21CMMC: an MCMC framework for the astrophysics of reionisation

Bradley Greig

Was: SNS, Pisa
Now: University of Melbourne (UniMelb)

In collaboration with A. Mesinger (SNS)

SCUOLA NORMALE SUPERIORE

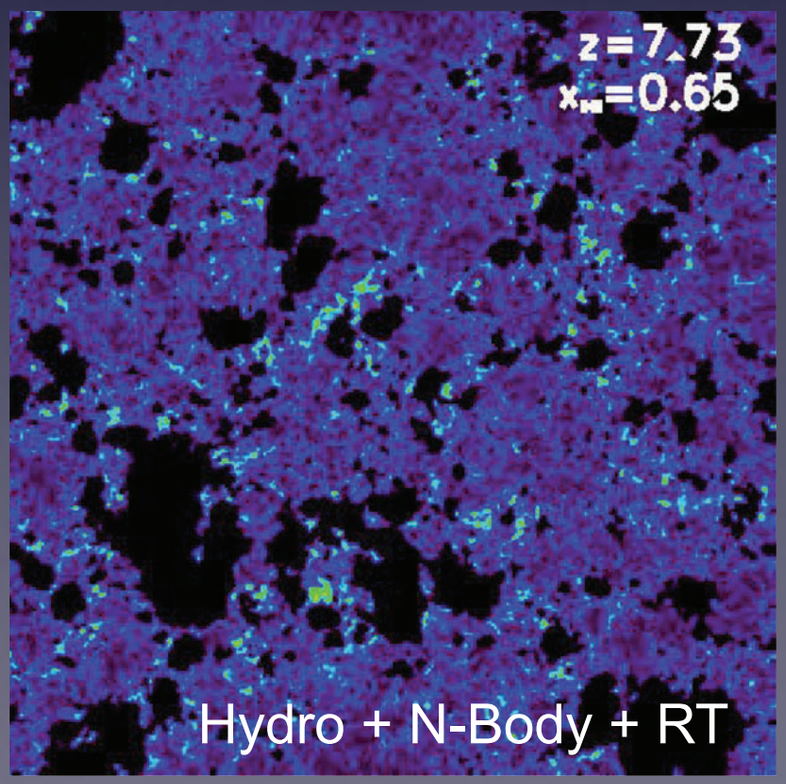
ASTRO 3D

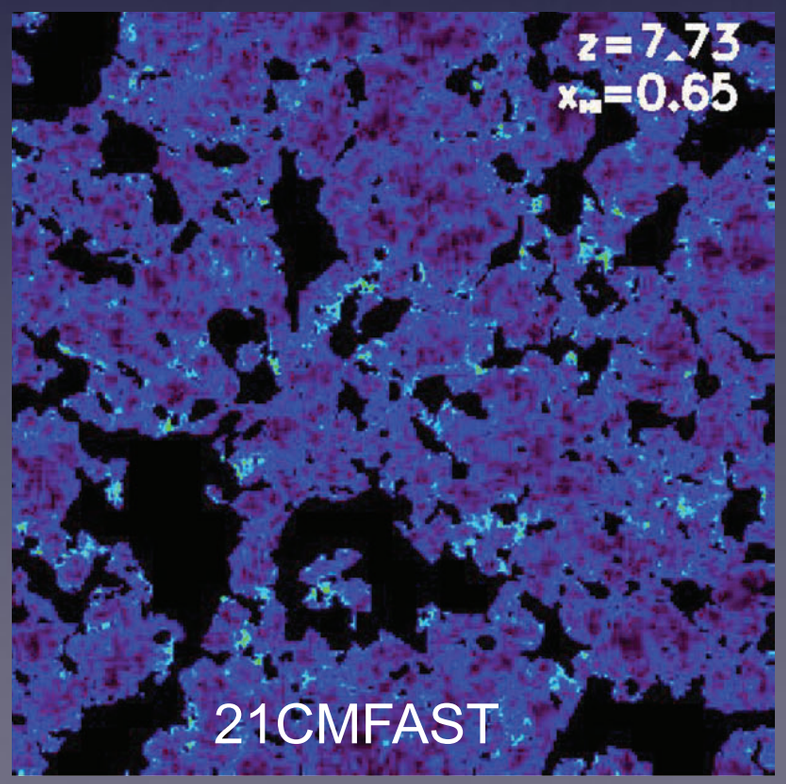
SALF IV, Sydney, Dec 14th

European Research Council

21CMMC

- Massively parallel MCMC driver for the EoR simulation code 21CMFAST
- 21CMFAST provides:
  - full 3D EoR simulations at a fraction of the computing cost of RT simulations
  - preserves the 3D structure of reionisation (superior to analytic models of EoR)
- Recovers astrophysical parameter constraints from any model of the EoR for any statistical measure of the 21 cm signal





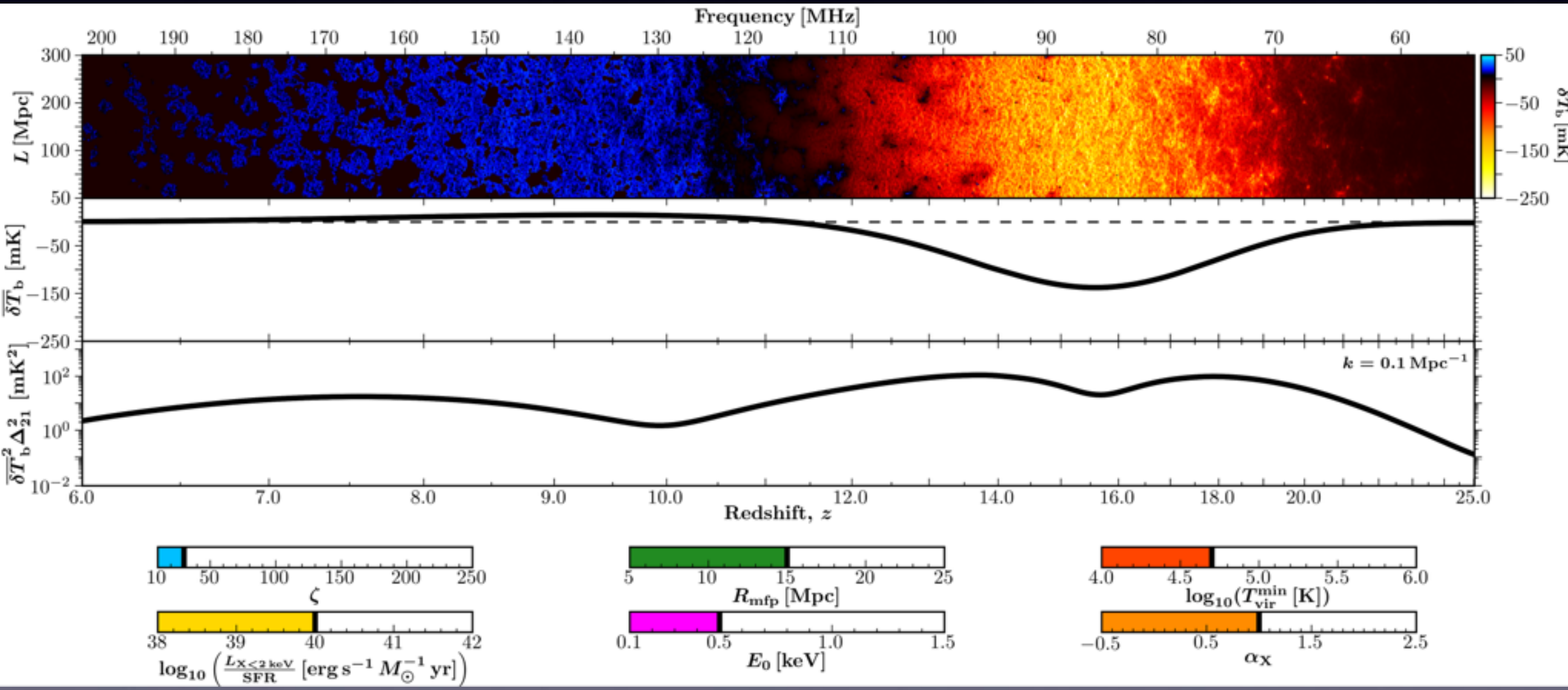
Mesinger et al. (2007)

Astrophysical Parametrisation in 21CMMC

- Current implementation contains 6 parameters
- Have 3 parameters describing the EoR
- Another 3 parameters describing the heating (X-ray) epoch
- Assume the same minimum mass threshold for ionisation and X-ray sources

Epoch of Reionisation

ζ: Constant ionising efficiency; $\propto f_{\rm esc}\, f_*\, N_{\gamma/{\rm b}}\, (1+n_{\rm rec})^{-1}$



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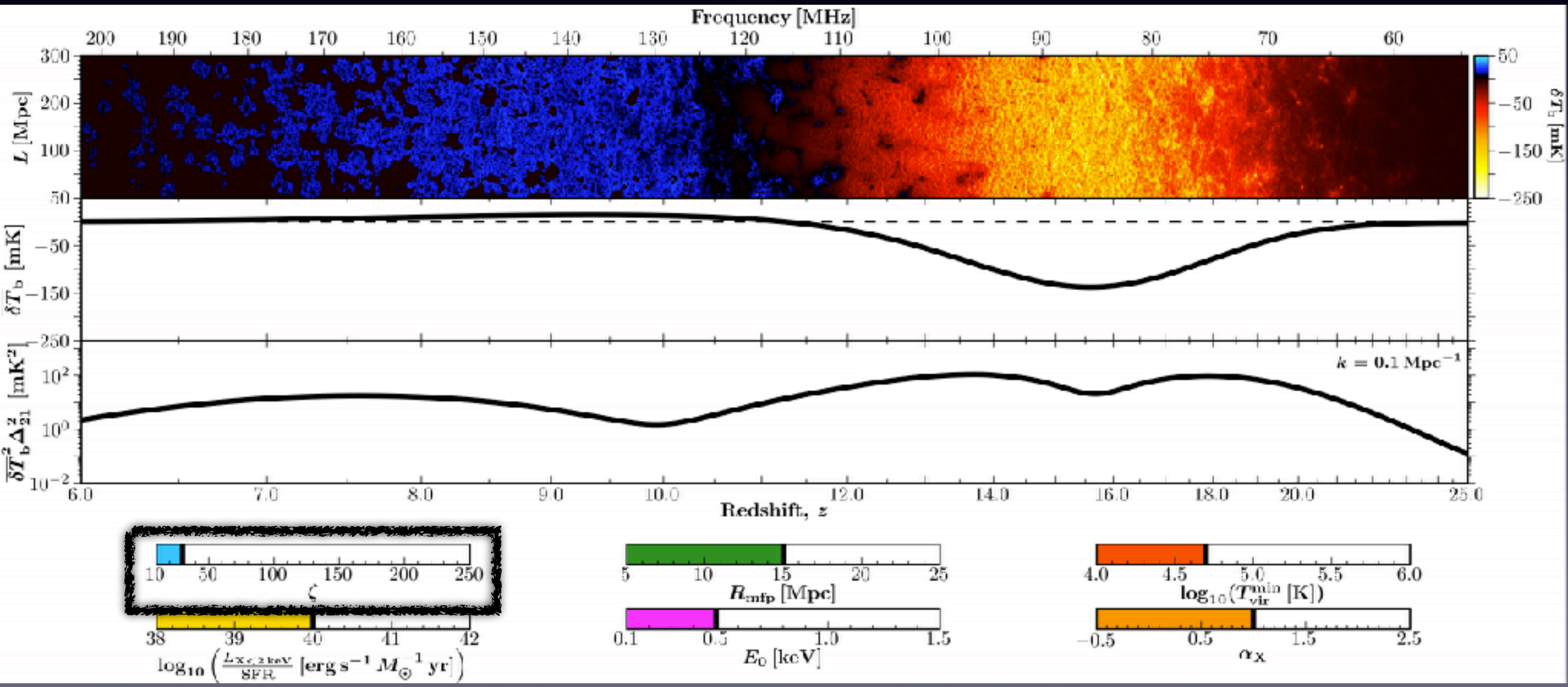

