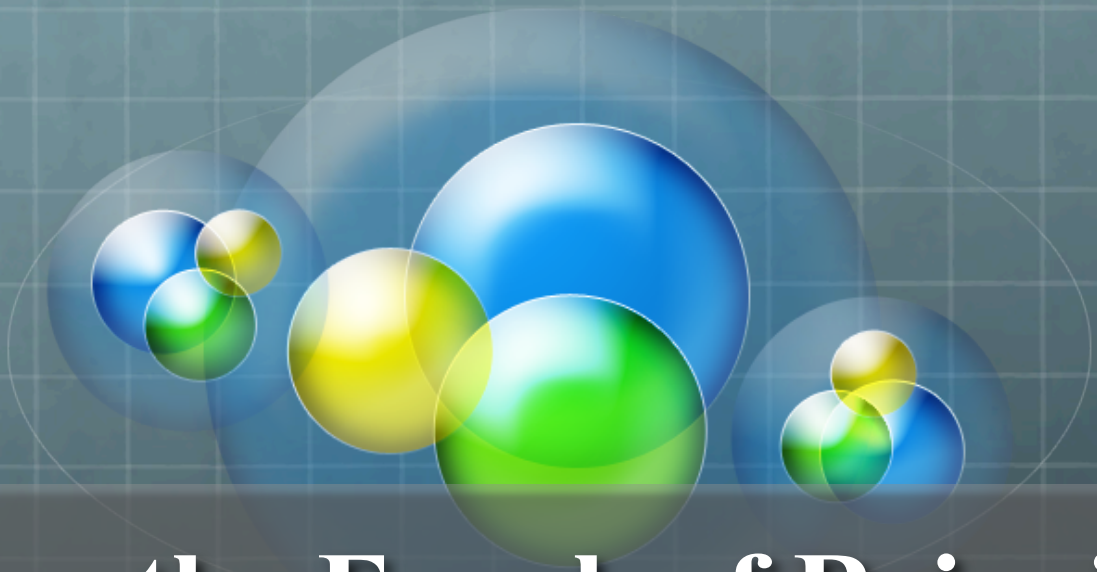


Mapping the Epoch of Reionization with the 21 cm signal

Benoît Semelin (Observatoire de Paris - UPMC)
AS SKA-LOFAR

SF2A, 2016

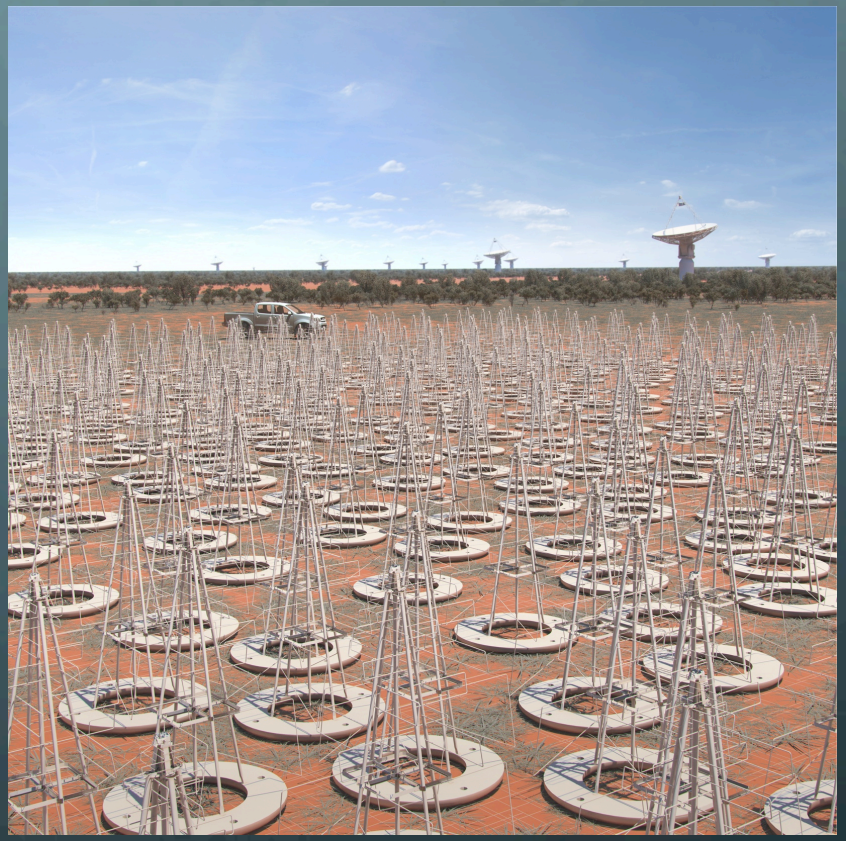
One of the main science goals of the SKA

