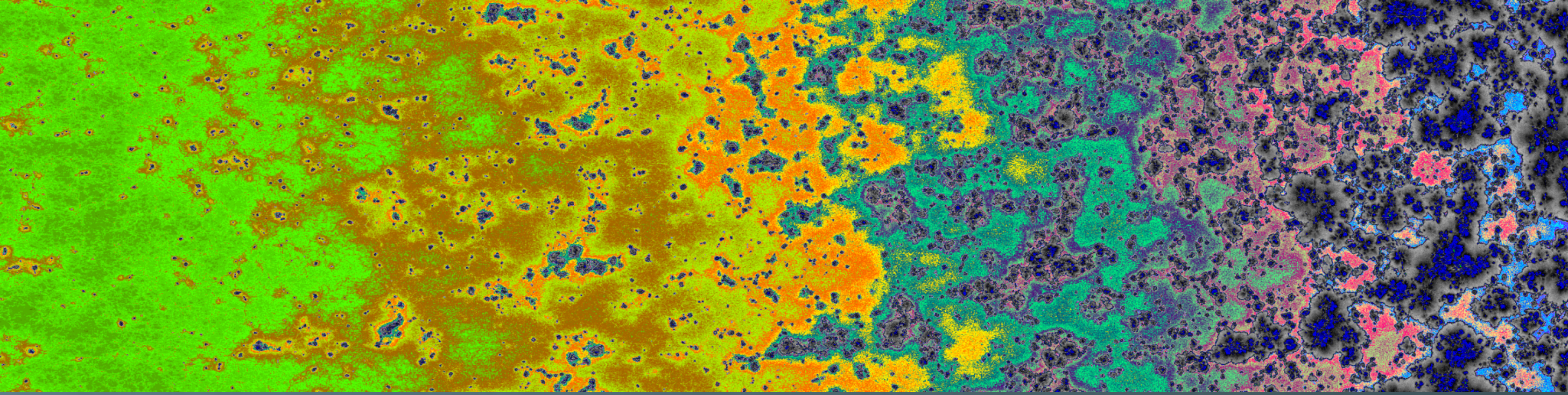


Epoque de la réionisation:

contraintes observationnelles et simulations numériques

Benoît Semelin (SU - Observatoire de Paris)

Journée SKA-France, Nov 2018

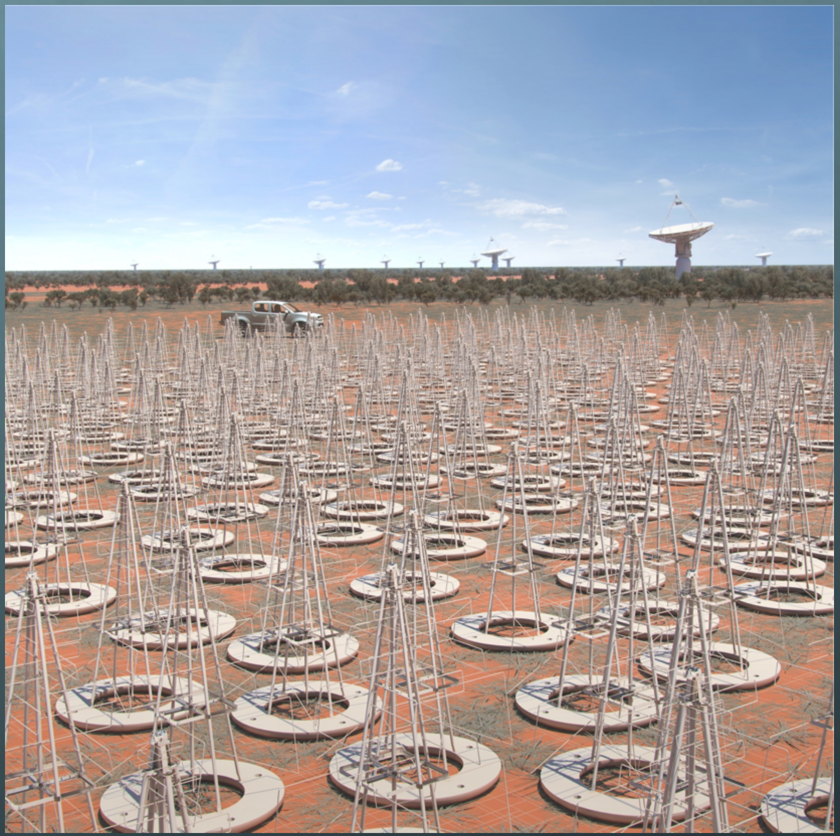
One of the main science goals of the SKA