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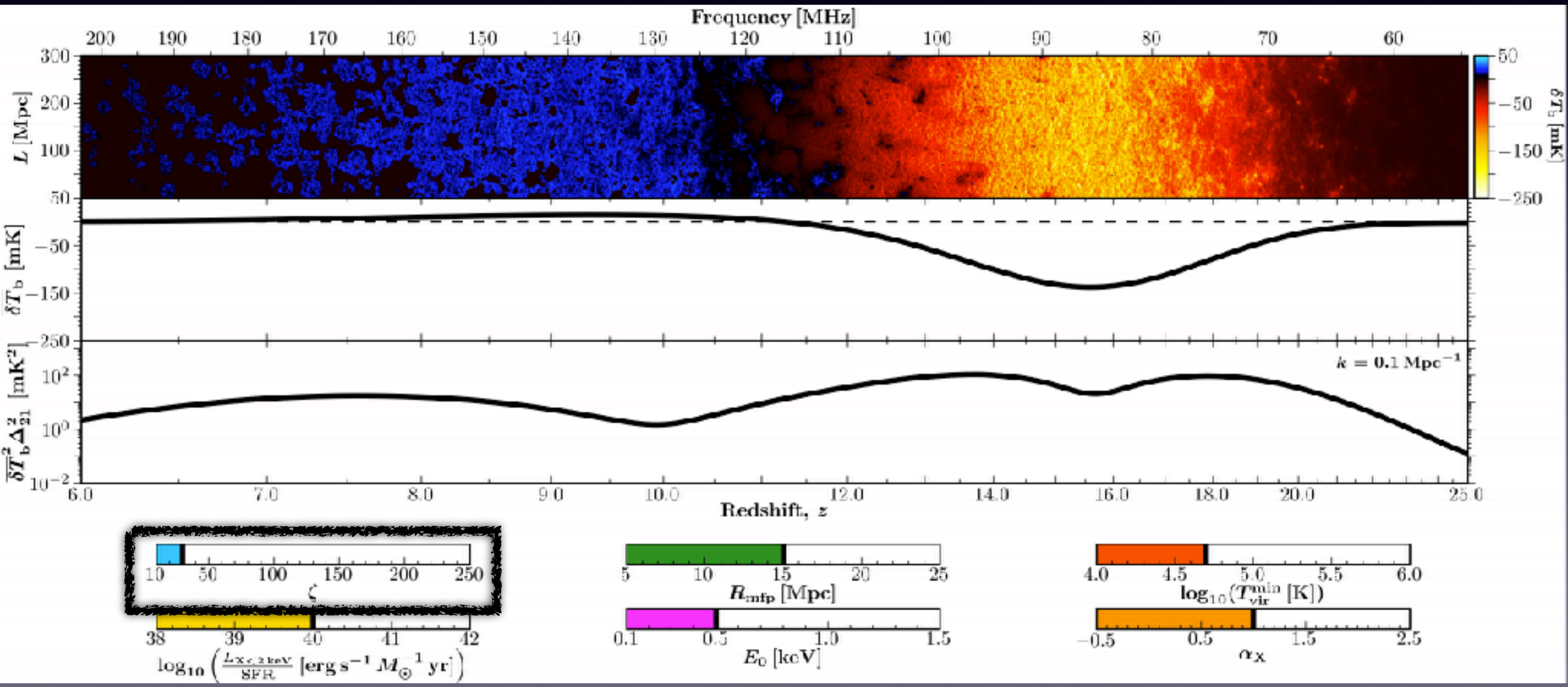
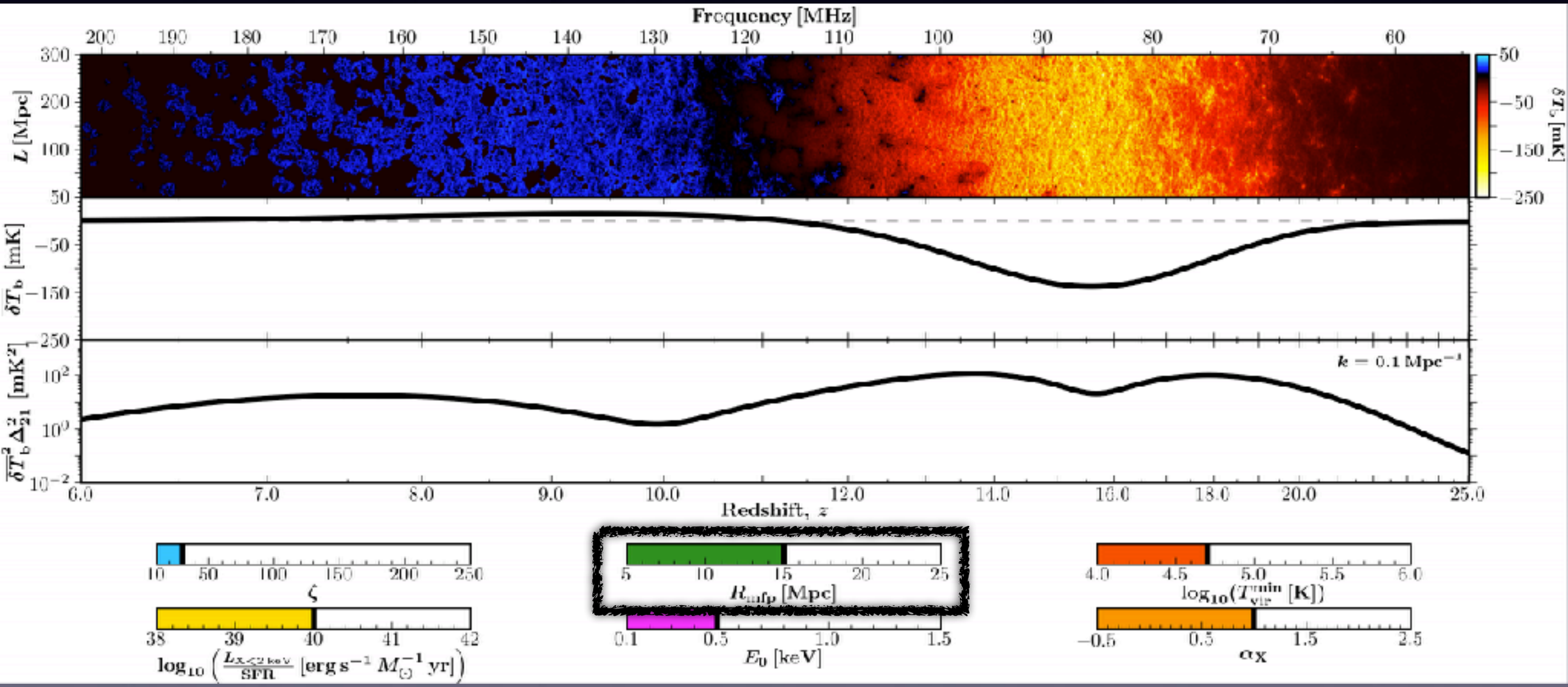


Epoch of Reionisation

R_{mfp}: Maximum horizon of ionising photons



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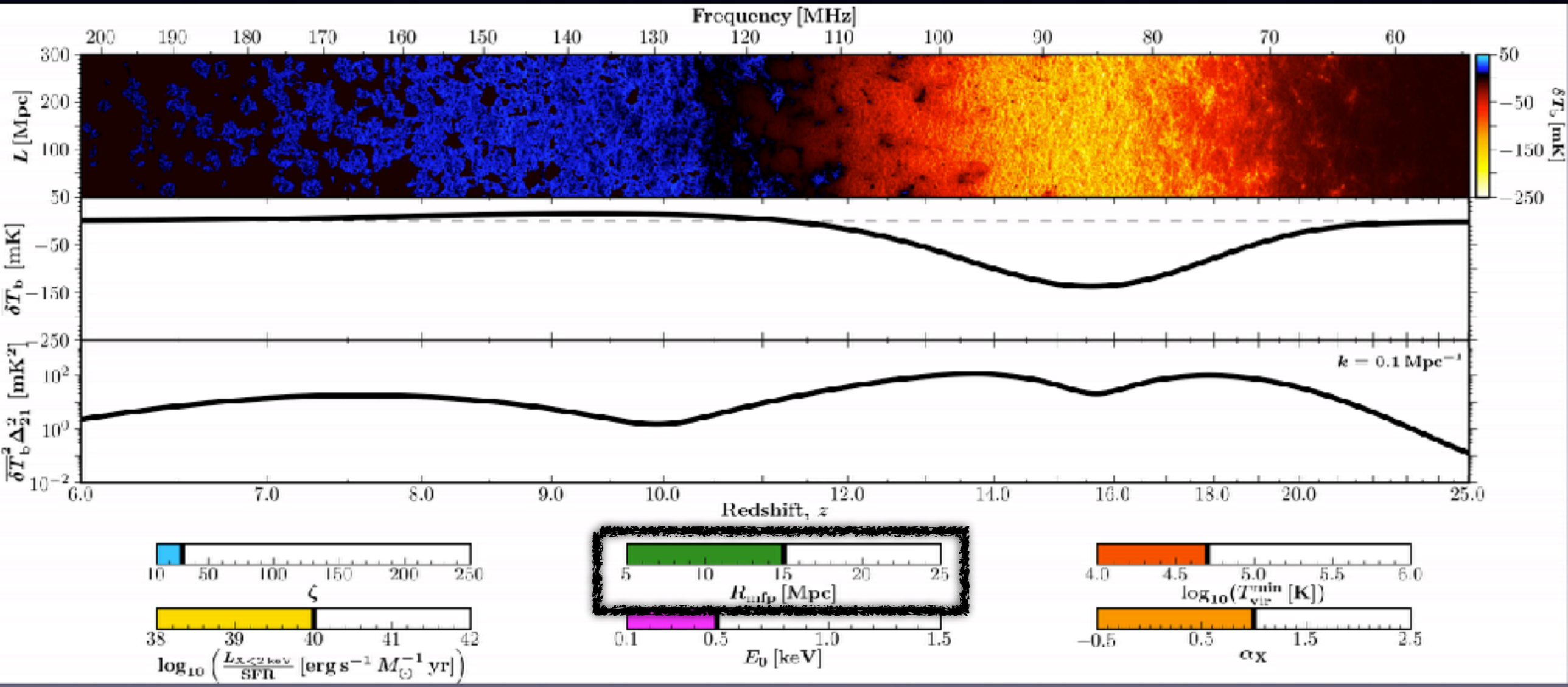
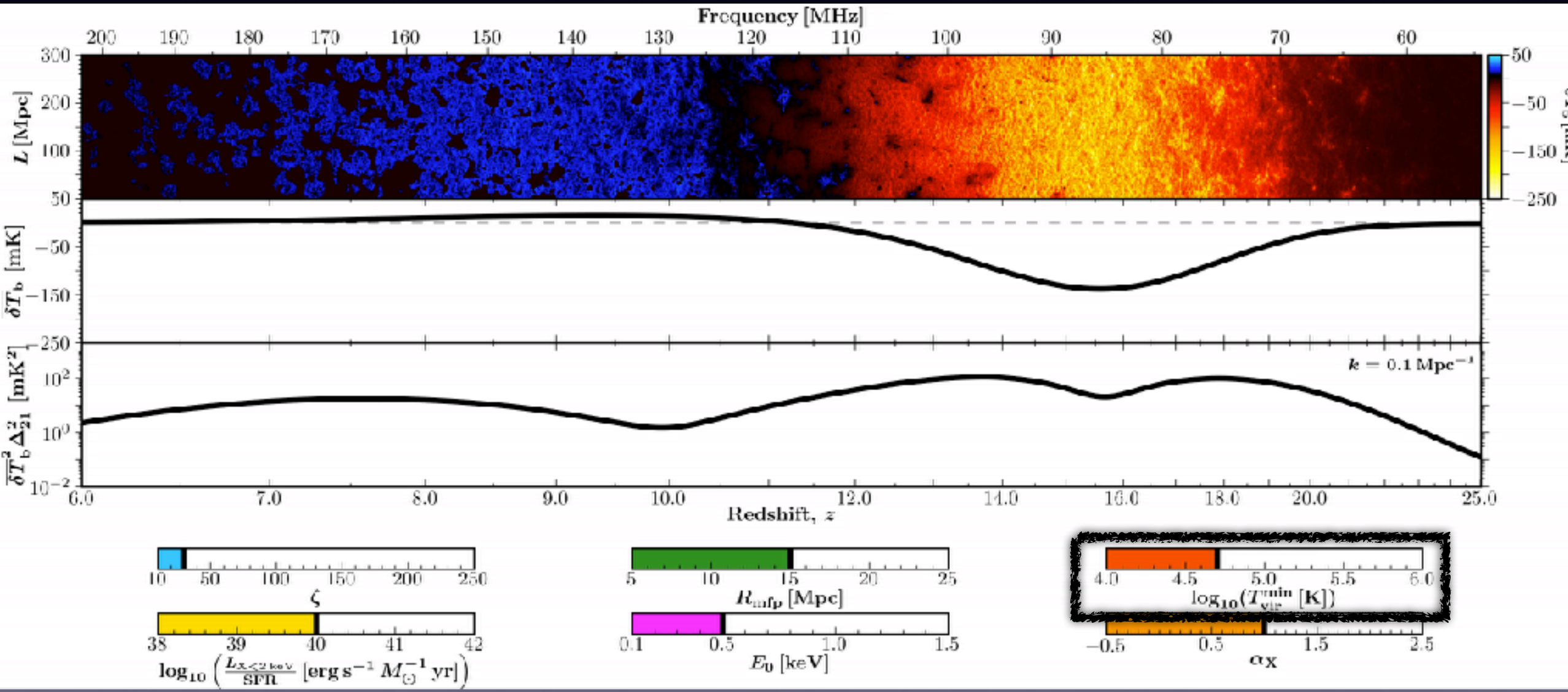