From the SKA science book:

- The Cradle of life
- Fundamental Physics with Pulsars
- Magnetism
- The Hydrogen Universe
- The Transient Universe
- The Continuum Universe
- Cosmology
- Epoch of Reionization (EoR)

Observe the redshifted 21cm signal
from the neutral IGM during the EoR:
50 - 200 MHz

=> SKA-Low



SKA –Low

Western Australia

130 000 dipoles

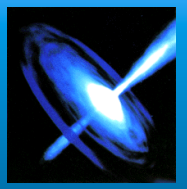
Bandwidth 50-350 MHz

Sensitivity: 500 m^2/K at 110 MHz

The first billion years

Massive stars:

Ionizing UV + some X-ray



Quasars:

More X-rays

z ~ 25 ?

z=1000

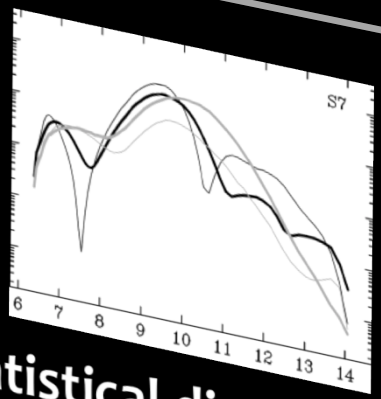
CMB

Dark Ages

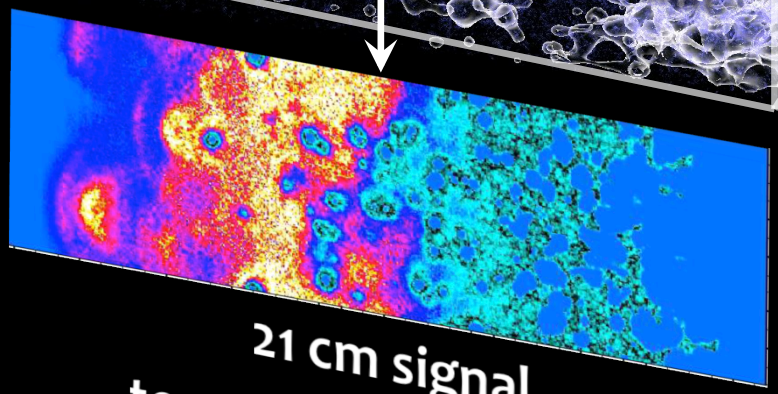
Cosmic Dawn

Epoch of reionization

z = 6



Statistical diagnostics with SKA and pathfinders

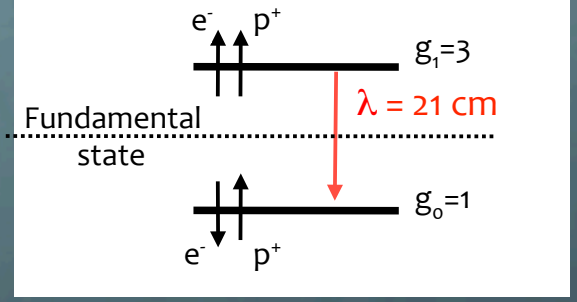


21 cm signal tomography with SKA

The 21 cm signal

Fondamental process:

Hyperfine transition



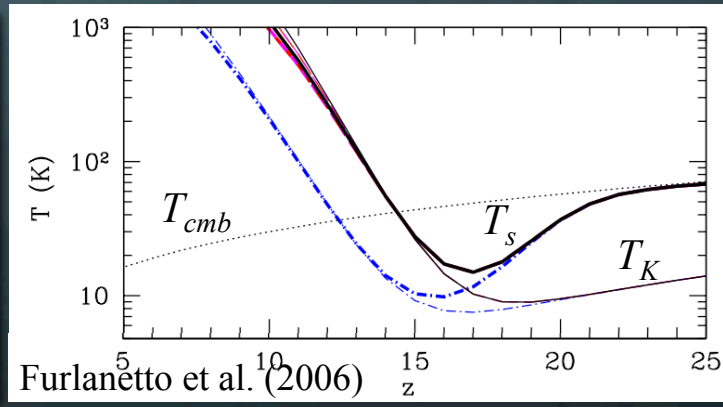
Level populations:

⇔ Spin temperature

⇔ emission proba

$$\frac{n_1}{n_0} \propto \exp\left(-\frac{h\nu_{21}}{k_B T_s}\right)$$

$$T_S^{-1} = \frac{T_{CMB}^{-1} + x_\alpha T_K^{-1} + x_{col} T_K^{-1}}{1 + x_\alpha + x_{col}}$$



Observed intensity:

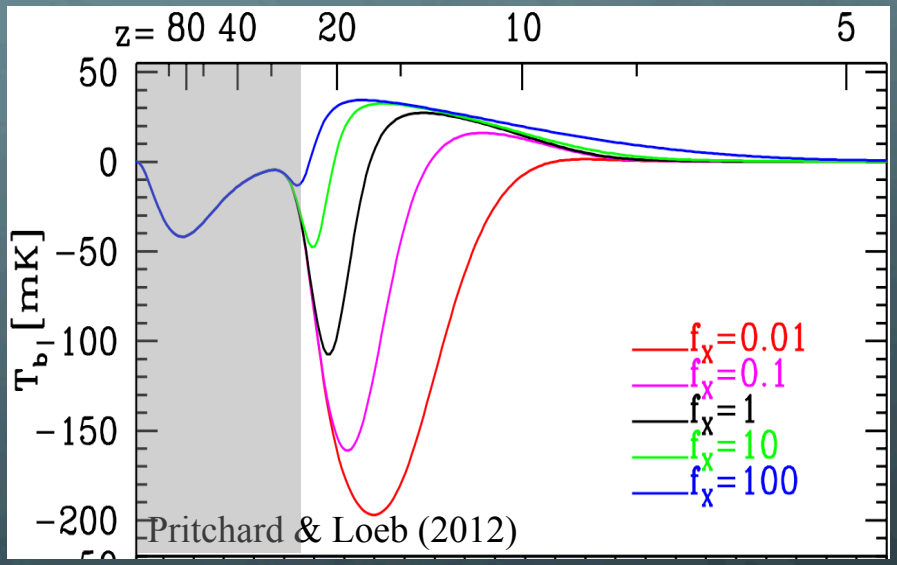
Nb of emitting atoms — intensity per atom

$$\delta T_B \propto 28\,\mathrm{mK}\ (1+\delta)\, x_{HI} \left(\frac{T_S - T_{CMB}}{T_S}\right)\left(1 + \frac{1}{H}\frac{dv}{dr}\right)^{-1}$$

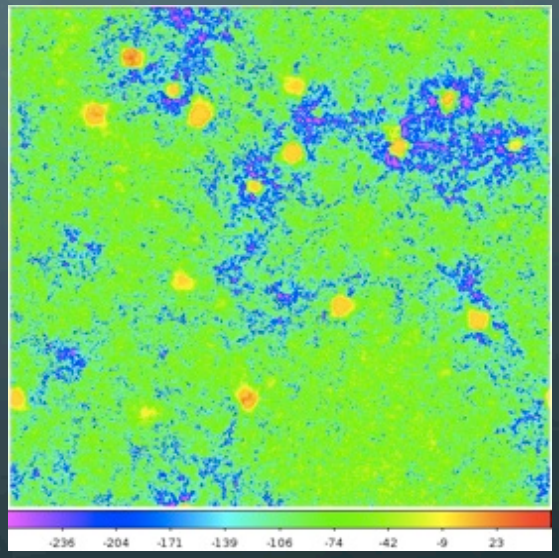
astro — cosmo

21 cm signal observables

Integral signal: $\langle \delta T_B \rangle_{sky}(z) \propto \langle x_{HI} \rangle_{sky} \langle 1 - T_{cmb}/T_s \rangle_{sky}$