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



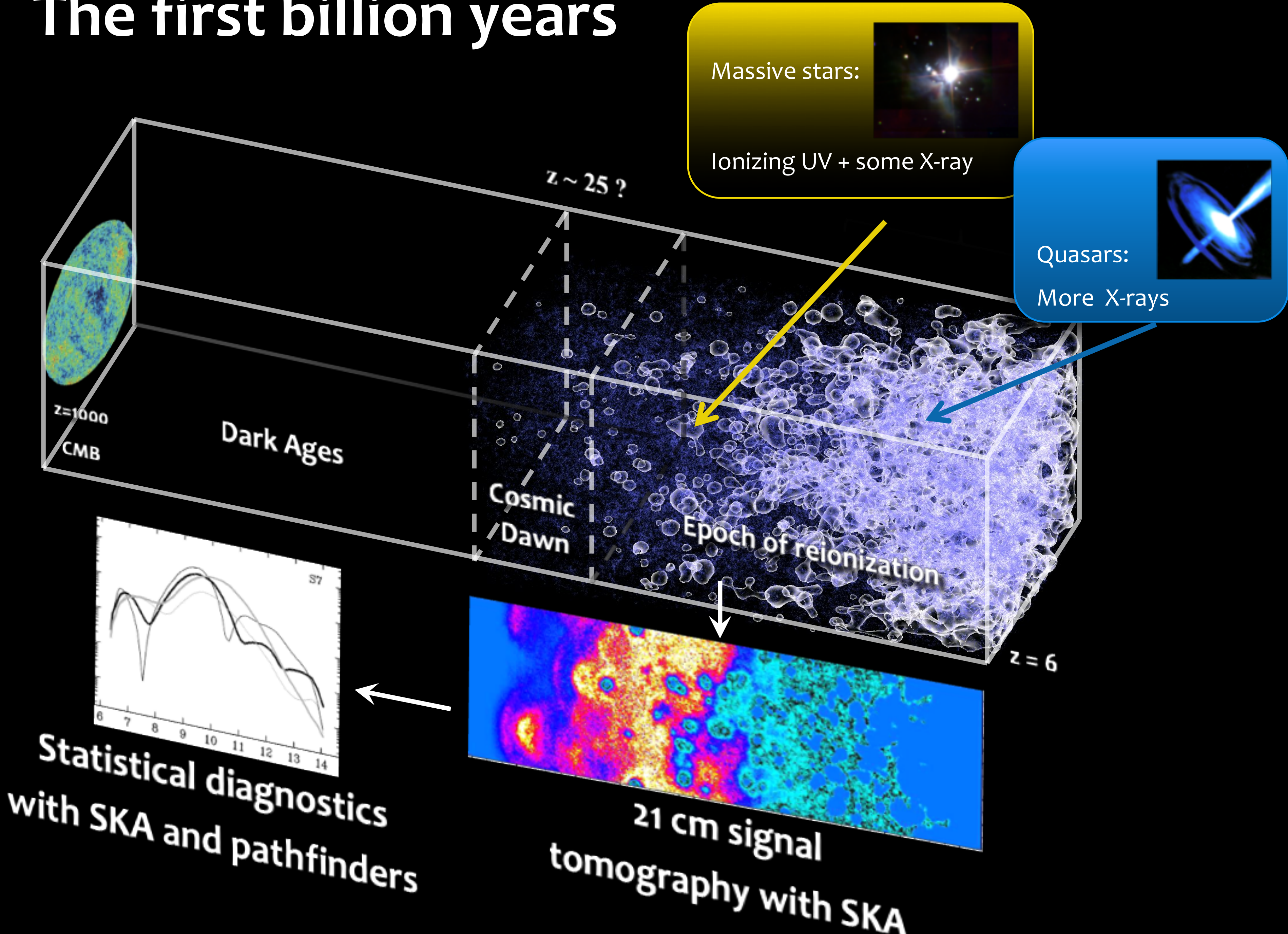
SKA –Low

Western Australia

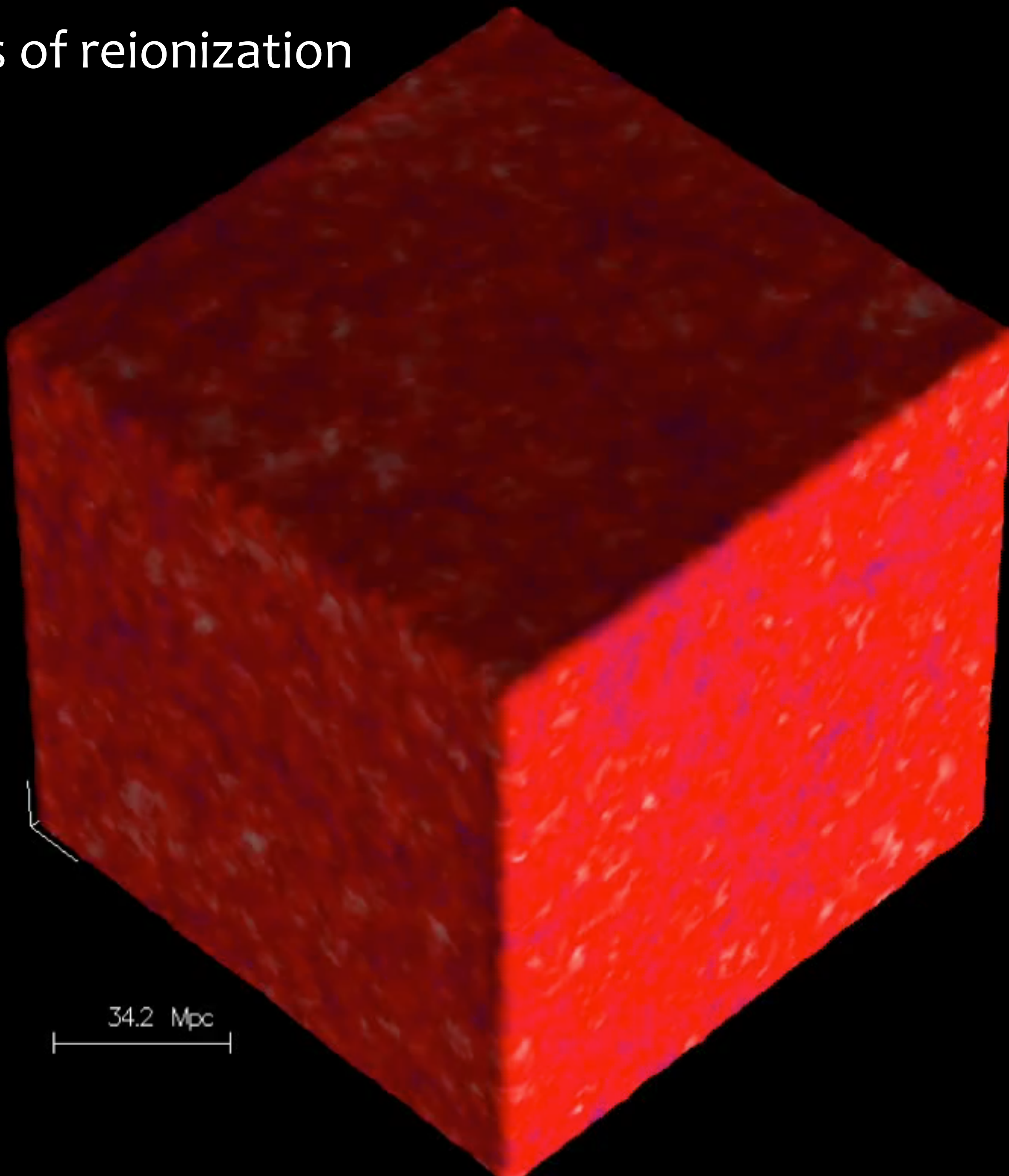
130 000 dipoles

Bandwidth 50-350 MHz

The first billion years



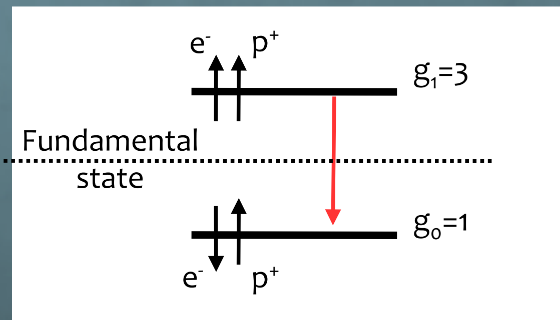
The process of reionization



The 21 cm line emission

Fondamental process:

Hyperfine transition



λ = 21 cm <=> ν = 1420 MHz
But redshifted!