Epoch of Reionisation

T_{vir}: Minimum mass threshold for the formation of star-forming haloes



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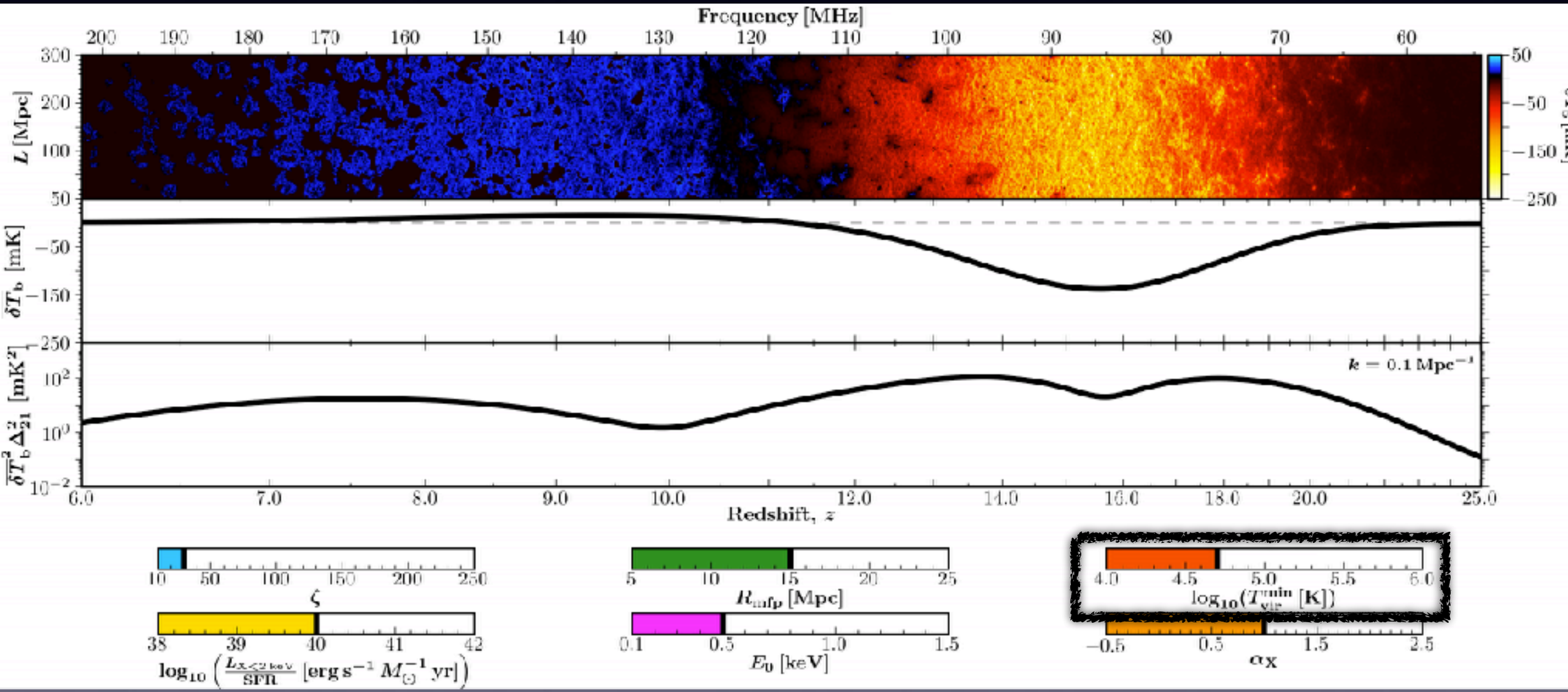
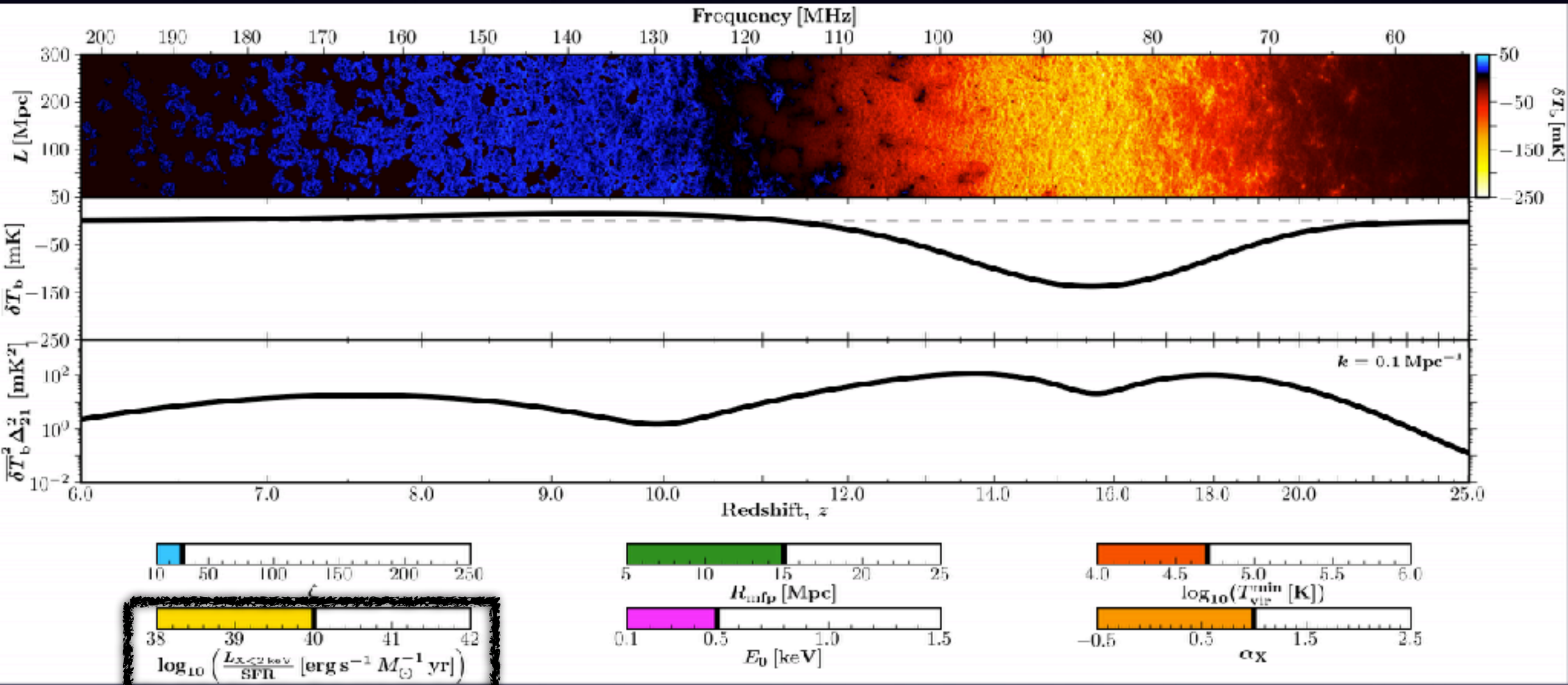


