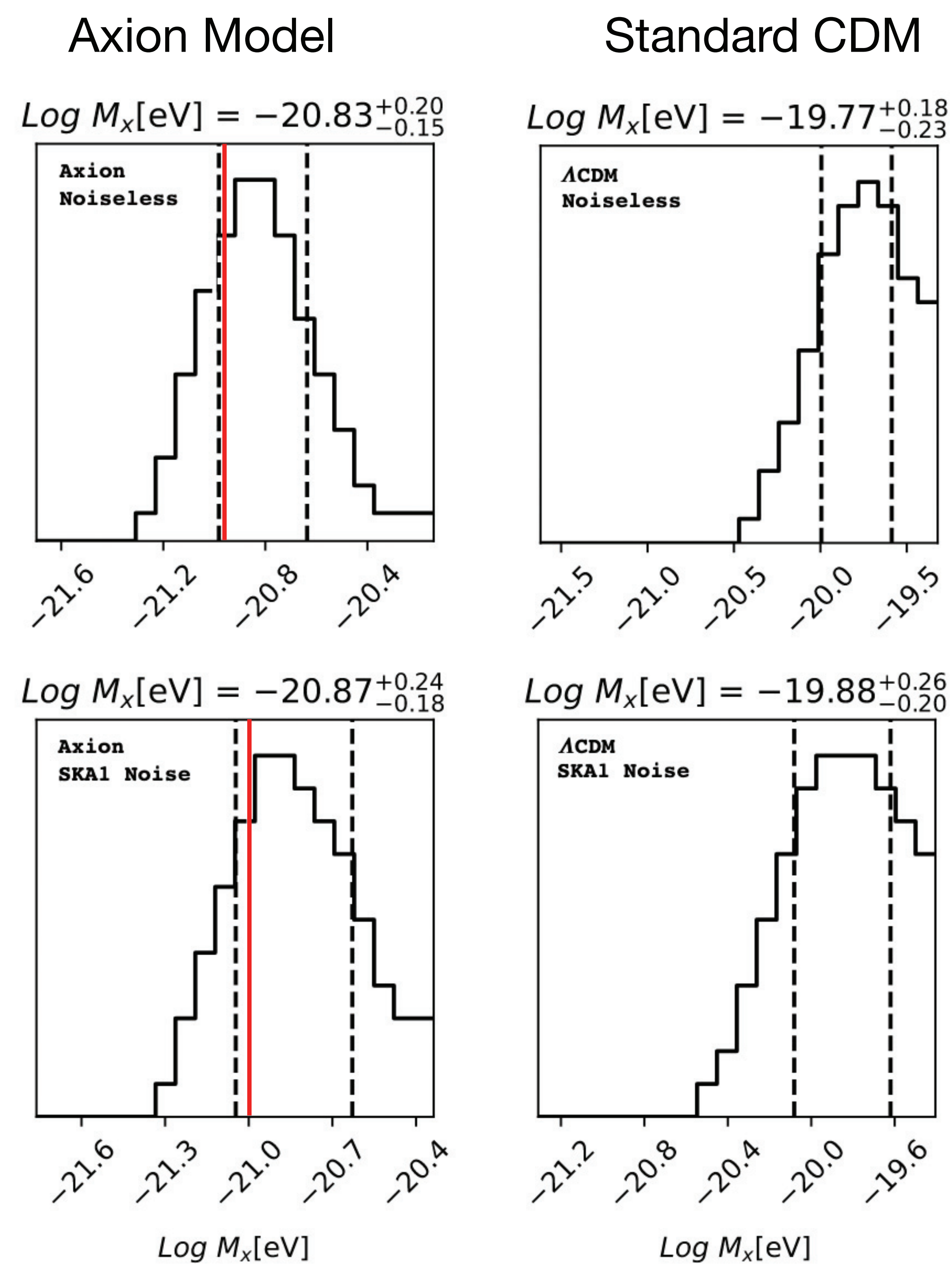




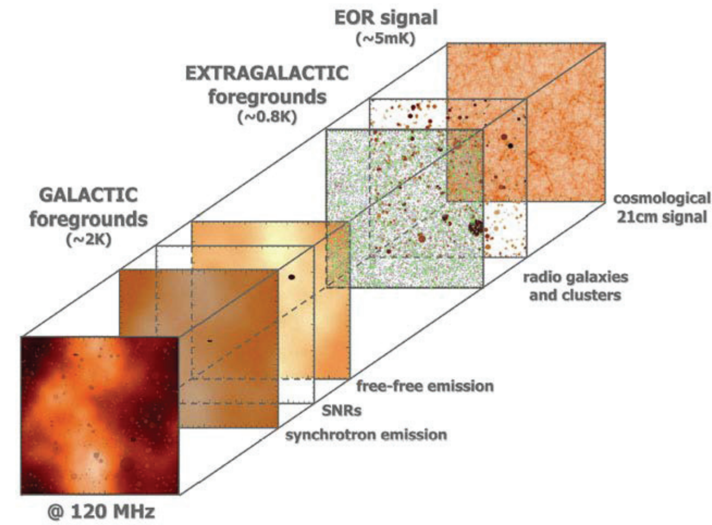


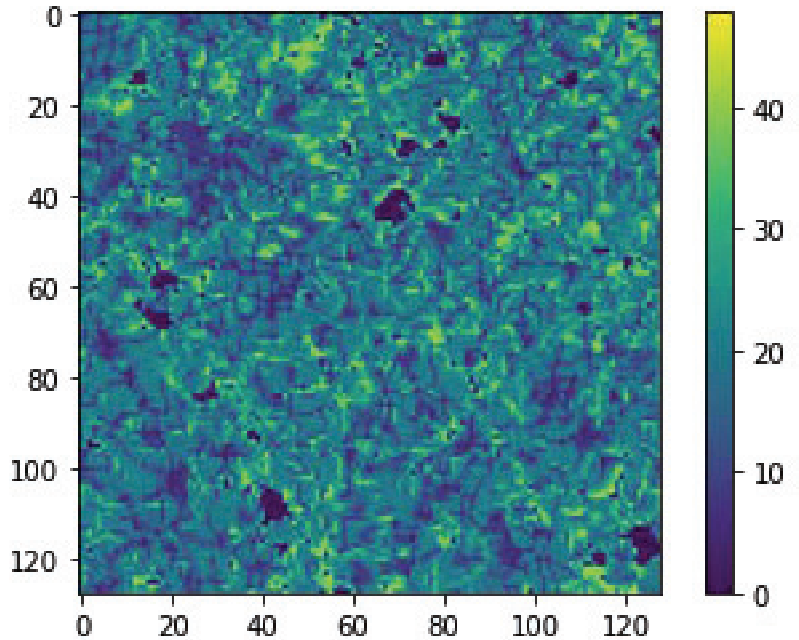
Results & Conclusions

- We made realistic SKA-1 LOW images of the 21cm signal in an axion DM scenario.
- We applied a machine learning approach using convolutional neural networks and found that the trained network could constrain the axion particle mass
- Astrophysical Parameters can mimic the axion signature - but not exactly
- Marginalising over a wide range of nuance parameters we were able to constrain the **axion mass to ~20%** using a modest SKA1-Low design while assuming a fiducial Planck 2015 cosmology.