Cosmological signal intensity:

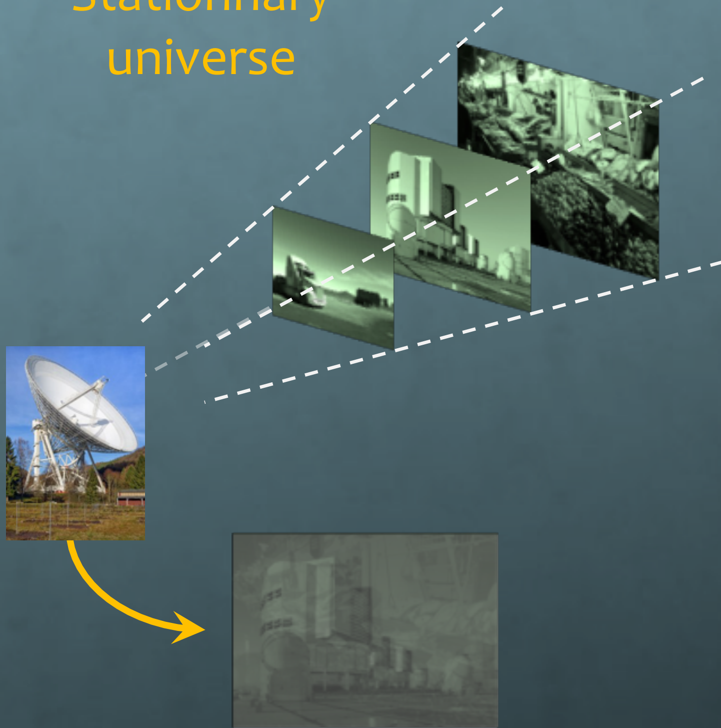
Nb of emitting atoms — intensity per atom

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

astro — cosmo

21-cm tomography: an unexpected gift from expansion

Stationnary universe



Information is lost !

Expanding universe

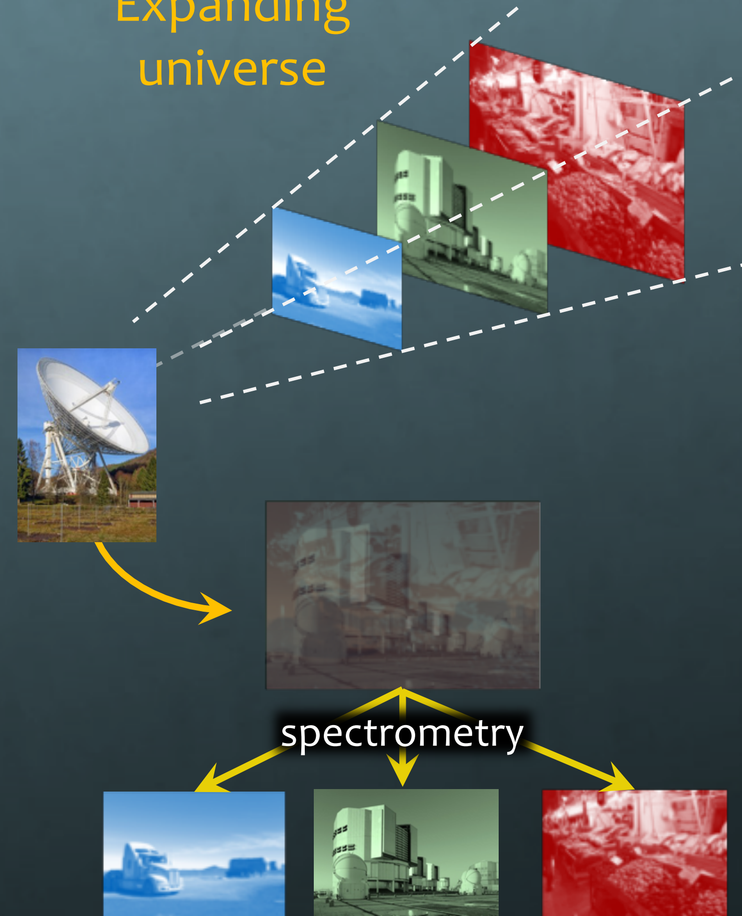
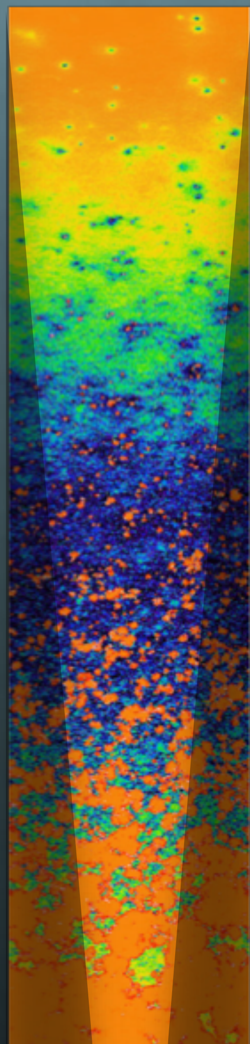