Epoch of (X-ray) Heating

L_X/SFR: Integrated soft-band (<2keV) luminosity of the X-ray sources



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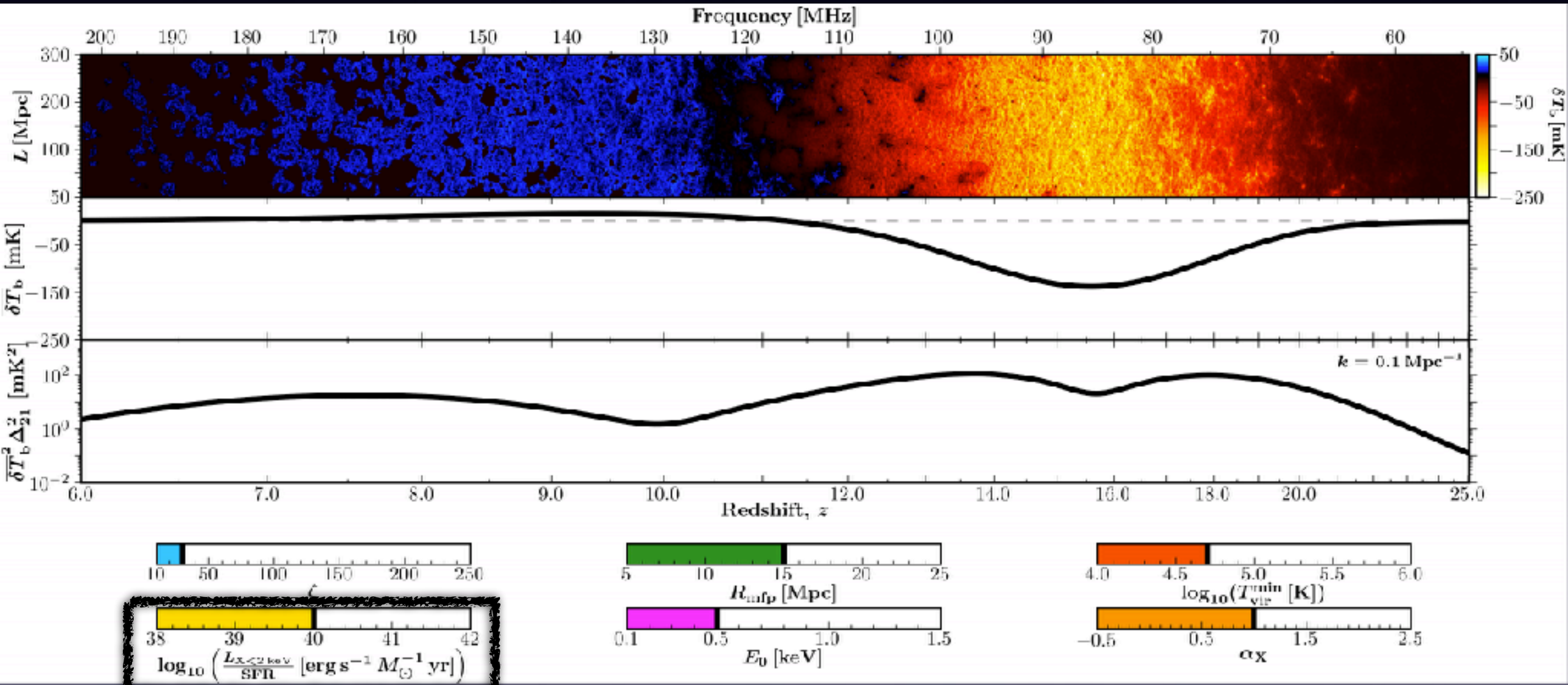
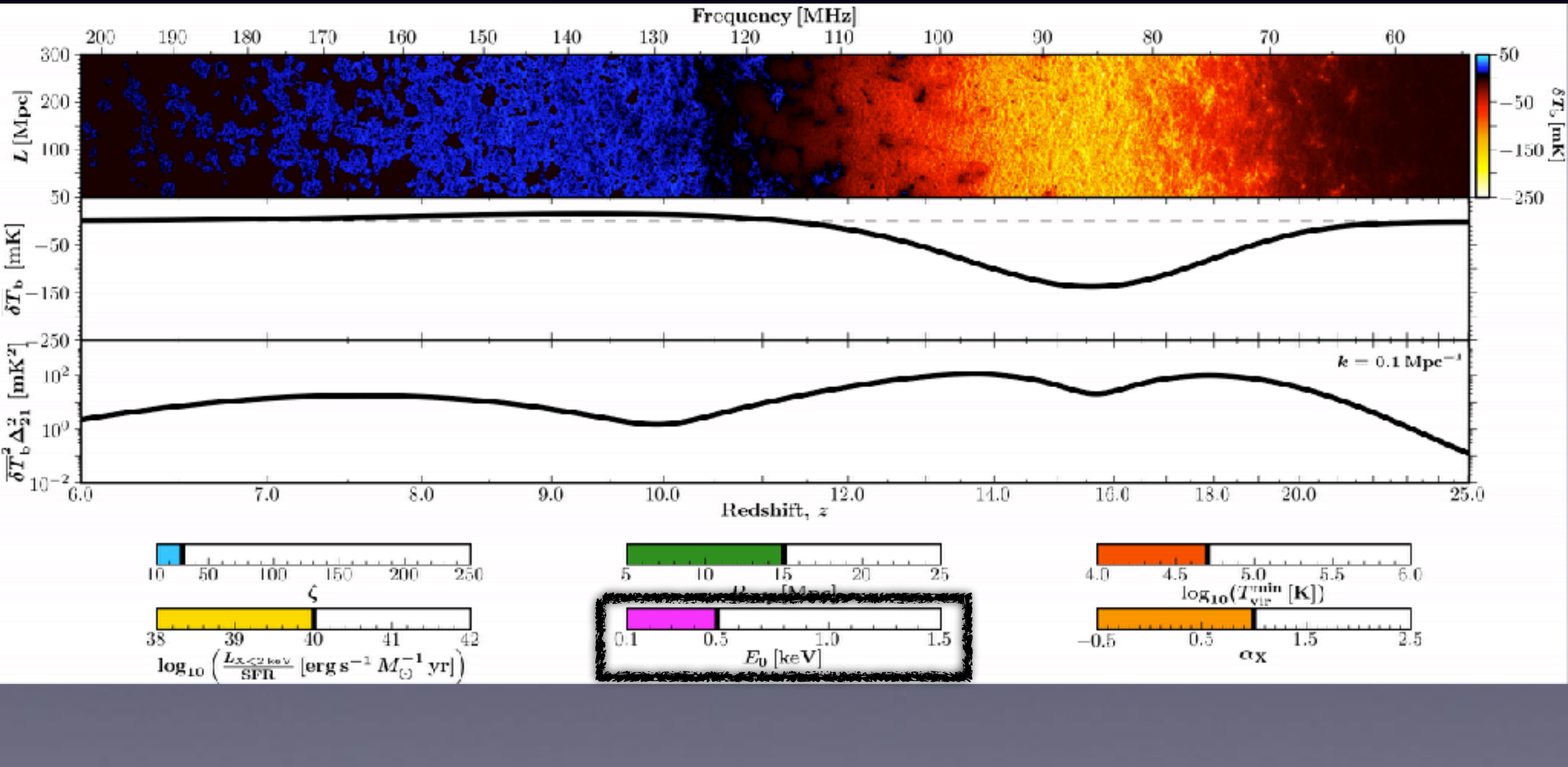


Epoch of (X-ray) Heating

E_0: energy threshold below which X-ray photons are absorbed by the host galaxy



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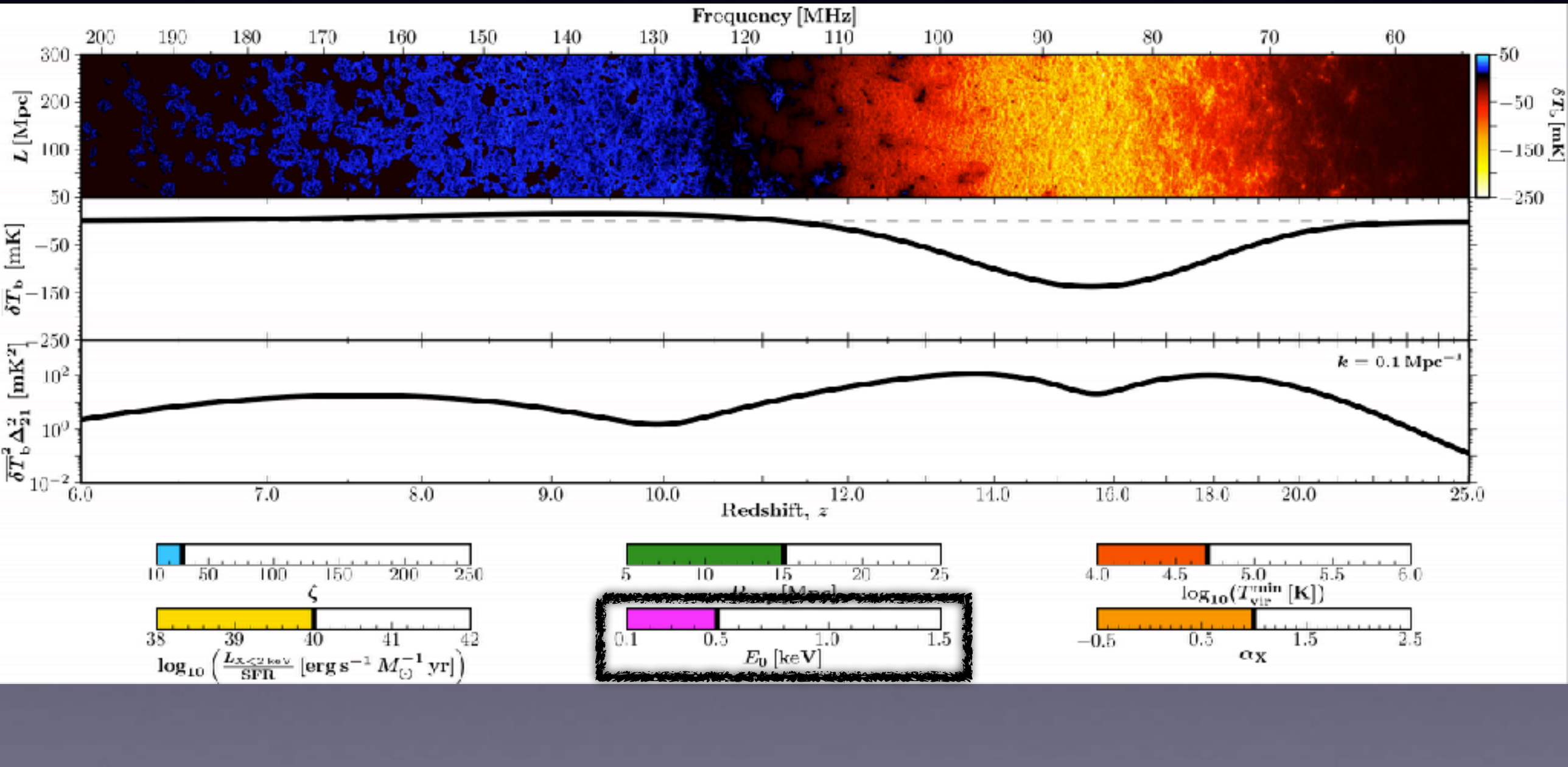
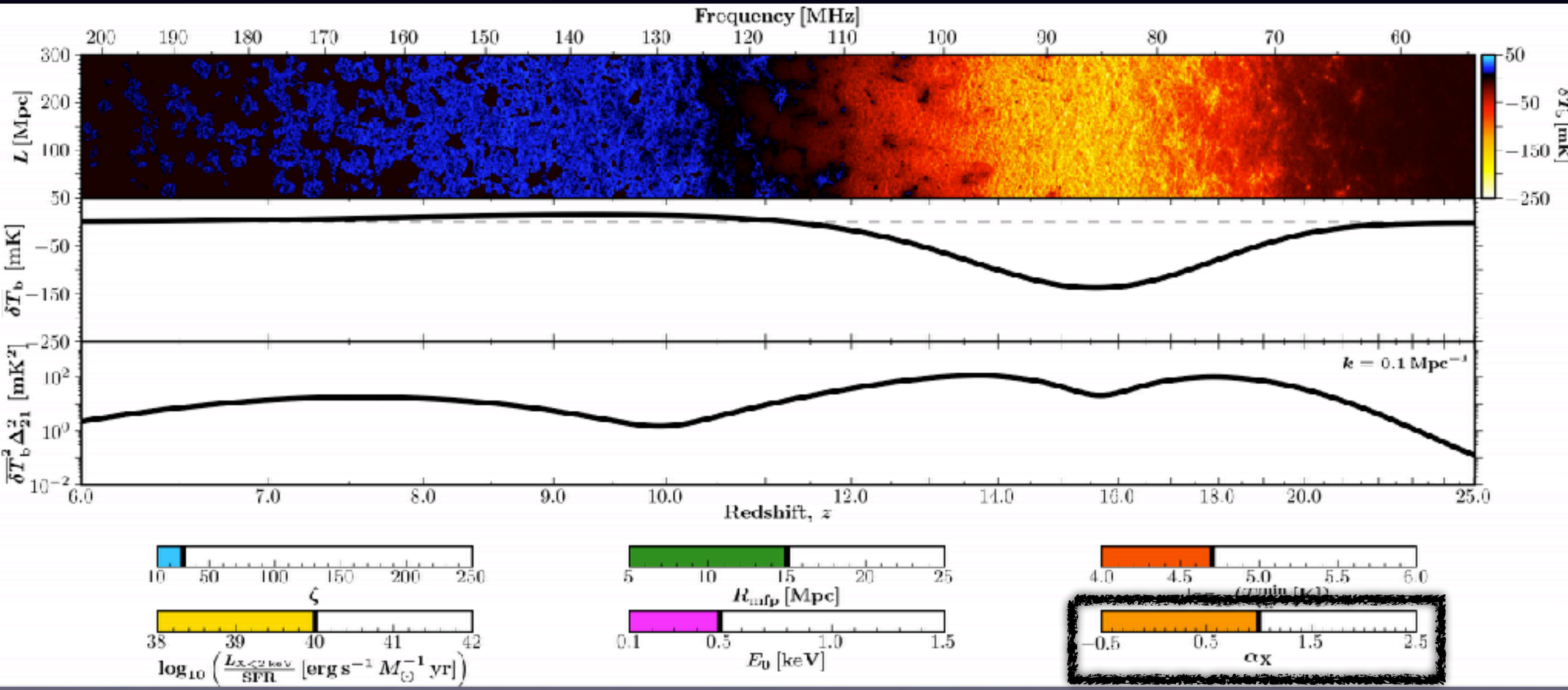


