Cross-correlating cosmic fields in the Epoch of Reionisation

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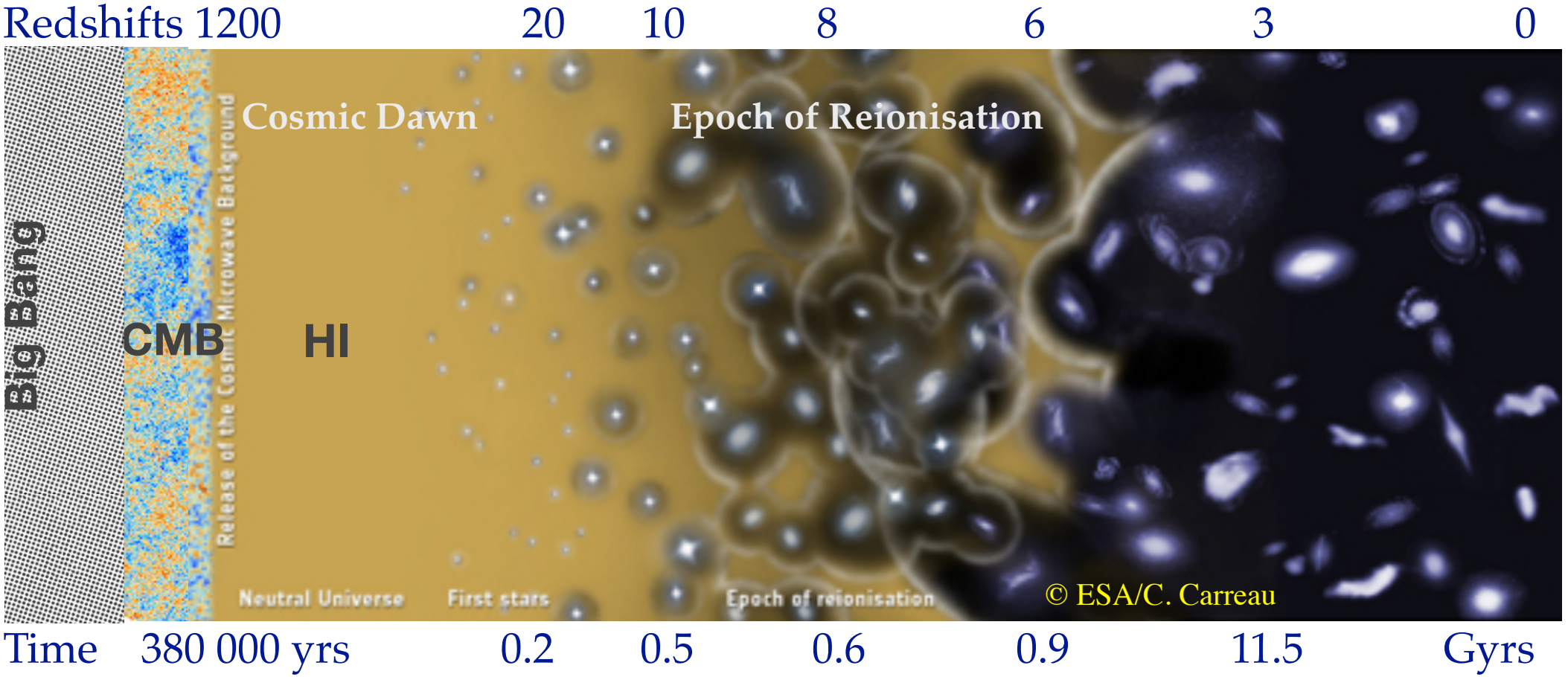
Cosmic dawn and the Epoch of Reionization



From recombination to reionisation

… a very brief history of the Universe

Epoch of Reionization: When?

The Planck **breakthrough** (Planck collaboration 2016, XLVI & XLVII):

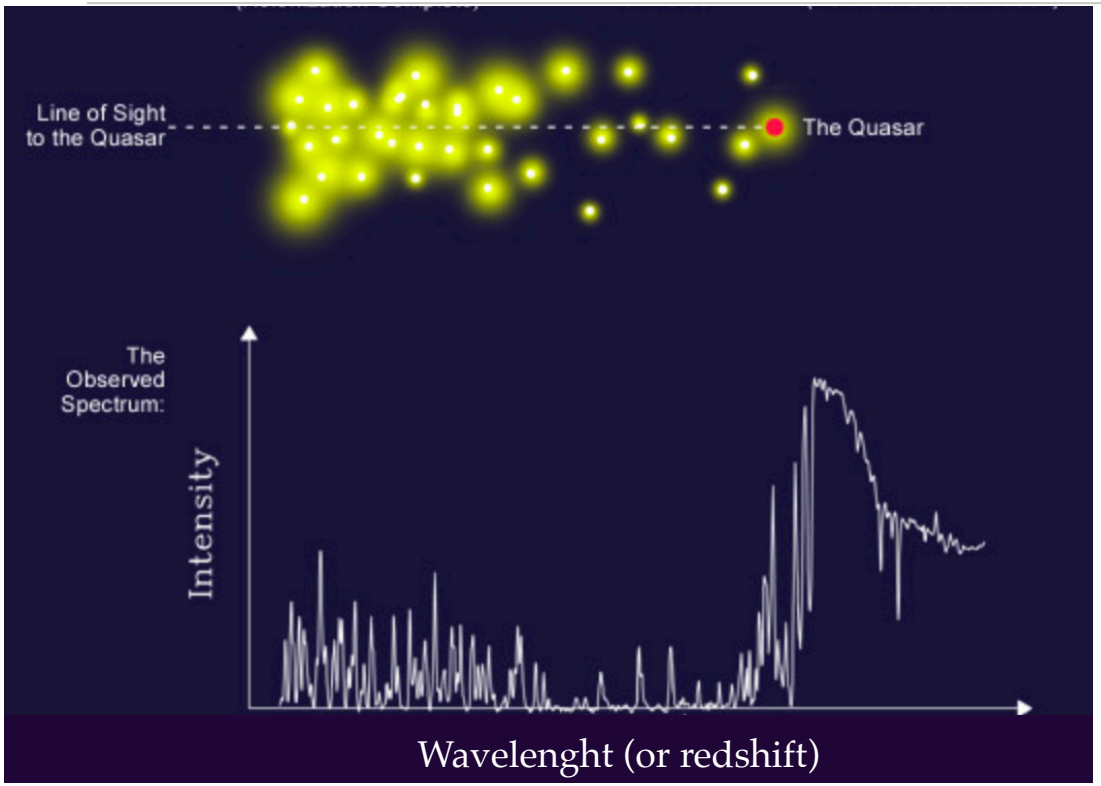
- Scattering optical depth due to free electrons:

$$\tau(z) = \int_{t(z)}^{t_0} n_e \sigma_T \, c dt$$

- $\tau = 0.058 +- 0.012$ (Previously: $0.089 +-0.014$)
- Average redshift of reionization: $z \sim 8$
- Universe is ionized at less than the 10% level at $z>10$.

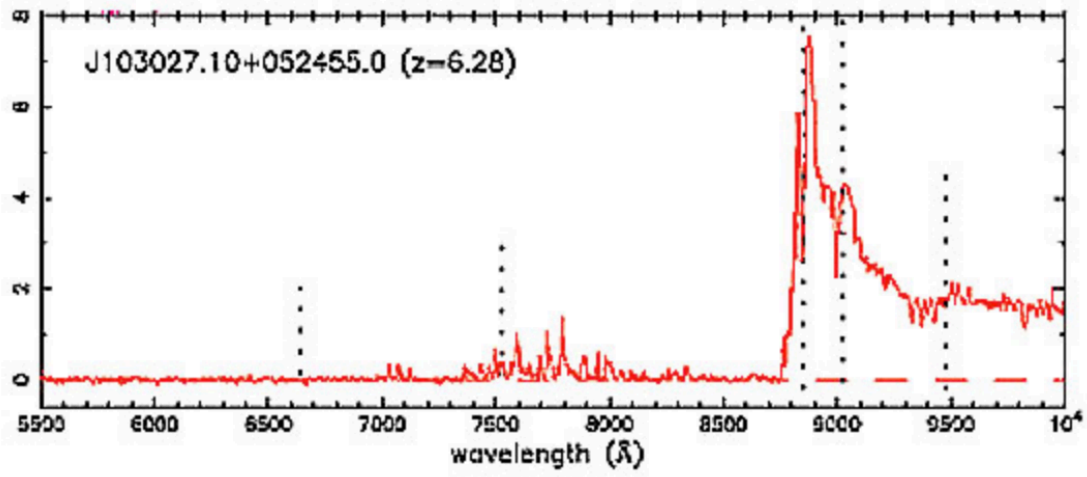
=> Reionization is extremely rapid and at our fingerprints!

Epoch of Reionization: When complete?



The Gunn-Peterson trough in high-redshift quasars

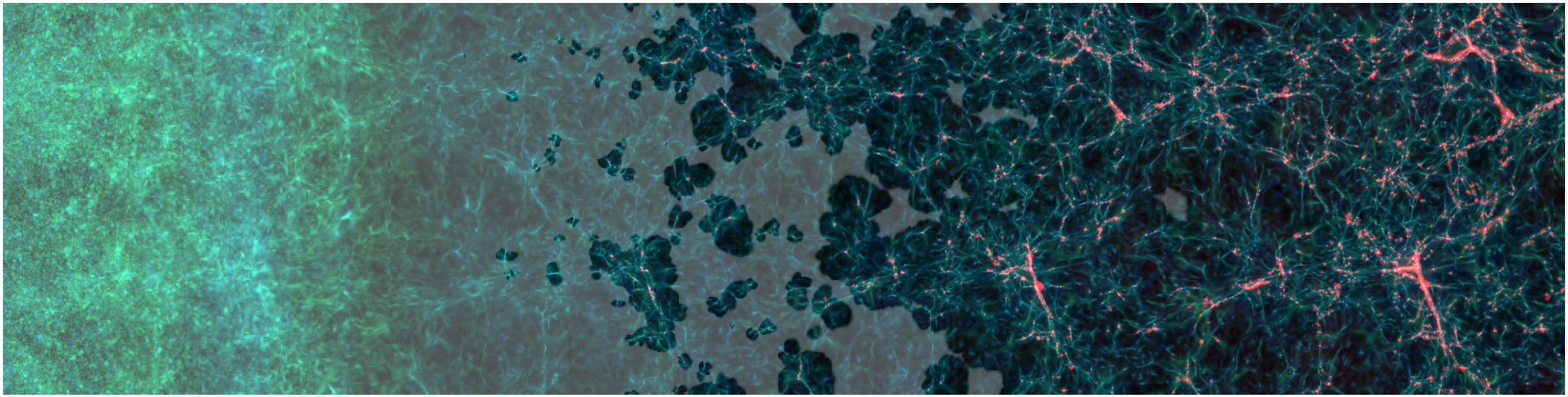
Ly-α line: even trace amounts of HI, $x_{HI} > 10^{-5}$ result in no flux being detected in the forest.



=> Reionization is extremely rapid, and complete at z~6

We have now a reasonable handle of when….

The Epoch of Reionisation: what and how?



EMMA simulation, D. Aubert & N. Deparis

… But what and how?…… we don't really know!

Stellar populations vs black holes, IMF in first galaxies, role of supernovae and radiative feedback, metal pollution, efficiency of star formation, IGM structures, UVB evolution etc..

Galaxy candidates have been found out to z~10. Are these the stellar populations responsible for the Cosmic Dawn and reionization?