Image « thickness »: $L_{thick} = v_{th} / H(t)$

For 21-cm: L_{thick} = a few ckpc

21 cm signal observables

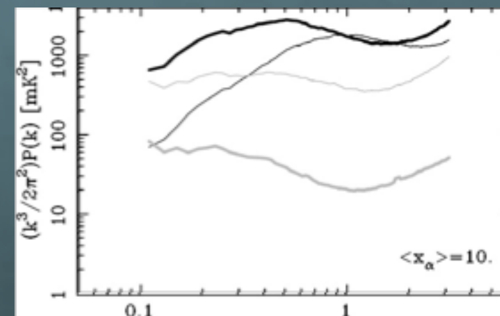
Imaging: $\delta T_B(\mathbf{x}, z)$



SKA

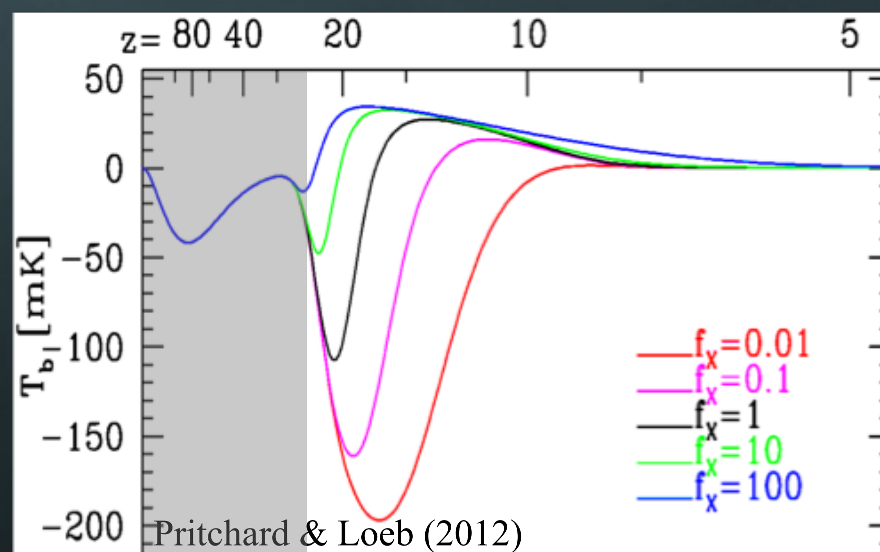
All information + random phases

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



LOFAR
PAPER -> HERA
MWA
GMRT
NENUFAR

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



EDGES
SARAS
LEDA
SCI-HI
PRIZM
NCLE
…

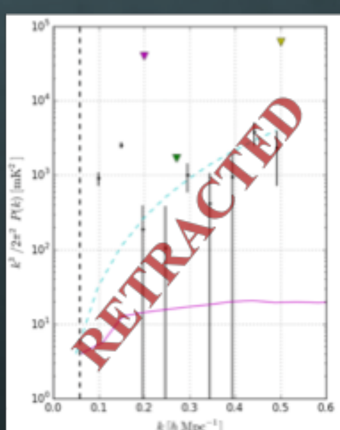
Upper limits by SKA pathfinders/precursors

PAPER (S. Africa)

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

several 100h integration

(Ali et al. 2015)



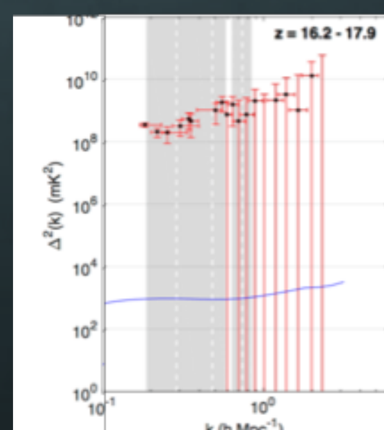
MWA (Australia)