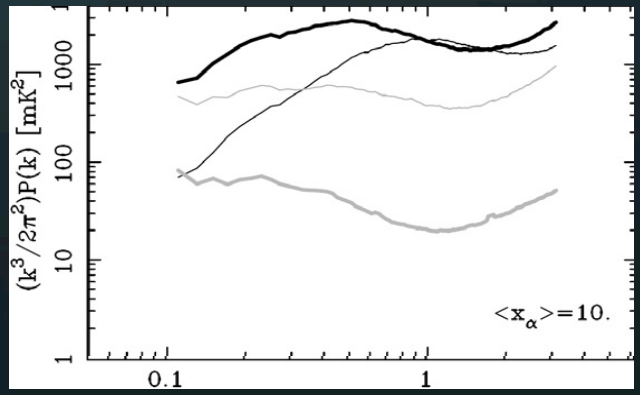


Imaging: $\delta T_B(\mathbf{x}, z)$



All information + random phases

3D power spectrum: $P_{\delta T_B}(k, z)$



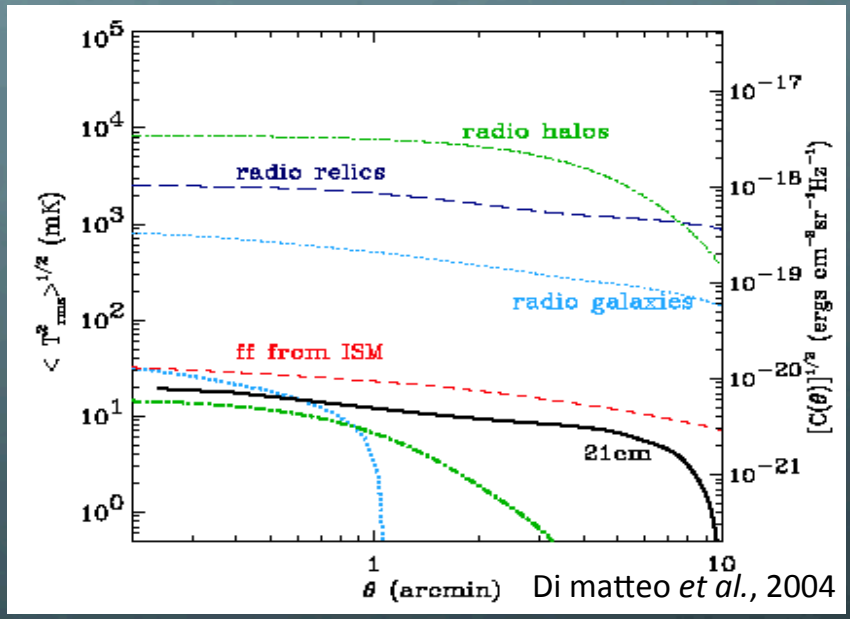
Warning! The signal is not gaussian.
$P_{\delta T}$ does not have all the information.

Foregrounds and calibration

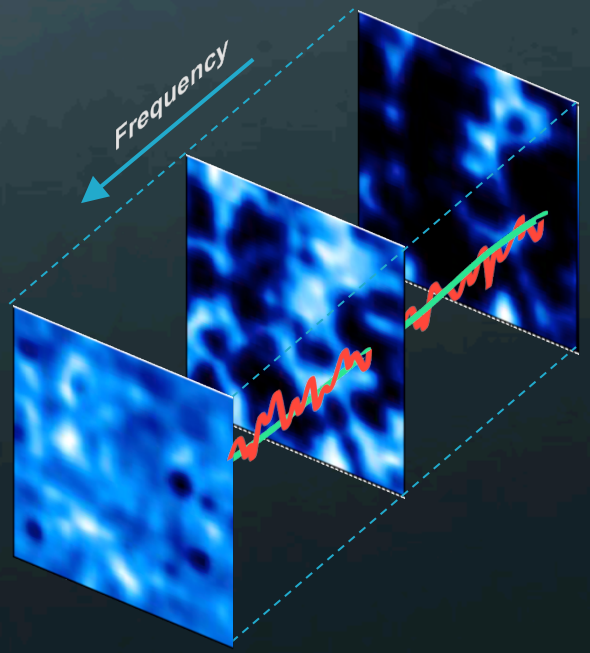
Foregrounds 100 to 10^4 brighter than the 21 cm signal.

Removal possible because of frequency structure.

But high accuracy calibration is required .



Di matteo *et al.*, 2004



Upper limits by SKA pathfinders

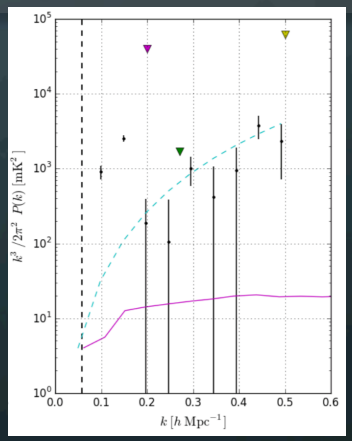
PAPER (S. Africa)

~150 MHz

$(22\ \mathrm{mK})^2$ at z = 8.4

several 100h integration

(Ali et al. 2015)