Epoch of (X-ray) Heating

α_X: The spectral index of the X-ray emission from early galaxies



Epoch of (X-ray) Heating

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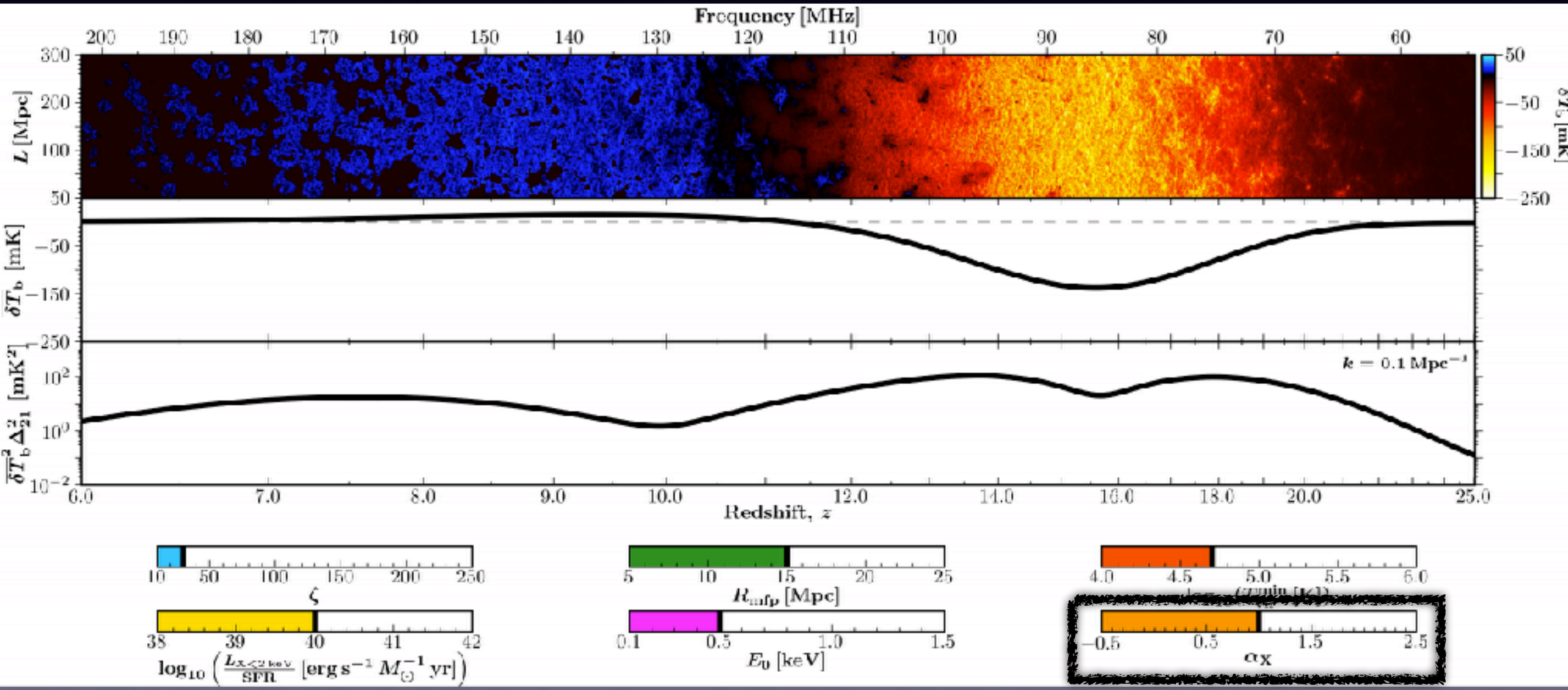
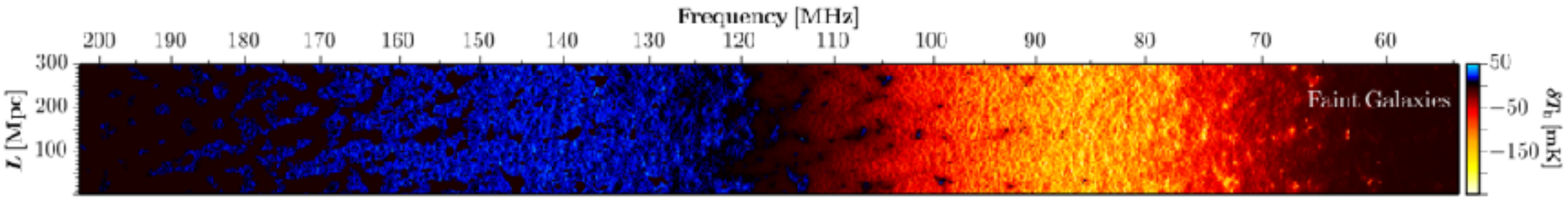
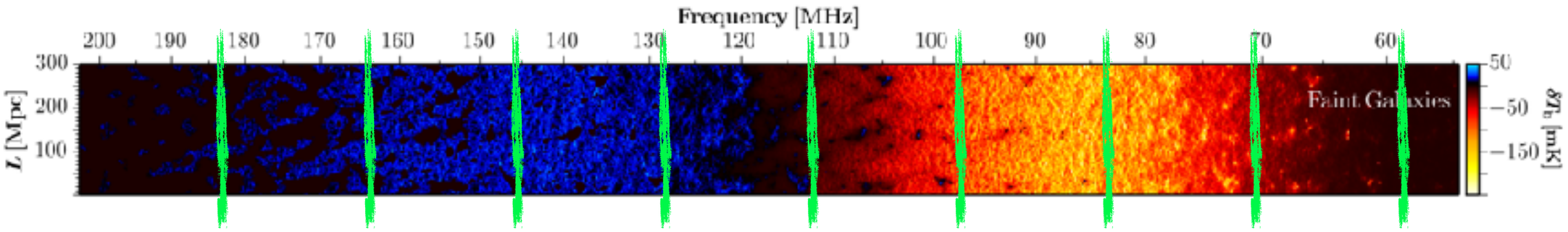


What does 21CMMC do?

Bradley Greig (UniMelb), Dec 14th, SALF IV, Sydney


Frequency [MHz]
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
300
200
100
L [Mpc]
Faint Galaxies
50
−50
−150
δT_b [mK]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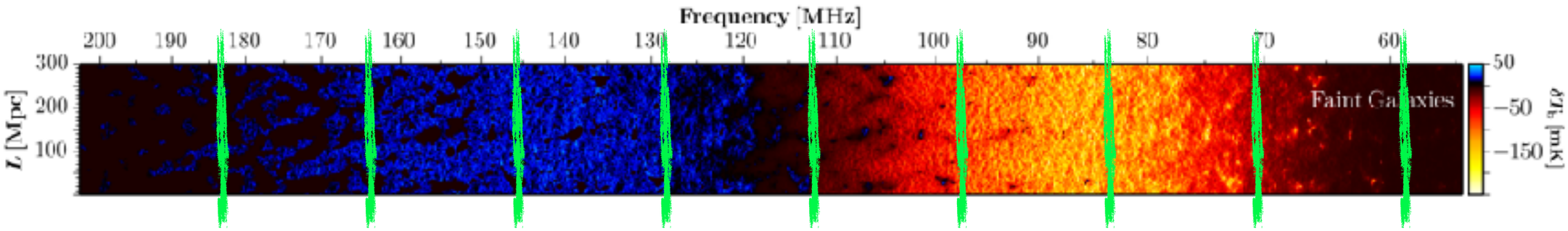
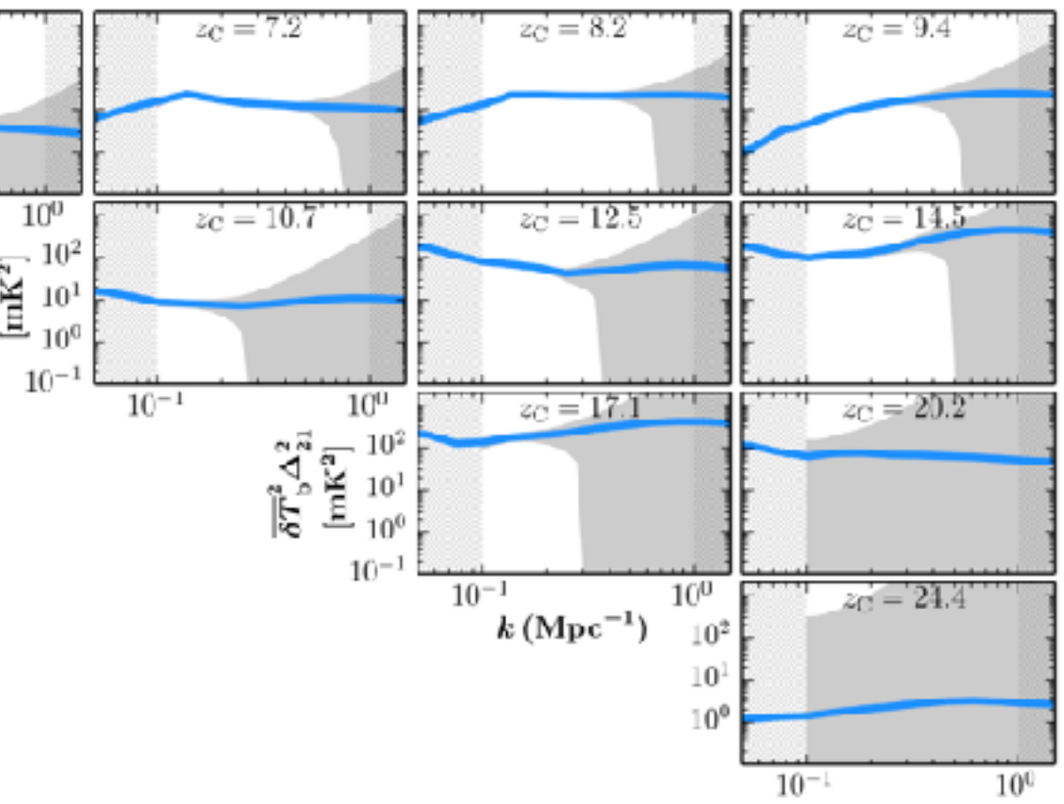
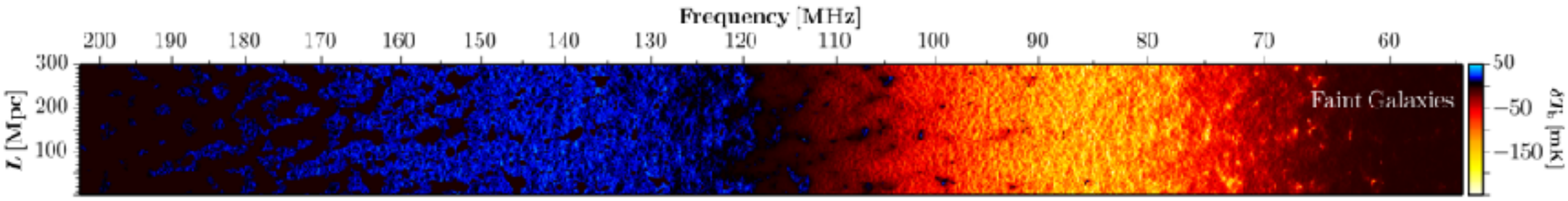