The Epoch of Reionisation: galaxy candidates

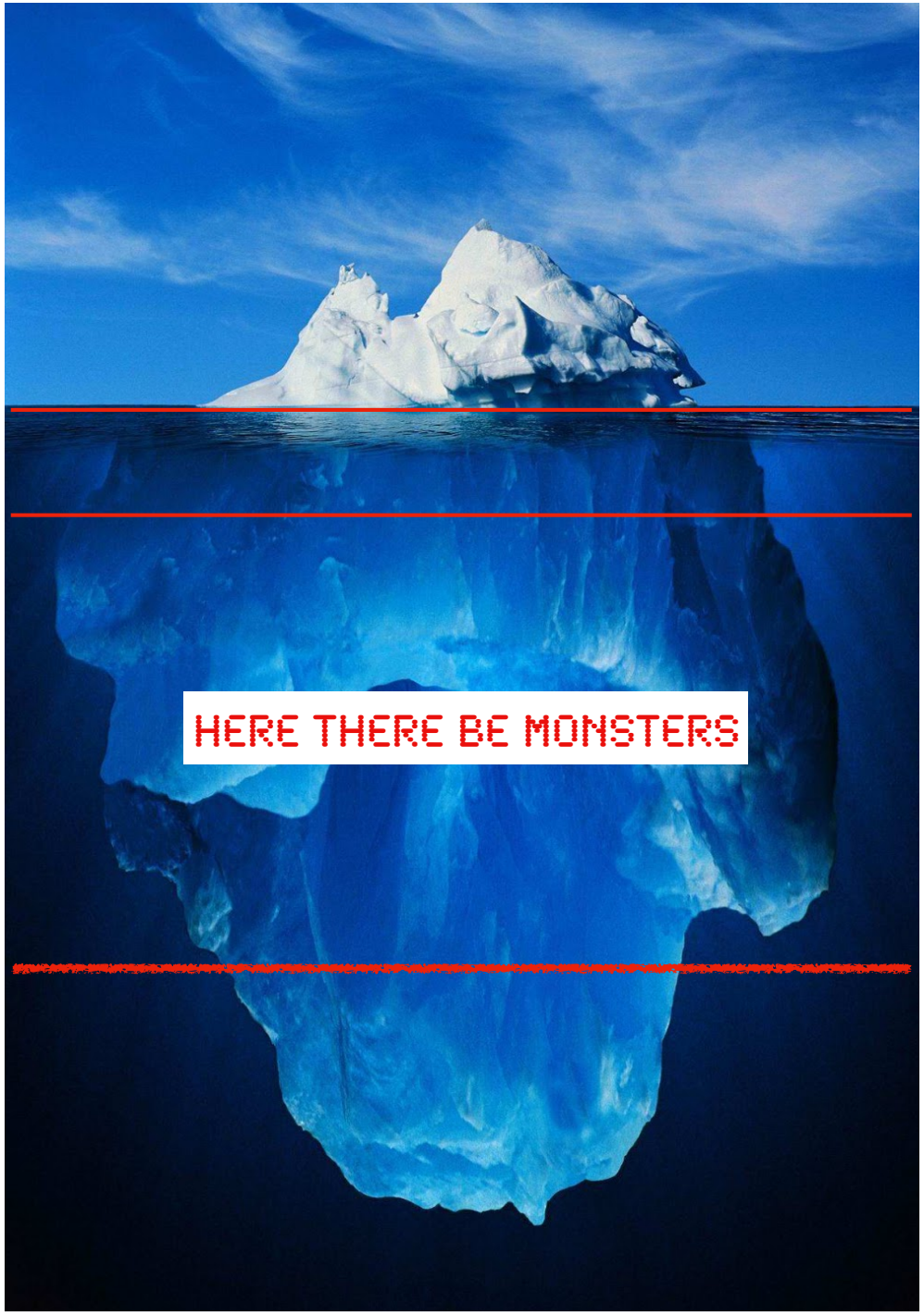
@ z=8

Hubble limit

JWST limit

Hidden population of faint and abundant galaxies?

Complete reionisation



M_{AB}=-22

M_{AB}=-18

M_{AB}=-14

M_{AB}=-10

Idea: Mesinger

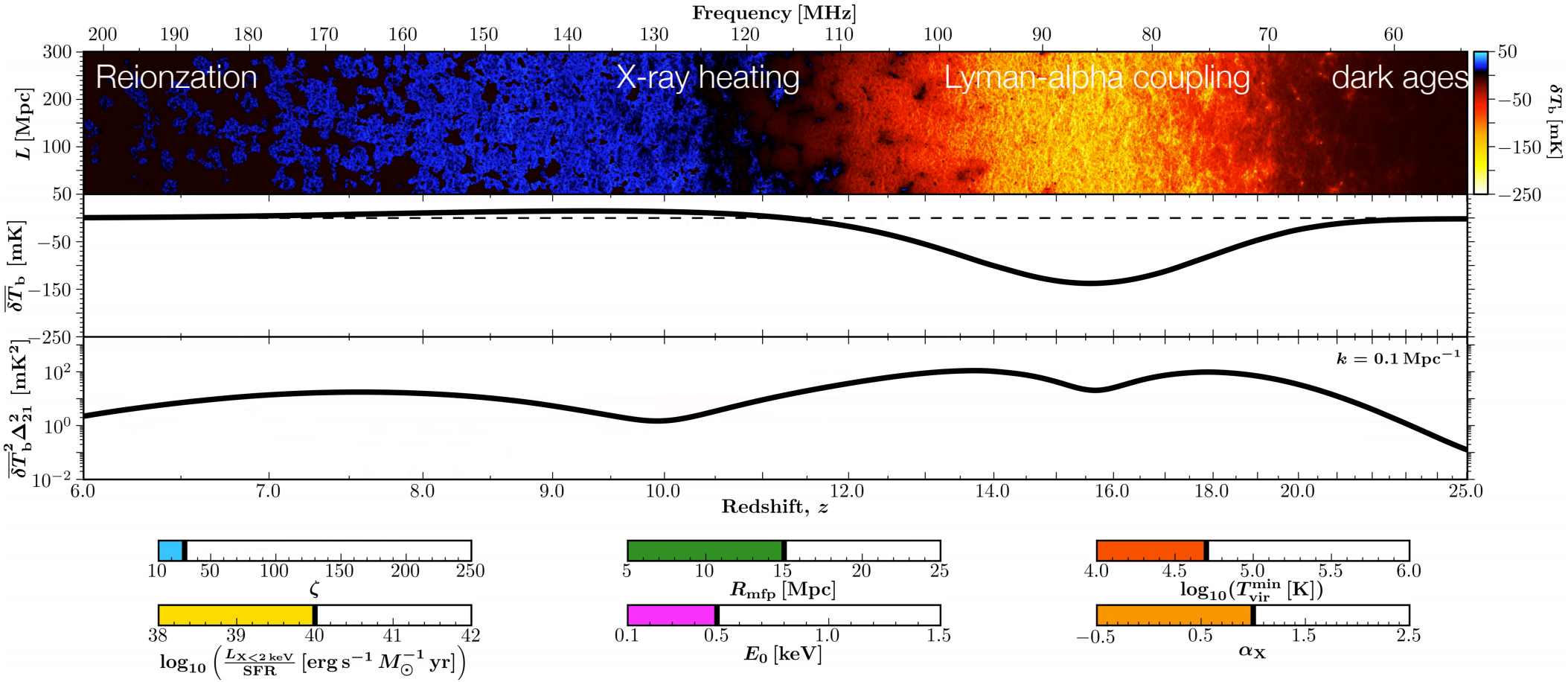
Get ready for the revolution:

the cosmic 21 cm signal with SKA

HI at 21cm, the most natural probe of reionisation

HI in the EoR: difficult to predict

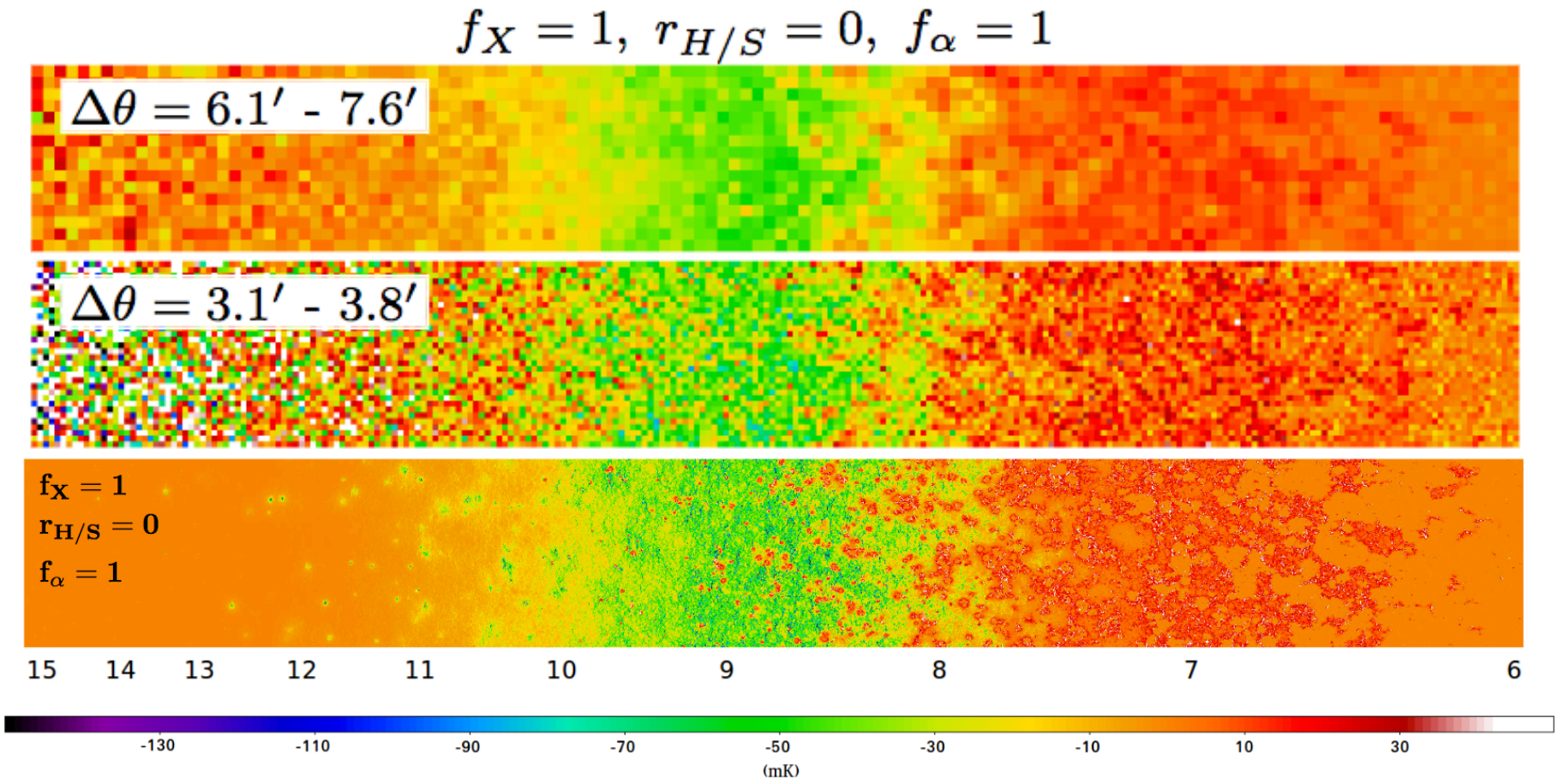
Movie from Bradley Greig, Greig & Mesinger, 2015, 2017….. in the case of faint galaxies…..



Different astrophysical models of galaxies and the IGM show different 21-cm power spectra
A lot of degeneracies