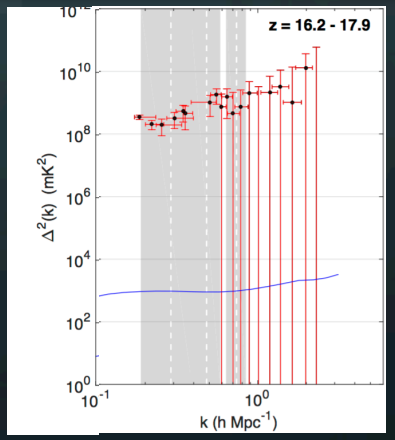
MWA (Australia)

75-112 MHz band

$(\mathrm{qq}\ 10\ \mathrm{K})^2$ at z ~16

4h integration

(Ewall-Wice et al. 2016)



LOFAR (NL)

118-200 MHz band

?

> 200 h integration

(XXX et al. 2016 ?)

?

Nenufar, a pathfinder for the SKA

Built in Nancay, extention of LOFAR. (PI P. Zarka)

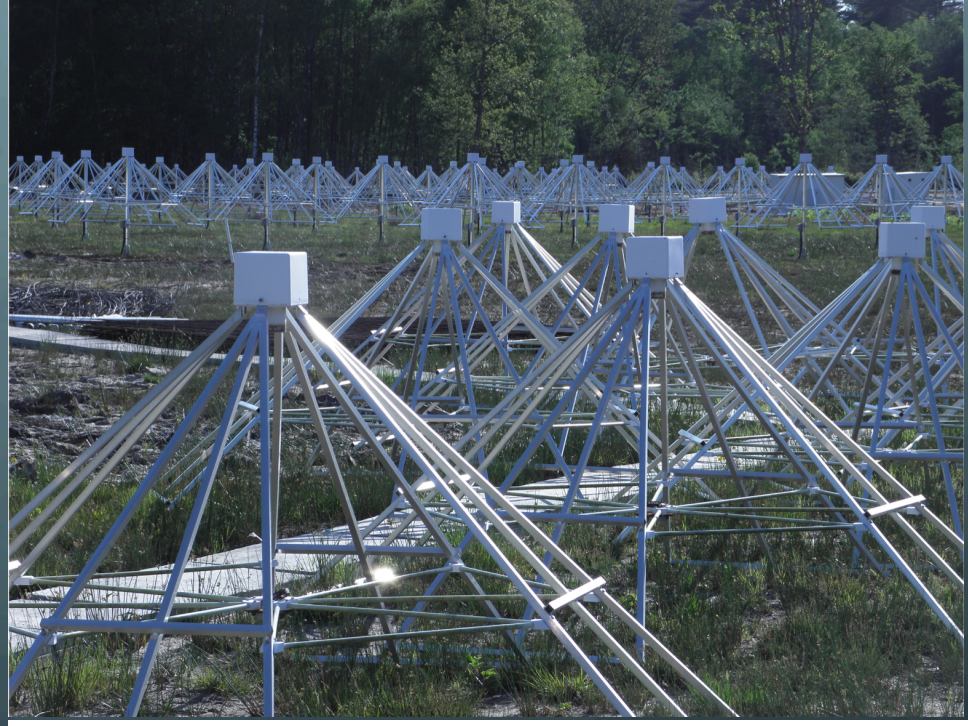
In the 20-80 MHz band (z>17):