Faint Galaxies 1000hr
10% modelling
uncertainty with
light-cone





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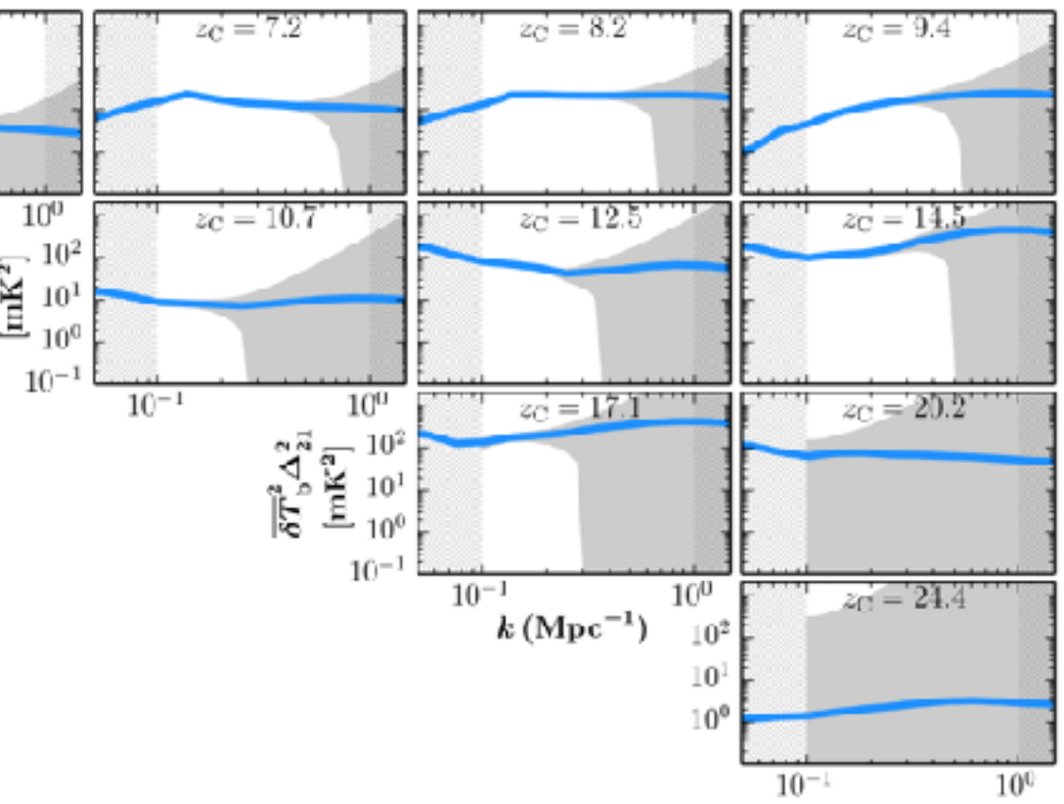

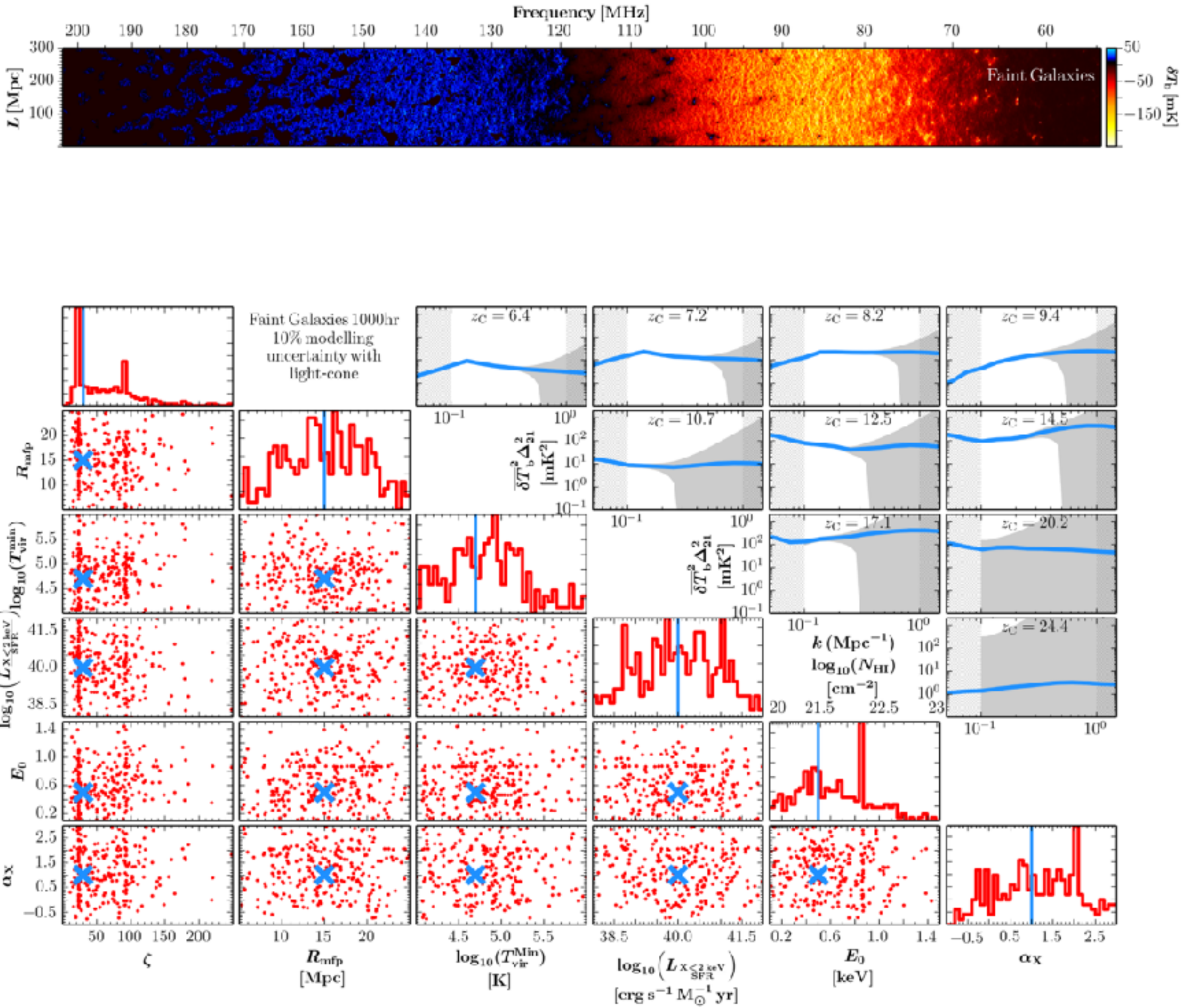
Frequency [MHz]
200 190 180 170 160 150 140 130 120 110 100 90 80 70 60
L [Mpc]
300 200 100
Faint Galaxies
50 −50 −150
δT_b [mK]
Faint Galaxies 1000hr
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$z_C = 6.4$
$z_C = 7.2$
$z_C = 8.2$
$z_C = 9.4$
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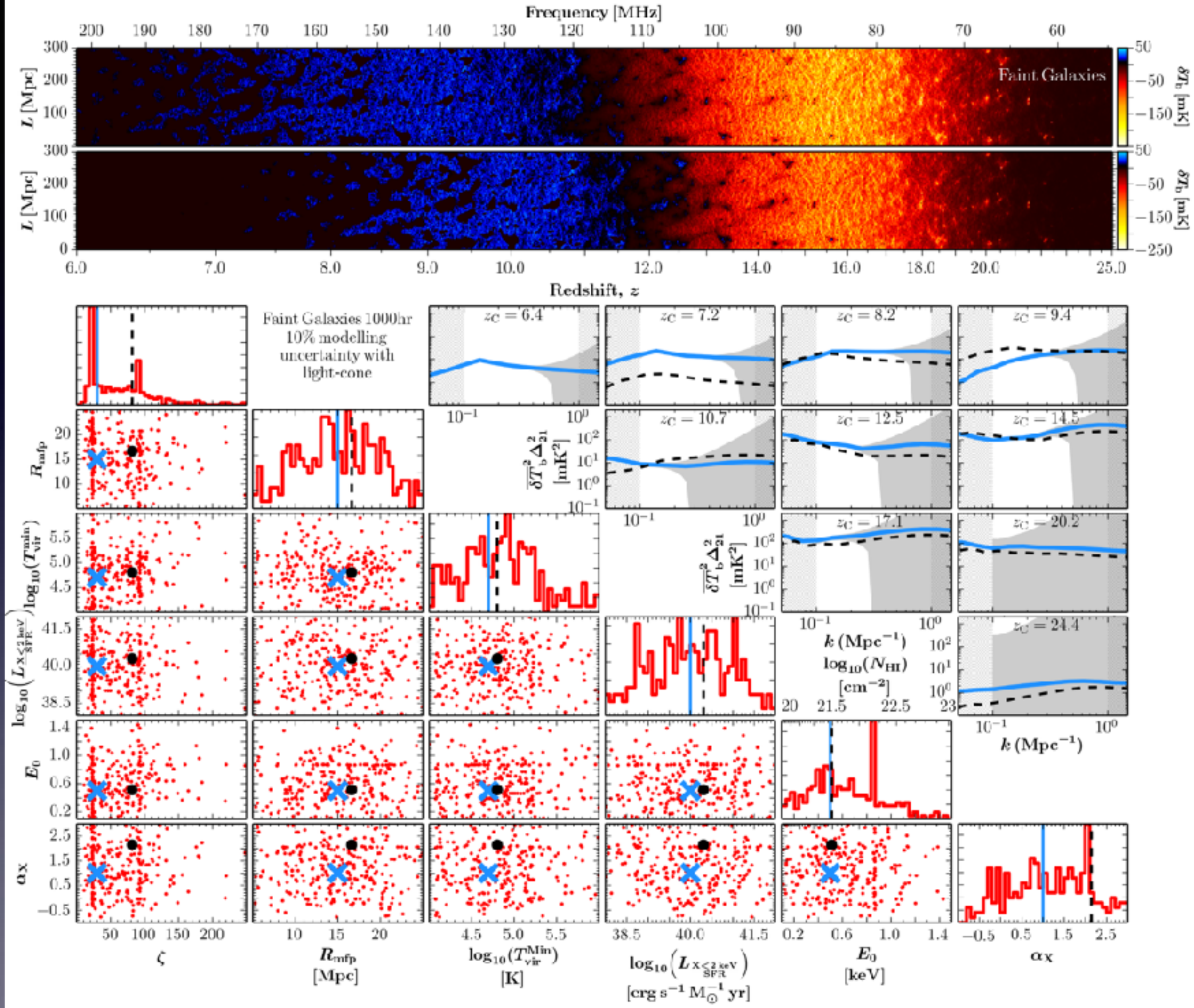
$z_C = 12.5$
$z_C = 14.5$
$z_C = 17.1$
$z_C = 20.2$
$z_C = 24.4$
$\overline{\delta T_b^2}\Delta^2_{21}$ [mK^2]
k (Mpc^{-1})
$R_{\rm mfp}$
$\log_{10}(T_{\rm vir}^{\rm min})$
$\log_{10}\left(\frac{L_{X<2\,\rm keV}}{\rm SFR}\right)$
$\log_{10}(N_{\rm HI})$ [cm^{-2}]
E_0
α_X
ζ
$R_{\rm mfp}$ [Mpc]
$\log_{10}(T_{\rm vir}^{\rm Min})$ [K]
$\log_{10}\left(L_{X<2\,\rm keV}\right)$ [erg s^{-1} M$_\odot^{-1}$ yr]
E_0 [keV]
α_X