Variation is up to a factor of ~10, at a fixed cosmic epoch…

HI in the EoR: difficult to detect



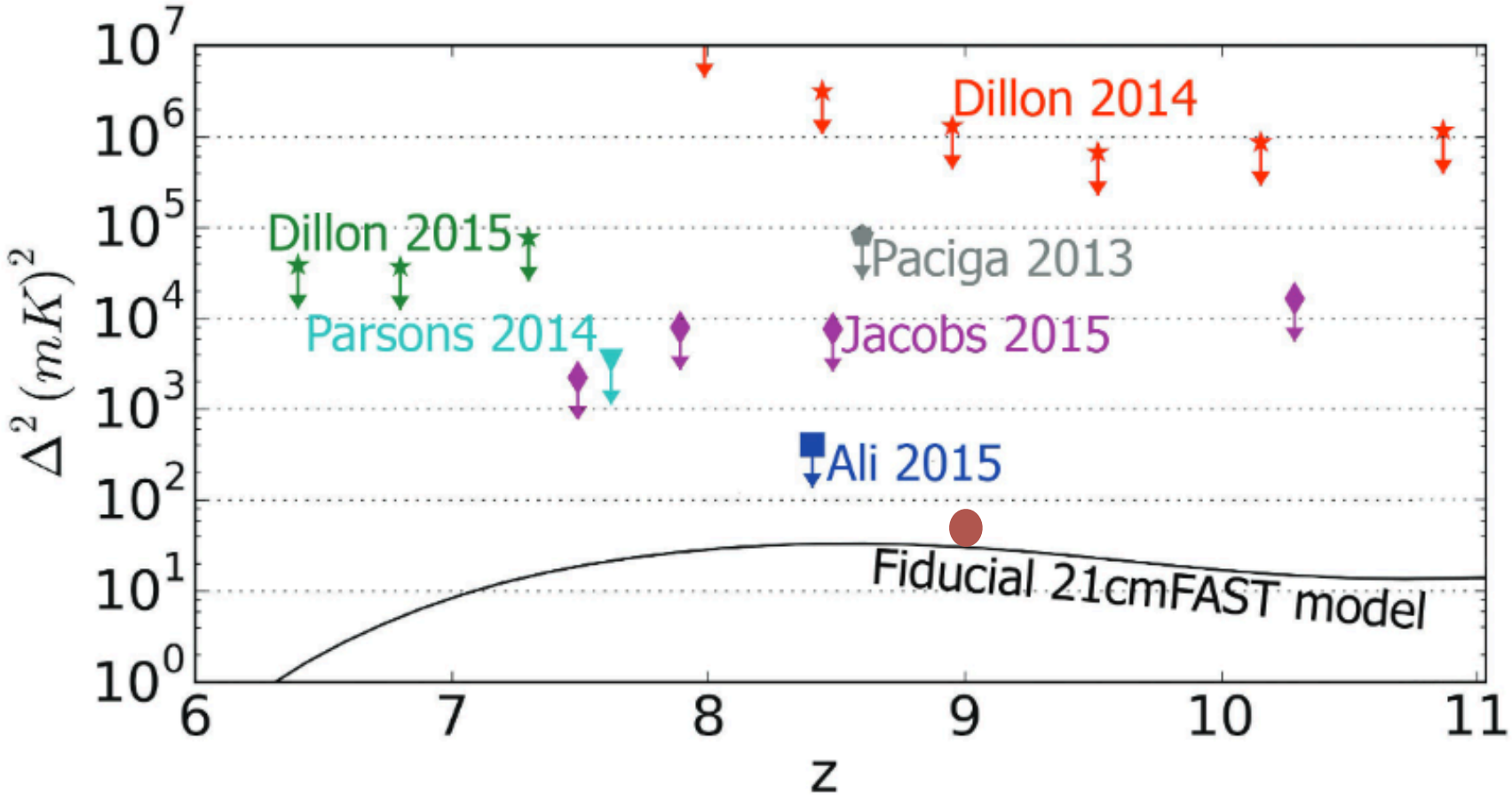
Tomography becomes difficult at z > 10

From Semelin et al. 2017, assuming 1000hr of SKA

HI in the EoR: Current status

LOFAR, PAPER, MWA, HERA:

Most effort so far is spent on “Discovery of Systematics”



From DeBoer et al. 2017

Other observables of the Epoch of Reionisation

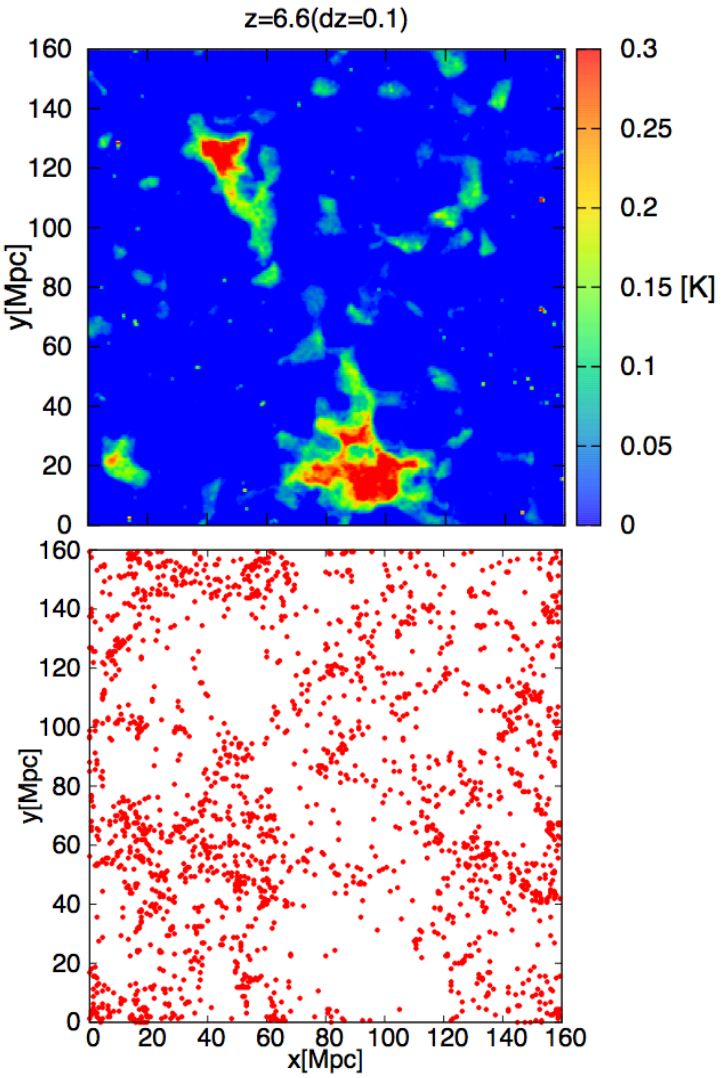
- Individual galaxies
  - detected from their continuum emission (UV rest-frame) or Ly-α line