$(164\ \mathrm{mK})^2$ at z~7

32h hours (Beardsley et al. 2016)

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

4 hours (Ewall-Wice et al. 2016)

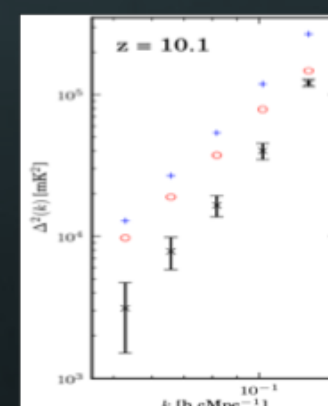


LOFAR (NL)

$(56\ \mathrm{mK})^2$ at z~ 10

with only 13h integration

(Patil et al. 2017)



The EDGES « detection » (Bowman et al. 2018)

EDGES:

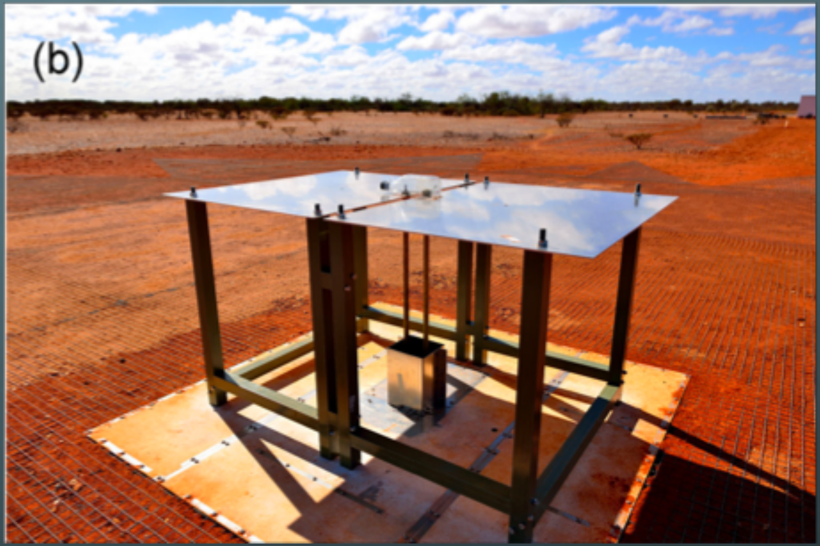
- single dipole experiment
- At future SKA site, Australia
- Lowband (50-100 MHz) antena
- Highband (90-200 MHz) antena
- > 100 h integration

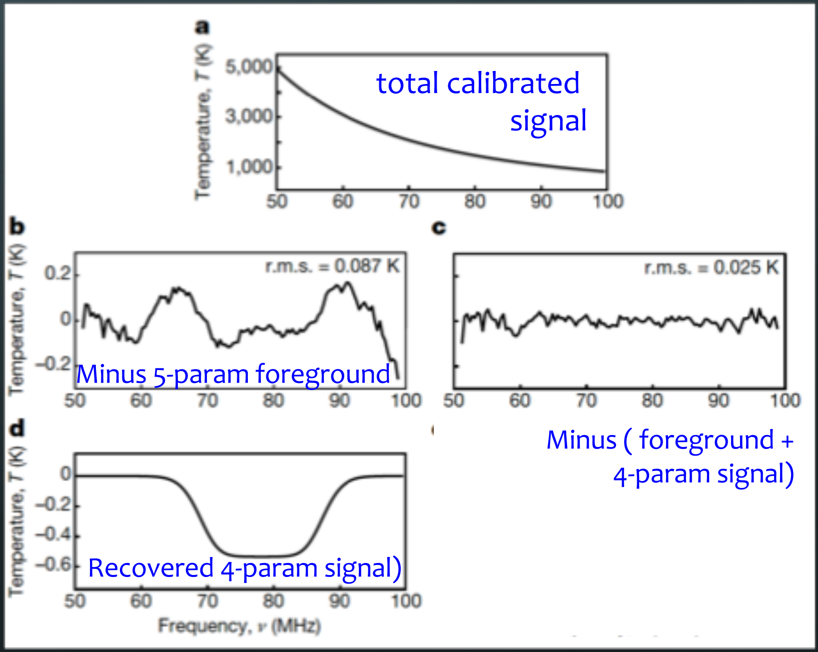
Validations tests:

- 6 hardwares configs (ground plane, orientation, etc.)
- 18 processing configs (time of obs, temp, beam, calib solution, foreground, …)

Caveat: Hills et al. (2018), Badley et al. (2018)

Some serious questions about foreground modeling and instrumental effect (ground plane)





The EDGES « detection »: implications

More than 50 papers triggered by EDGES results in 2 month! Even more now…

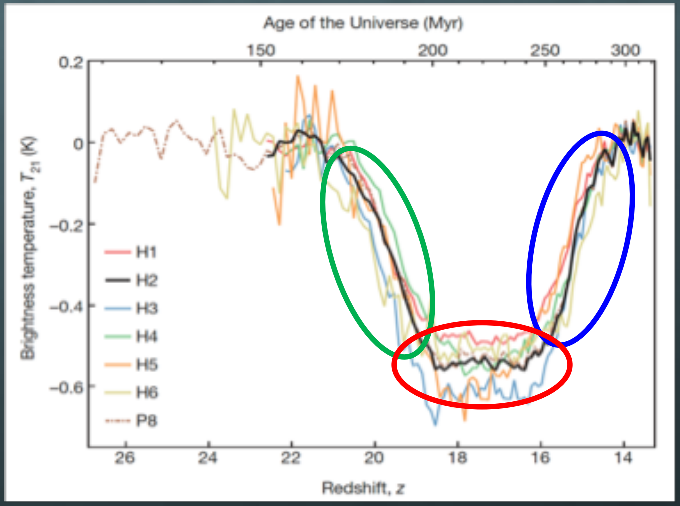
« Standard model »
- If no heating: $T_K \approx 400 \left(\frac{1+z}{151}\right)^2 \approx 6$ K
- At z=17 : $\langle \delta T_b \rangle \approx 26 \sqrt{\frac{1+z}{10}} \left\langle -\frac{T_{CMB}}{T_K} \right\rangle \approx$ **−220 mK**

<u>Early Ly-α production</u>:

-> Constraints on first stars formation (tension with lower z LF)

-> Constraint on WDM particle mass

Very sudden!



<u>Heating of the gas:</u>

-> Constraints on DM annihilation

-> Constraints on primordial BH populations

Very sudden heating…

Strength of absorption feature:

-> Colder gas, new physics (DM-baryon interaction, new DE)

-> Stronger radio background (QSOs, new DM -> stronger radio CMB,
axions -> macro quark nuggets -> radio emission)

HPC simulations to predict the signal

The LICORICE code:

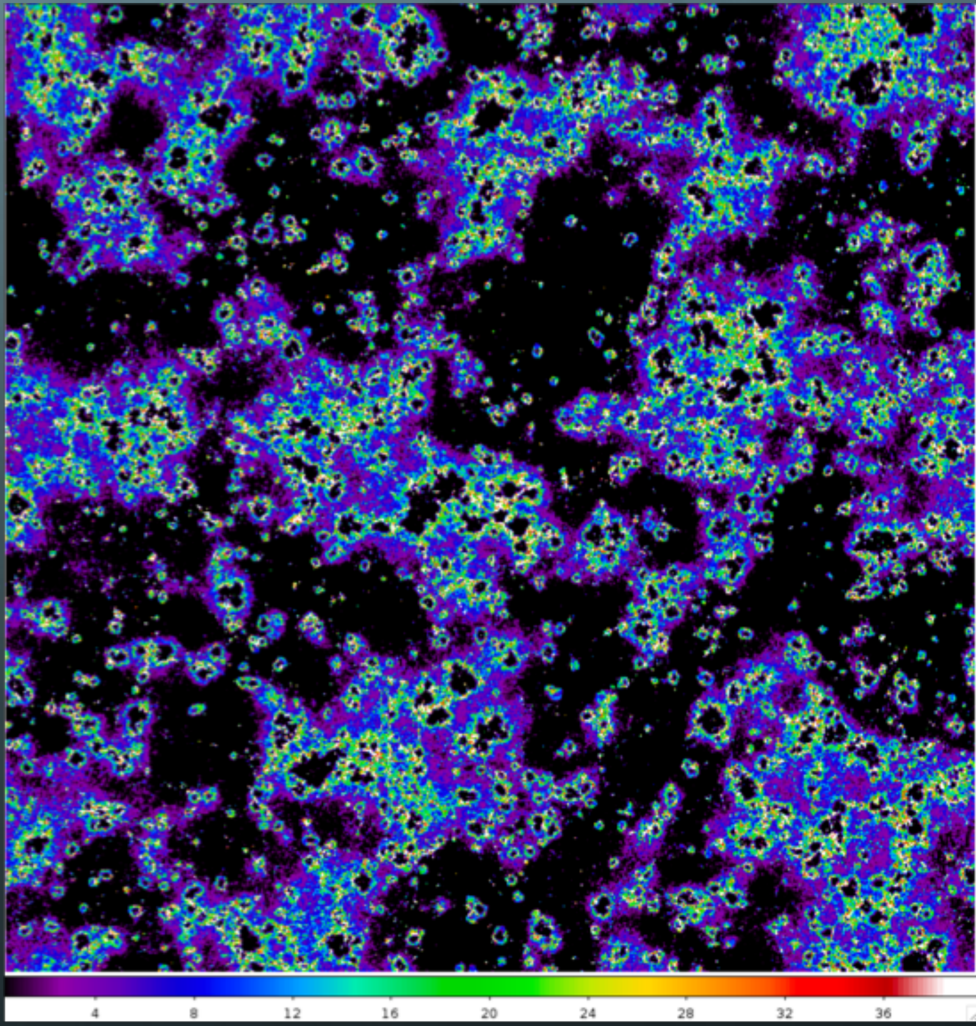
- Cosmology
- Gravitation
- Hydrodynamics
- UV / X-Ray / Ly-α radiative transfer