- The axion can be detected with SKA at if the axion is <u>$M_X < 1.86 \times 10^{-20}$eV</u> although this can decrease to <u>$M_X < 5.25 \times 10^{-21}$eV</u> if we relax our assumptions

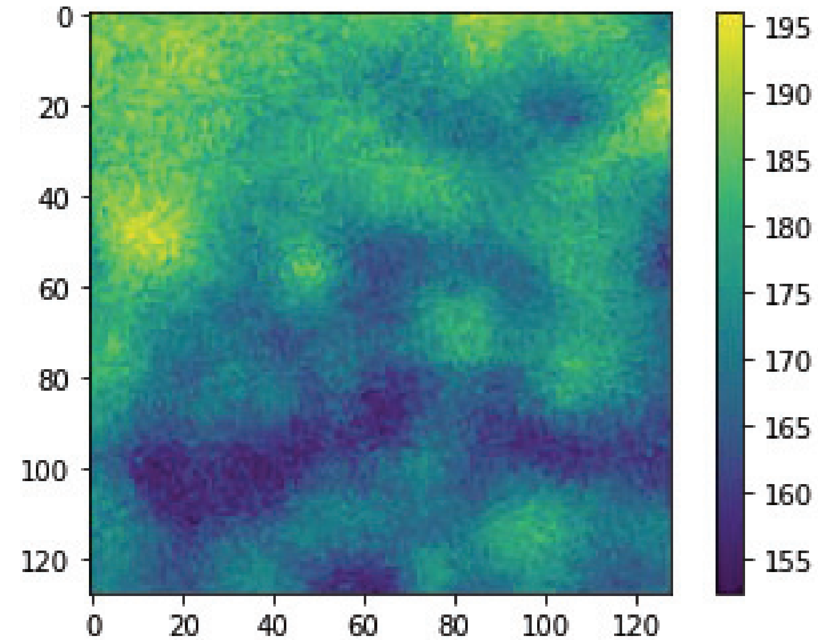


Future - On-going Work

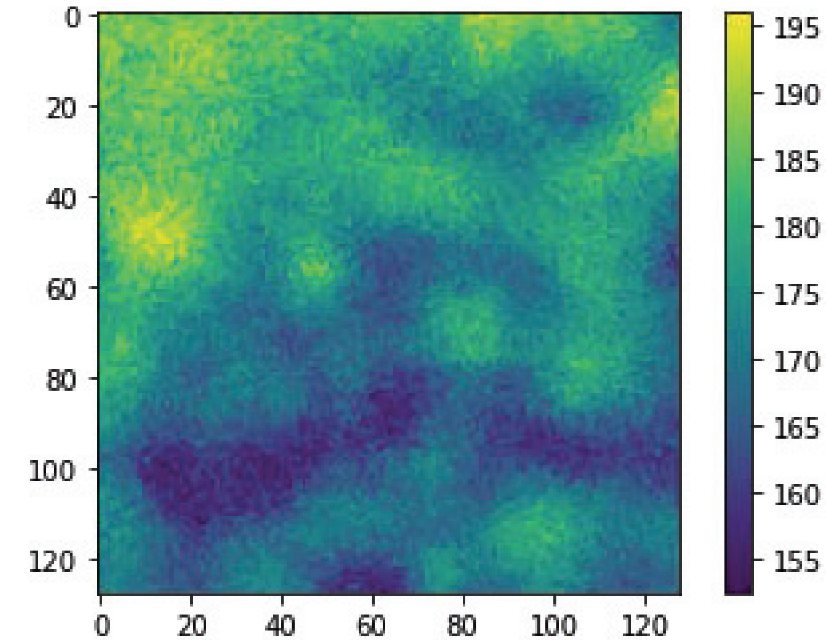




Axion/fuzzy dark matter $M=10^{-22}$eV at 157.4Mhz (~z=8.0)



a realisation of the foreground contamination, using the Global Sky Model (GSM, de Oliveira-Costa et. al 2010)



It looks bad, but the synchrotron emission is expected to be very smooth in frequency so should be removable

★ We are now adding realistic foreground contamination and will see the effect on our ability to infer DM properties with 21cm observations

Thank You - 감사합니다