- Diffuse background from galaxies (collective emission) — Intensity Mapping
  - detected from their CII and Ly-α lines
  - near-IR and far-IR continuum

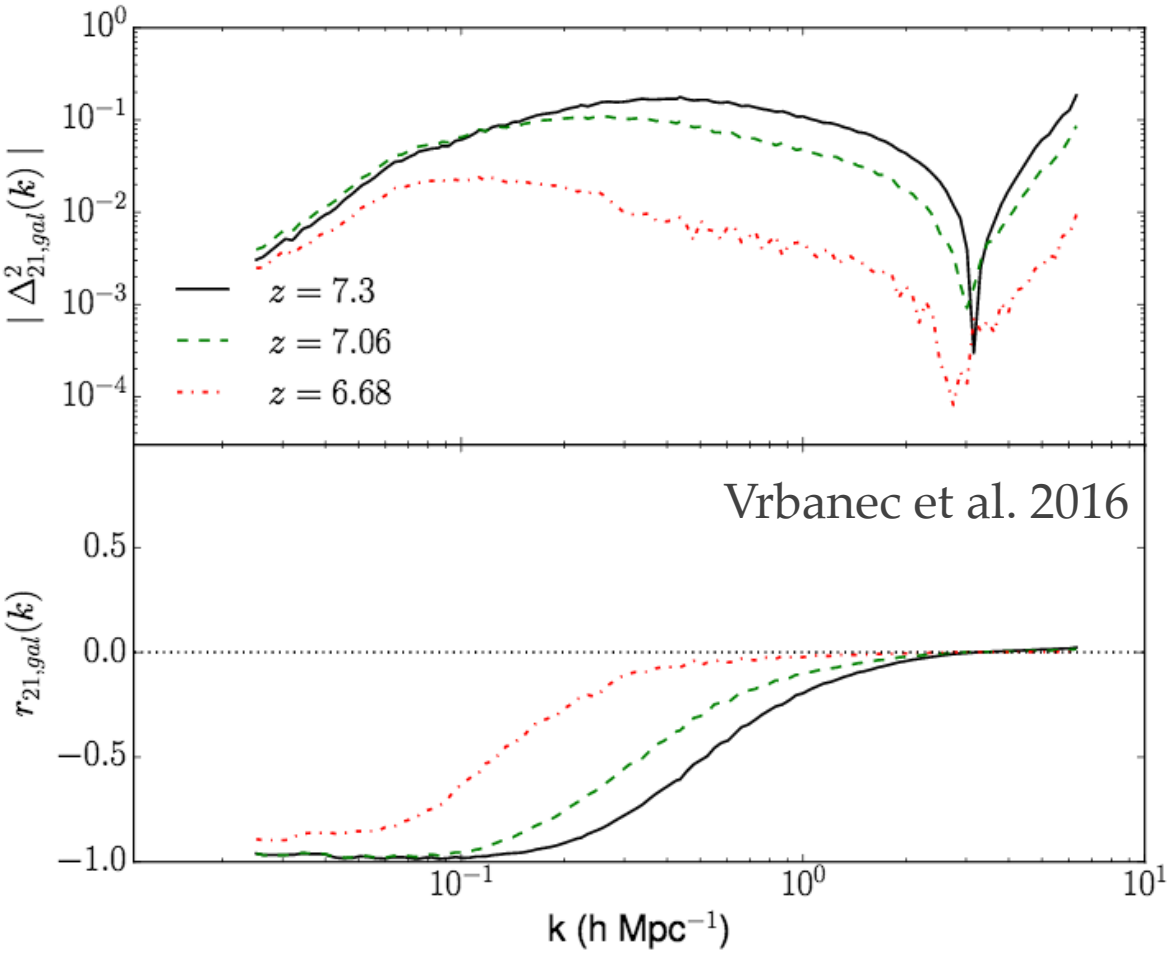
- Cosmic Microwave Background fluctuations
  - in temperature
  - in polarisation (hopeless for cross-correlation…, Tashiro et al. 2010)

=> cross-correlation or cross-analyses with HI

HI x Ly-α emitters: the theory



Kubota et al. 2017



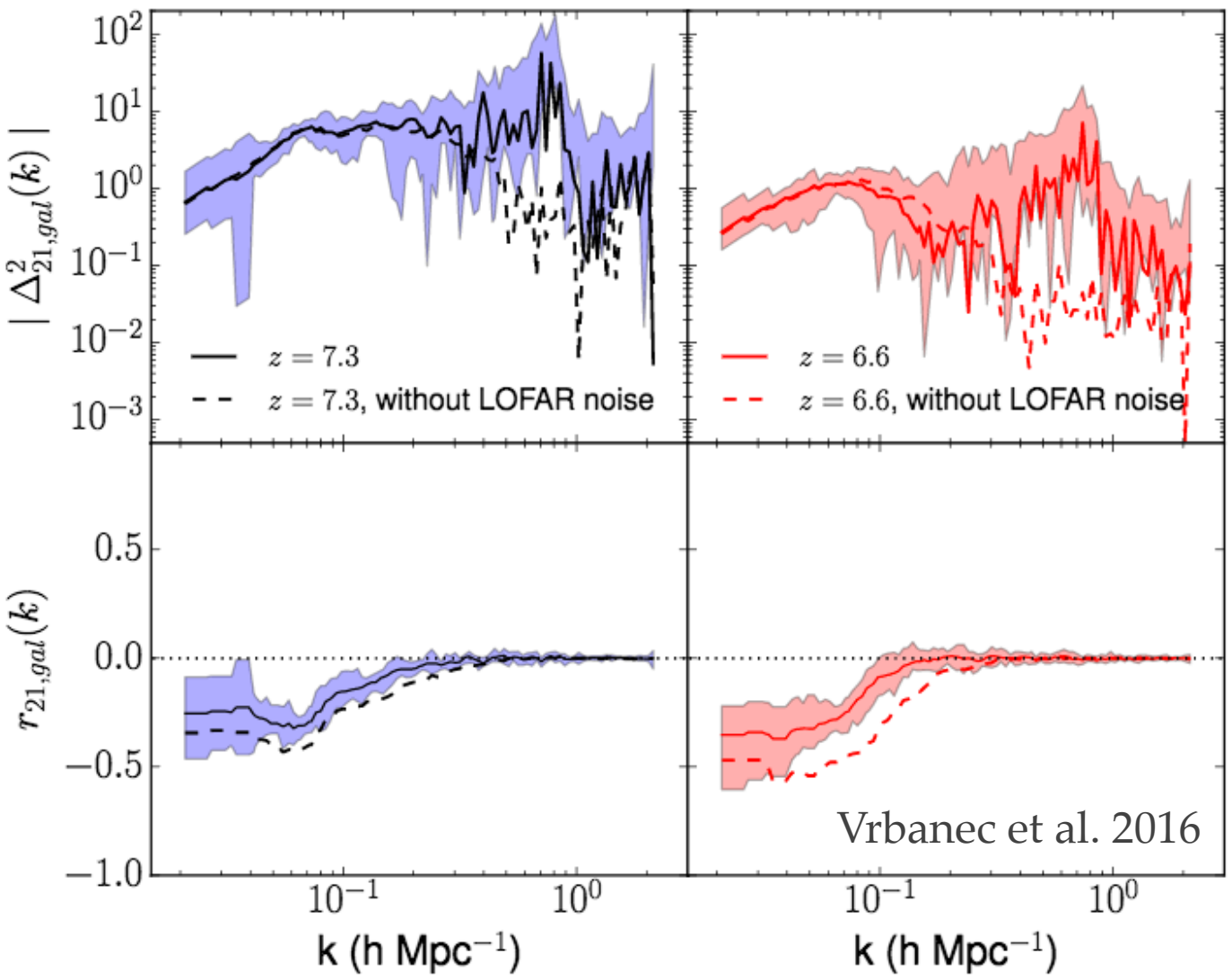
- Amplitude of the power spectrum decreases with decreasing redshift.