Frequency [MHz]
Faint Galaxies
δT_b [mK]
L [Mpc]
Redshift, z
Faint Galaxies 1000hr
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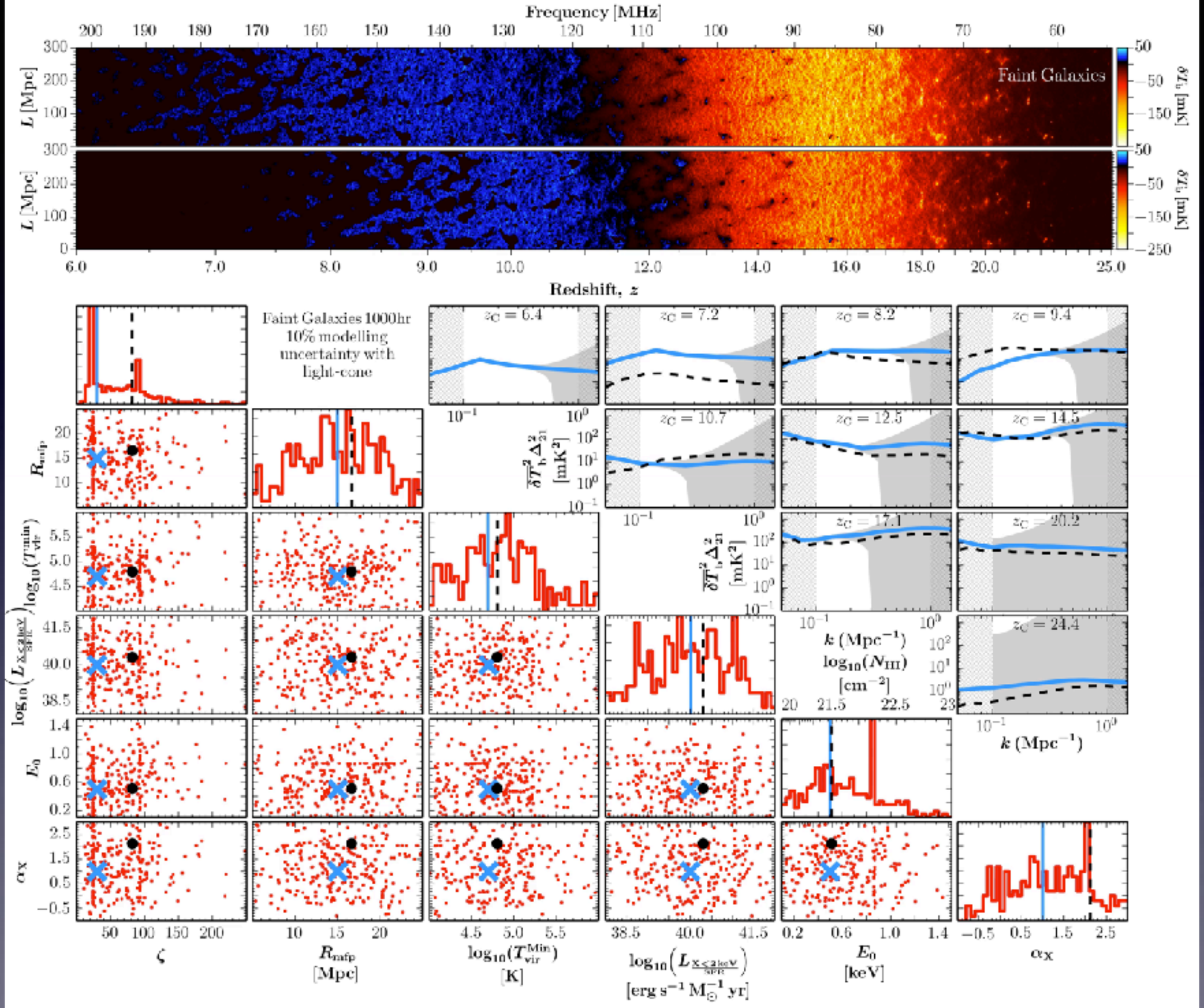
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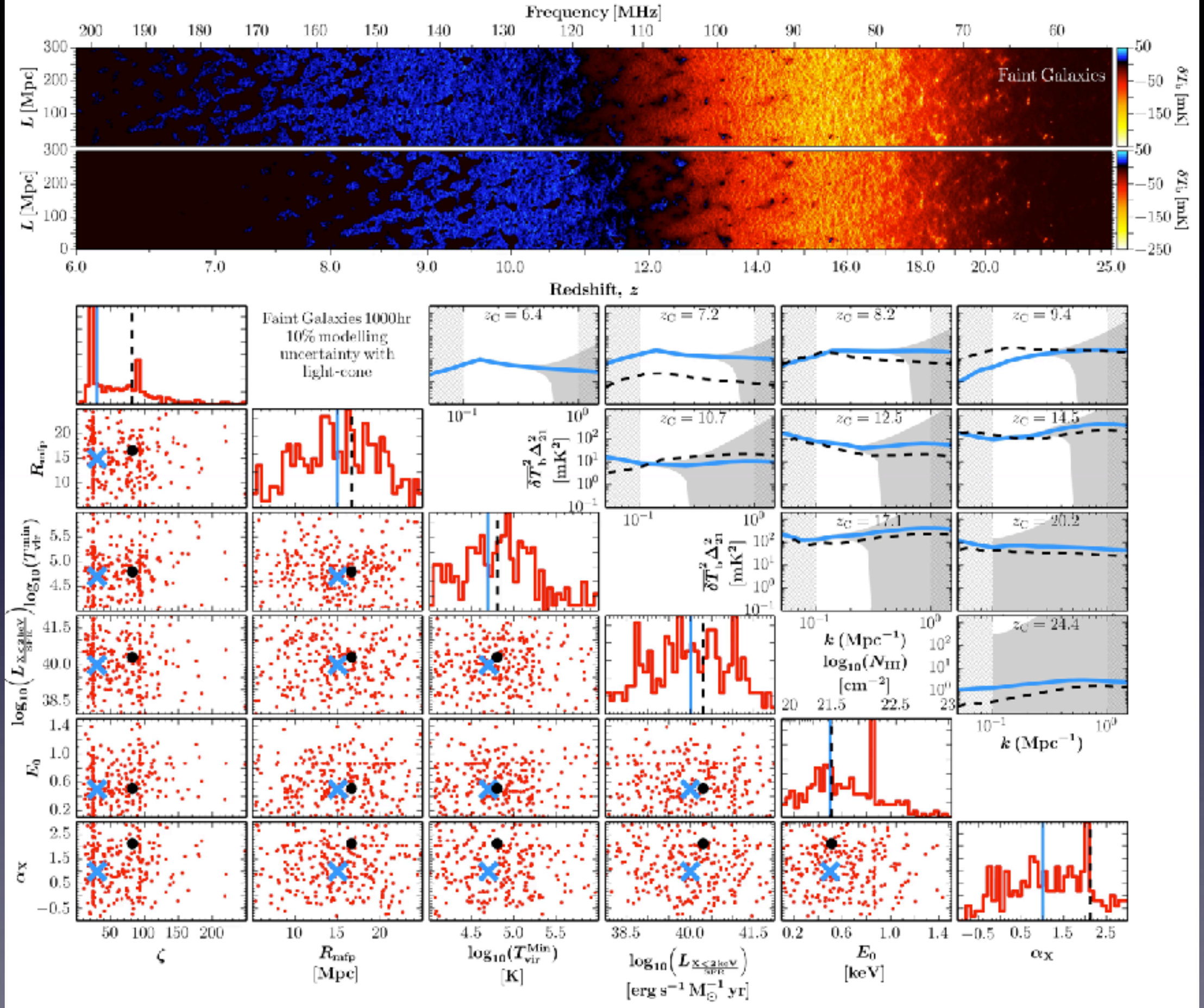
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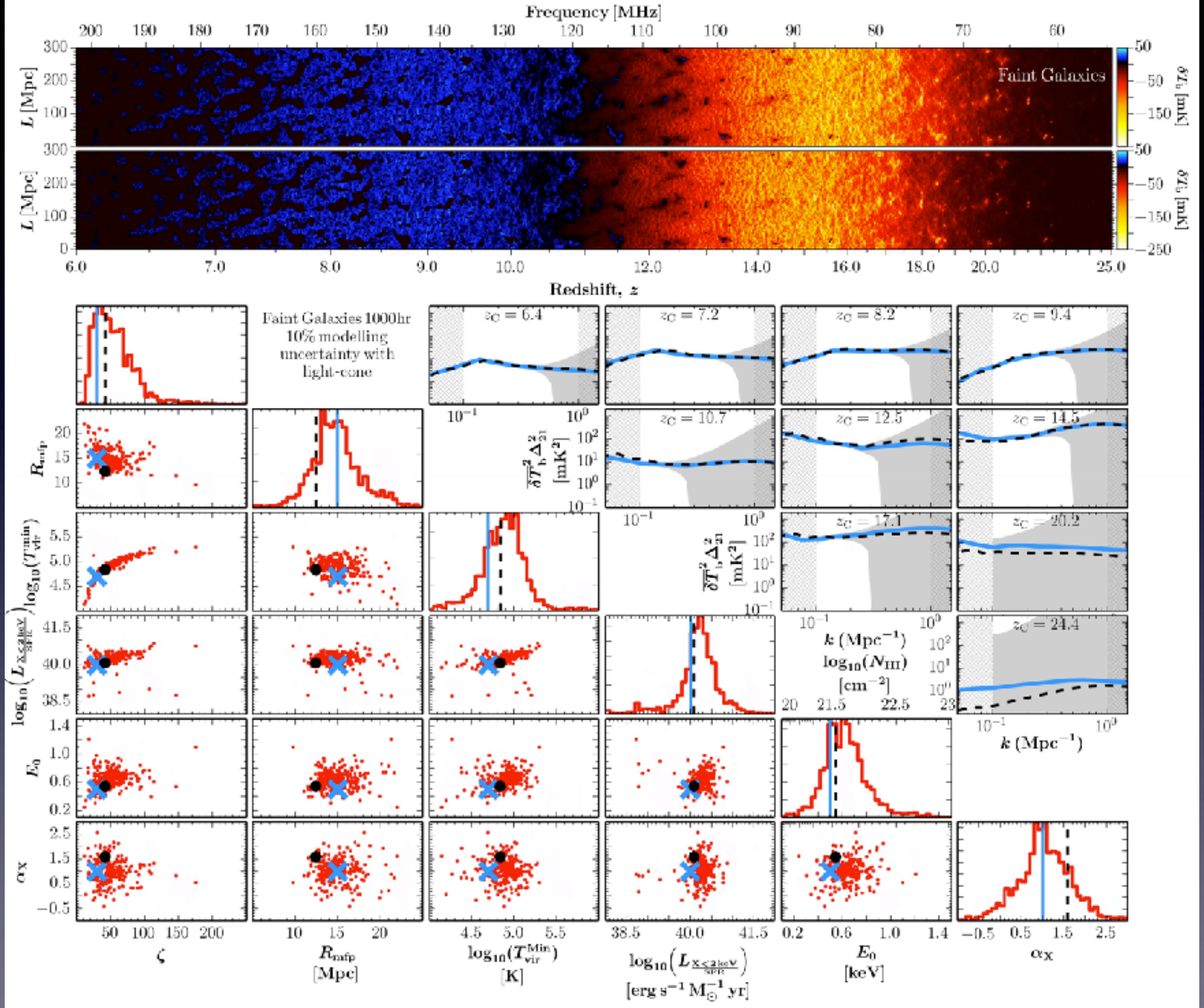
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E_0 [keV]
α_X
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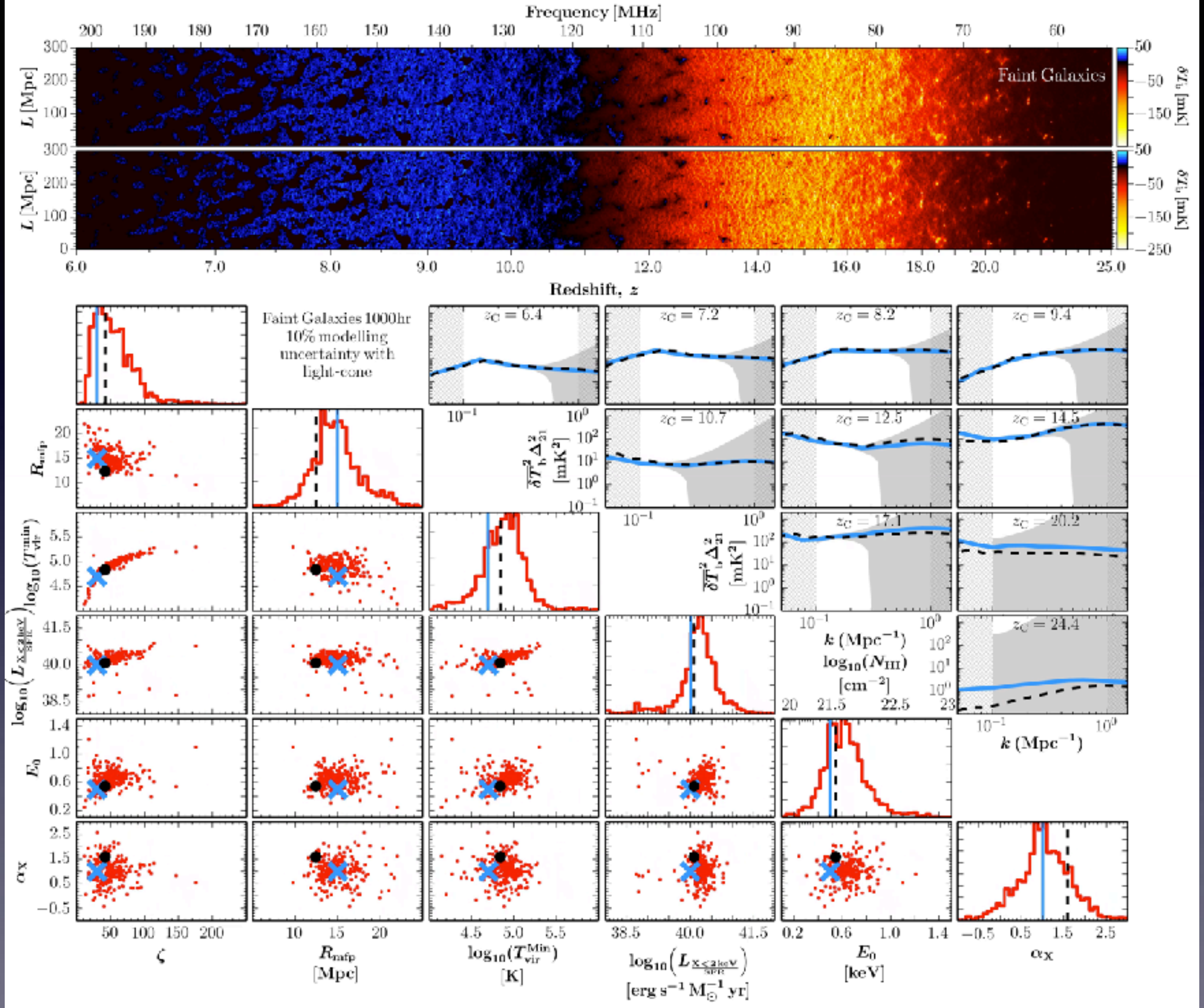
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k (Mpc^-1)
ζ
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log10(T_vir^Min) [K]
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E_0 [keV]
α_X
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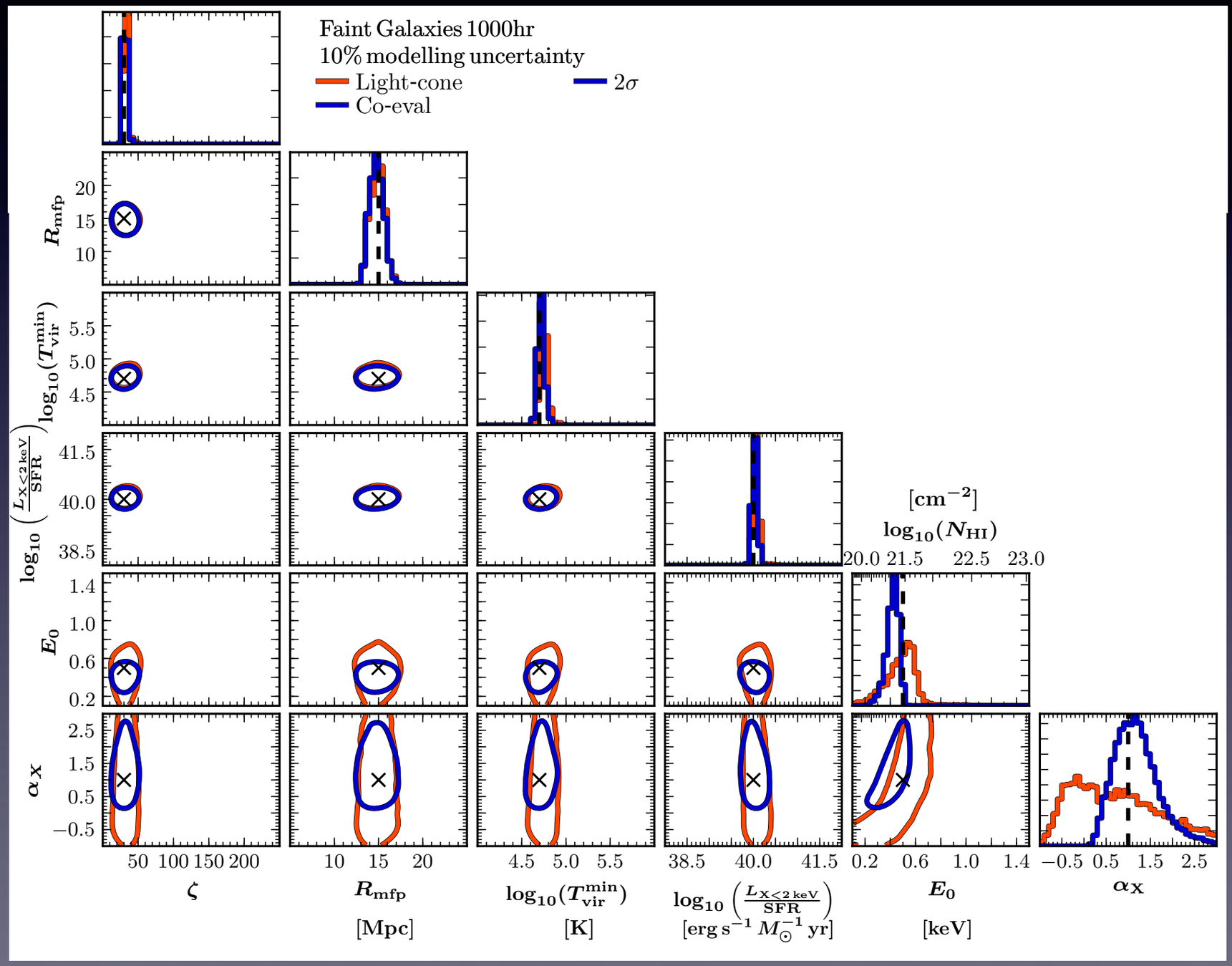
Flexibility of 21CMMC