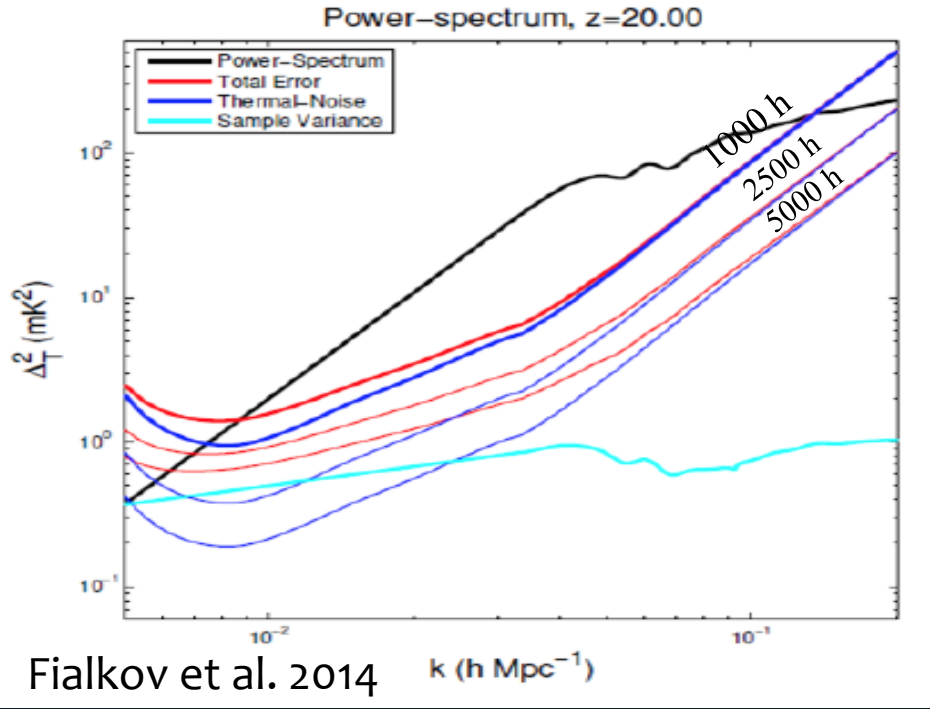
largest collecting area worldwide

Final intrument: 1800 dipoles
Currently: 418
End 2016: 779

LWA: 256 dipoles

An EoR project is being setup.



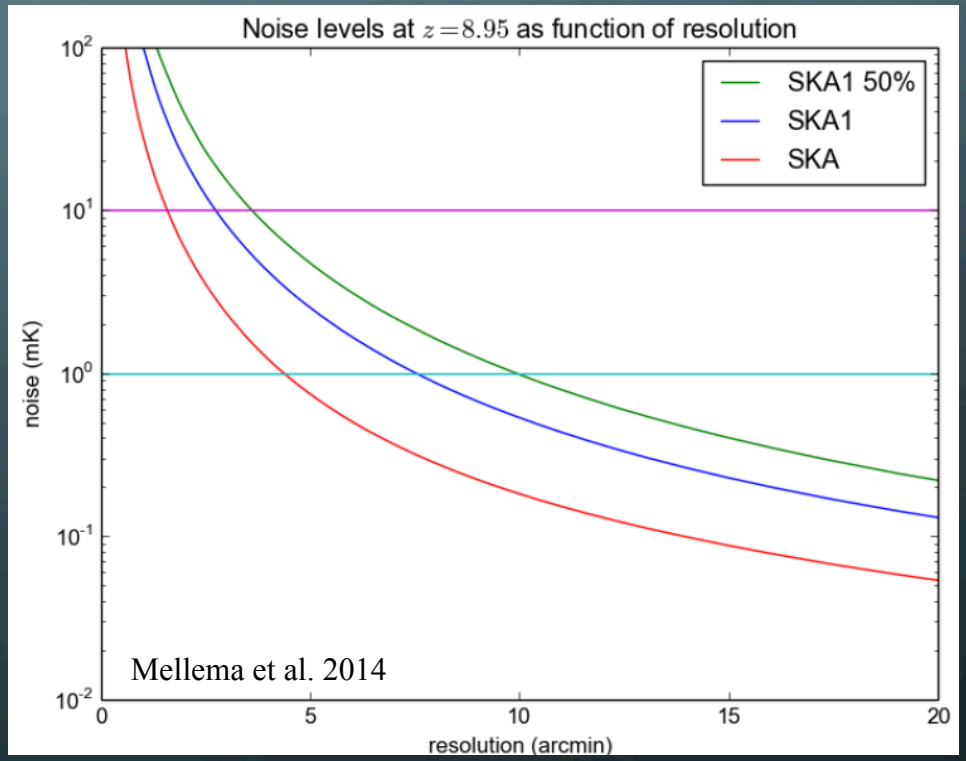


Fialkov et al. 2014

Imaging the EoR with the SKA

Imaging capability depends on:

- Required noise level
- Sky temperature
- Collecting area
- Antennas distribution
- Intregration time



With re-baselined SKA 1:

- 20 cMpc/h resolution a 1mK sensitivity

- 10 cMpc/h resolution at 4 mK sensitivity

Imaging the EoR with the SKA

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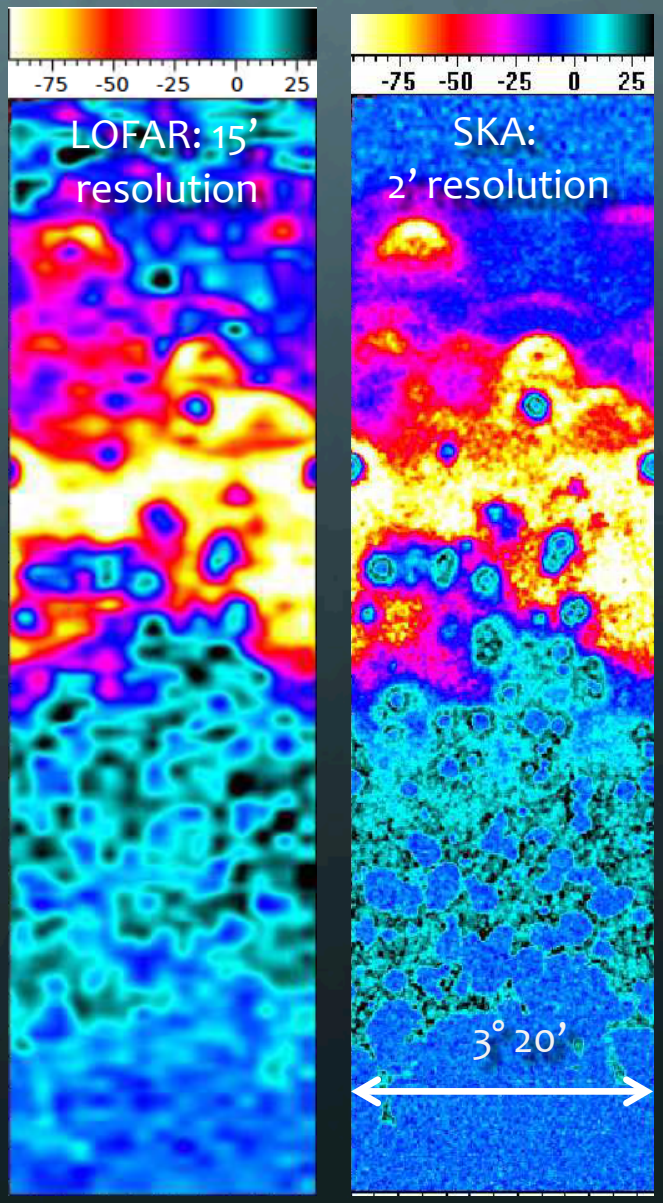
With re-baselined SKA 1:

- 20 cMpc/h resolution a 1mK sensitivity

- 10 cMpc/h resolution at 4 mK sensitivity

z ~ 15



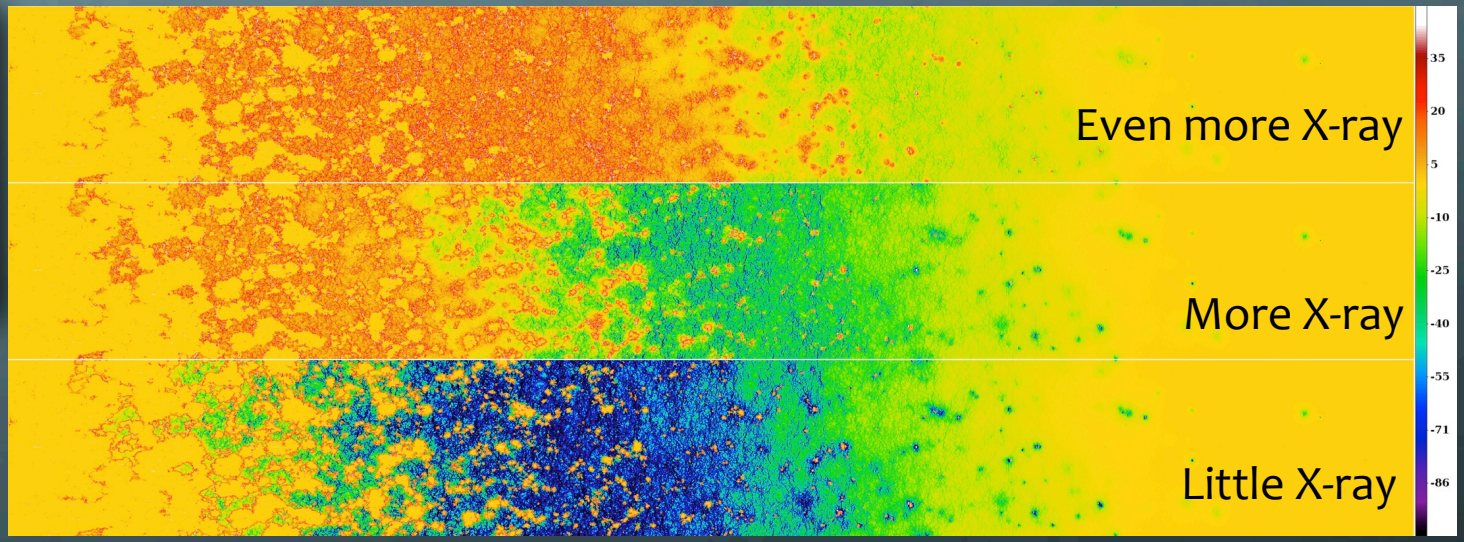
z = 6

Questions that 21cm can answer, one example:

nature and abundance of X-ray sources

$$\delta T_B \sim \left(\frac{T_s - T_{\mathrm{CMB}}}{T_s} \right)$$

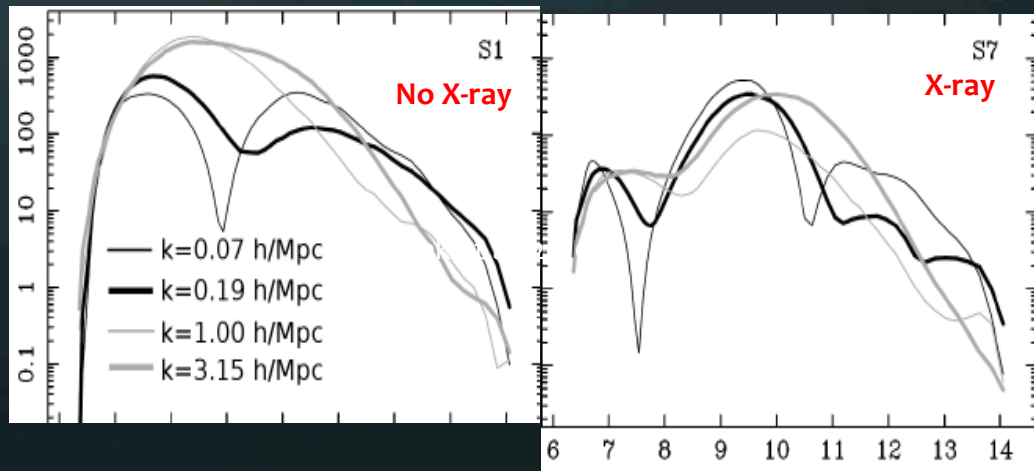
$$T_s \sim T_K$$



z=6 z=8,7 z=15

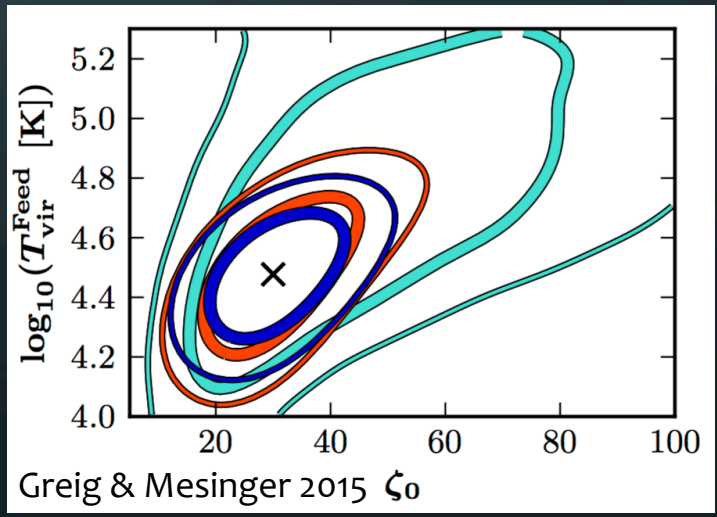
Imprint of AGN X-ray heating on the 21cm power spectrum (Baek et al. 2010)

Soft X-ray (AGN) and hard X-ray (XRB) can be differentiated (Fialkov & Barkana 2014)



Modelisation, the way forward

- Define a parameterization of the astrophysics (f_X, f_{esc},…)
- Define an optimal metric in the parameter space (quantifiy degeneracies)
- Recover parameter values for the observed signal:
  - MCMC exploration
  - PCA
  - Neural networks ?



Conclusions

- The 21cm signal may have an impact on astrophysics similar to the CMB.

- You don't need to be a radio-astronomer to be interested in SKA science.

- SKA **will** happen.

- SKA **will** produce breakthrough science.

- Now is the time to join the Science Working Groups.

Merci.

Simulation:

- Gravity, hydro, etc…
- UV, X-ray, Ly-α RT

- 200 cMpc/h box
- ~ 2° field
- Smallest halo: $10^{10}\ M_{\odot}$
- 5 ckpc resolustion