=> paucity of neutral hydrogen as reionisation proceeds.

- The turnover point shifts towards larger scales.

=> the ionized bubbles grow in size.

HI x Ly-α emitters: the practice

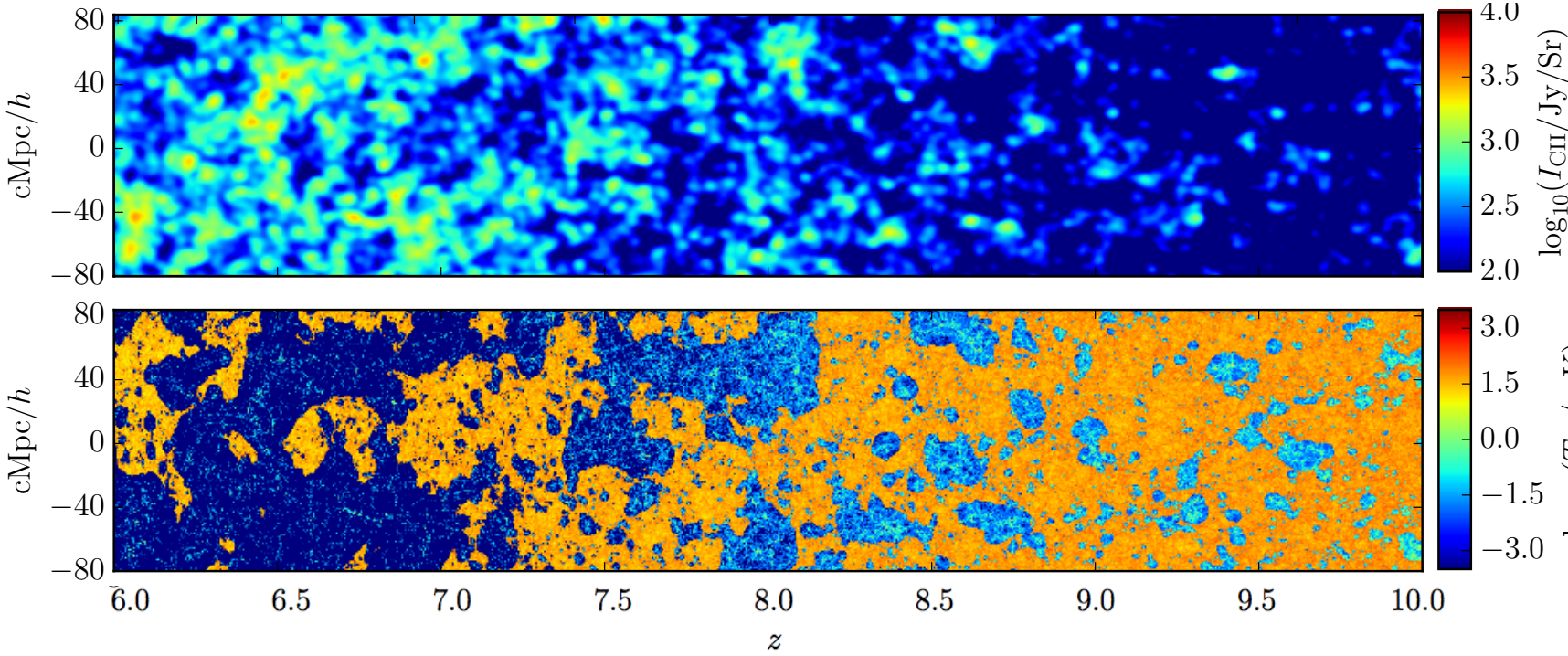


10 Mock Ly-α emitter catalogs

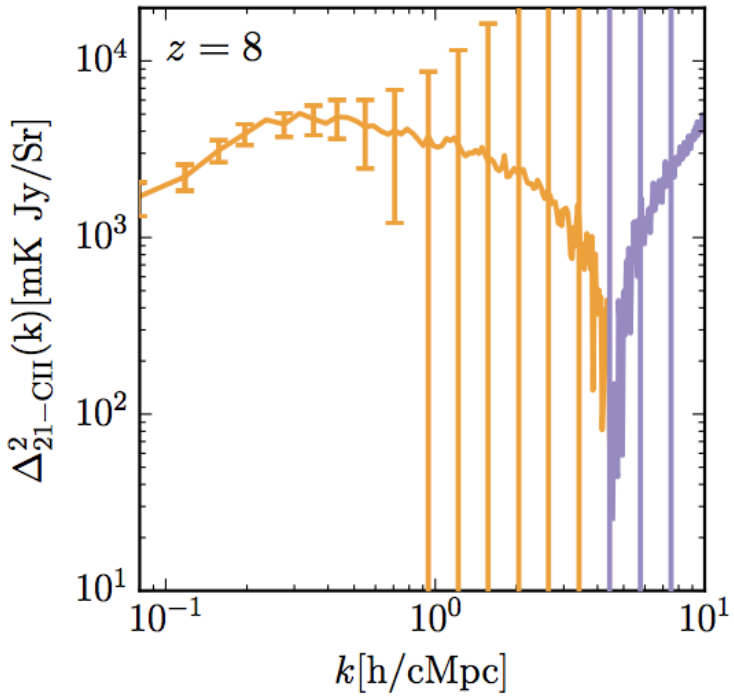
HSC FOV 16 deg²

+ foreground contribution to the error is larger than the thermal noise (Yoshida et al. 2017)

HI x CII intensity mapping



Dumitru et al, in prep



Galaxy-dominated late reionisation model

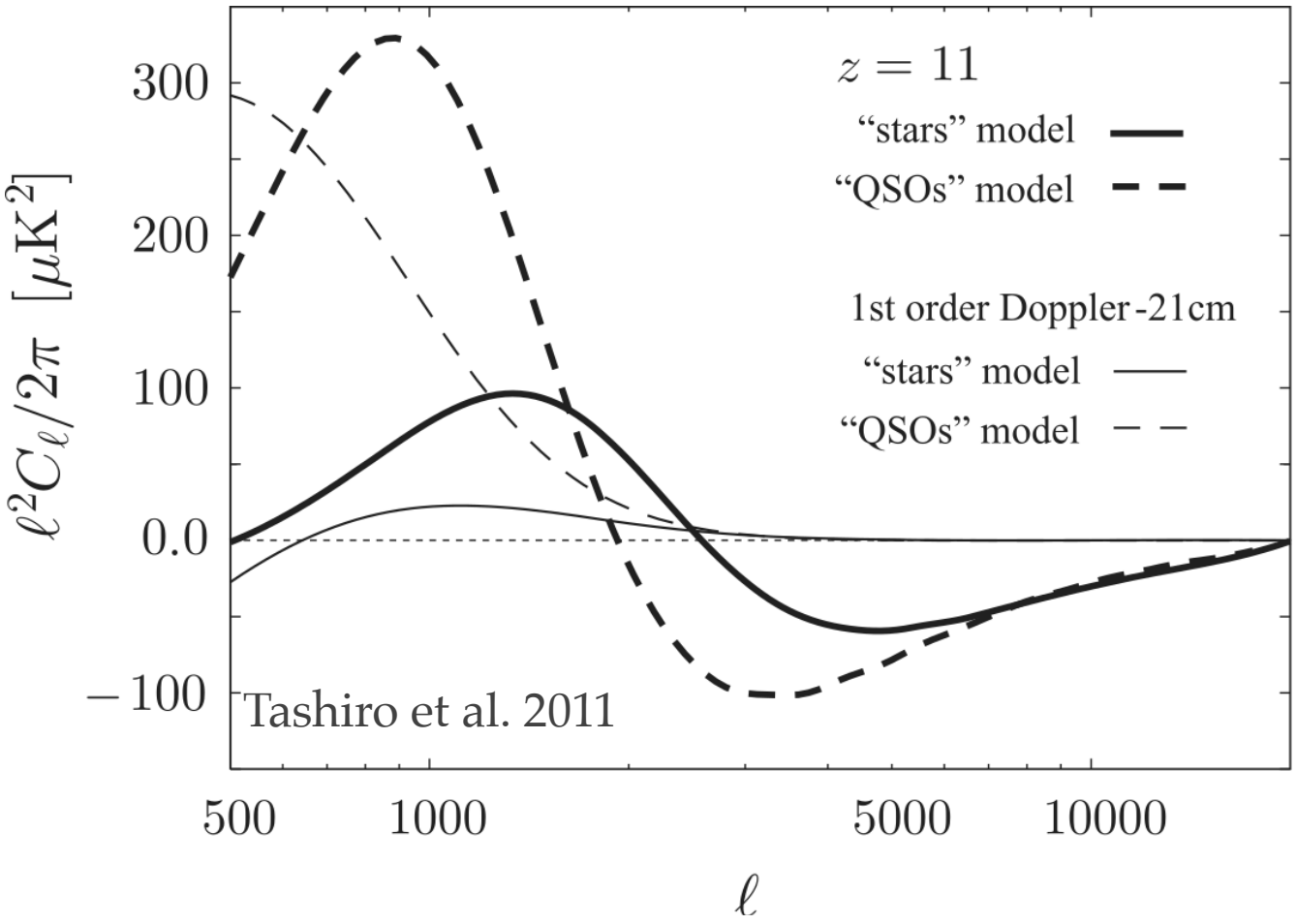
HI (LOFAR) x CONCERTO (CII - 16 Sq. Deg.)

=> Nature of sources

=> ionized bubbles growth during reionization

HI x CMB anisotropies

CMB kSZ signal x 21 cm fluctuations



kSZ effect: Doppler shifting of CMB photons as they scatter on radially moving inhomogeneities in free electron density.

=> Constraints on the source of reionisation (if detectable)

CONCLUSIONS

- The signal is faint but our future is bright
  - SKA1 and SKA will be the most sensitive radio telescopes to explore the cosmological dawn when the first galaxies formed

- SKA will trace the reionization of the intergalactic medium, but will not observe the young stars /black holes responsible for it.

=> Cross-correlation and joint analysis:

  - Get information on the nature of the sources, the statistical measure of average reionisation bubble size and ionisation fraction, redshift and duration of reionisation
  - Advantageous since the measurable statistics do not suffer in the same way from foregrounds and systematic effects as is the case of auto-correlation function measurements