A GENCI « grand challenge » simulation:

- 10^{10} particles
- 4×10^{12} « photons »
- About 5. x 10^6 hours. 16384 cores.

$10^9\ M_{\odot}$ halos in a $300^3\ \mathrm{Mpc}^3$ volume…

Almost there!



But… parameter space exploration needed! E.g. X-ray production efficiency.

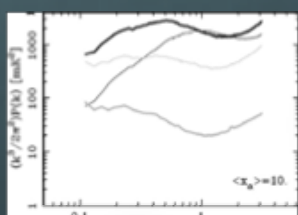
Parameter reconstruction with machine learning

Bayesian MCMC approach:

>10^5 instances of forward modelling
=> numerical simulations unsuable

Supervized learning on smaller sets (10^2 to 10^4):

1) With neural networks

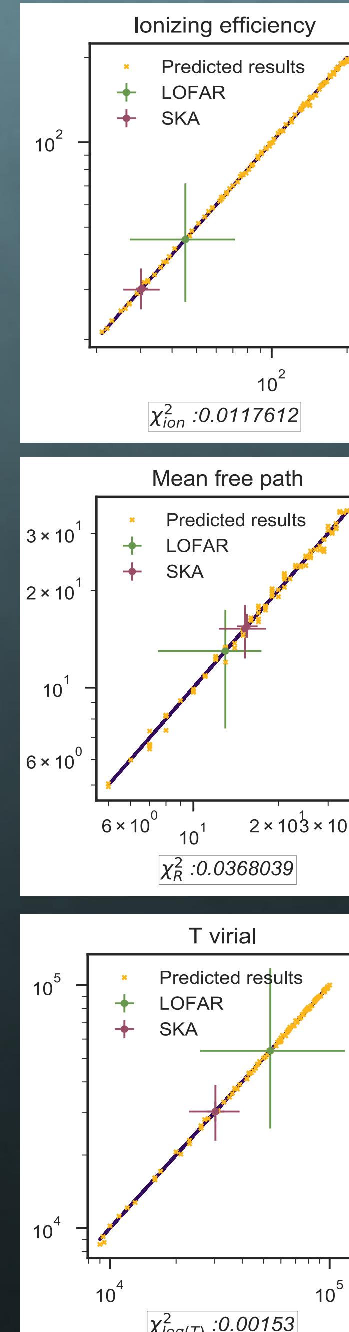


Neural network

Parameter Values (knowledge !)

Forward modelling ⇔ training

2) With other methods (e.g. local ridge kernel regression)



Doussot et al. (2018, in prep)

Conclusions

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

- We are on the brink of detection

- Numerical simulations are the key to extracting knowledge from upcoming observations.

- New “inversion” algorithms will have to be explored.