- Produces a full, 3D 21cm light-cone at every step in the MCMC
- Enables exploring any metric describing/characterising the 21cm signal (i.e. statistical/tomographical)
- The simulated signal can be more readily manipulated/corrupted to mimic realistic observations
- Can simultaneously constrain cosmology and astrophysical parameters (e.g. Kern et al. 2017)

Investigating light-cone effects

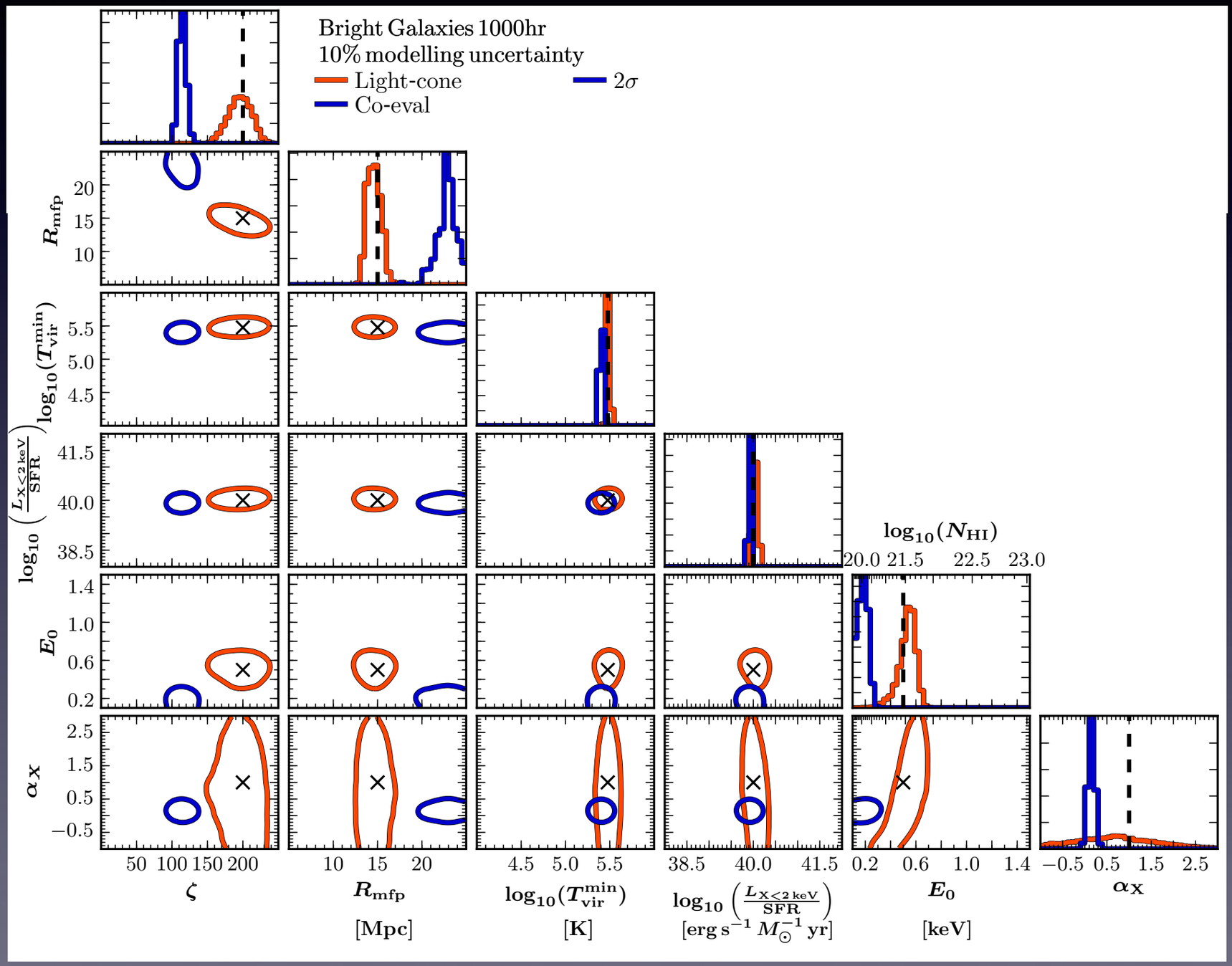
- Simulations naturally output co-evolution (co-eval) cubes
- Can quantify the bias in recovered astrophysical parameters when ignoring the light-cone effect

Investigating light-cone effects



Greig & Mesinger, in prep.

Investigating light-cone effects



Greig & Mesinger, in prep.

Conclusion

- First MCMC code to sample full 3D simulations of the EoR
- Can provide astrophysical parameter constraints on any EoR model, recovered from any statistical measure of the 21 cm signal
- New version to appear on github very shortly (https://github.com/BradGreig/21CMMC)
- Under going continual development, adding in more features and generalising the astrophysical parametrisation (source models etc.)
- Animations can be found at (http://homepage.sns.it/mesinger/21CMMC)