The LOFAR Epoch of Reionization Key Science Project

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The Team

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- Associate members

Science Goals

- Statistical detection of the global reionization history (rms noise).

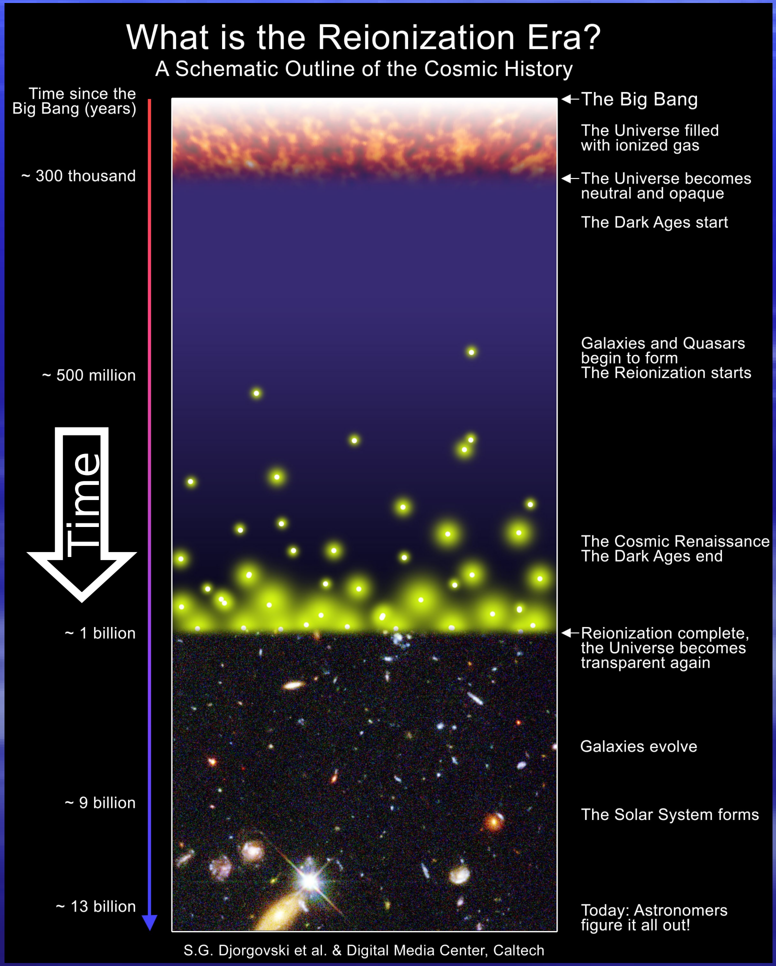
- Measure the underlying density power spectrum.
- Statistical characterization of the size of ionization bubbles with redshift.

- Cross correlation with other data: CMB, Ly-α emitters,....
- The environment of supermassive black holes
- 21 cm forest towards very luminous high-z radio sources

- A number of secondary science goals for worst case scenario

Reionization

- The era when the first (proto-) galaxies formed and created large scale H^+ regions around themselves, eventually leading to a globally ionized intergalactic medium (IGM).
- Last global phase transition in the IGM.
- Important process for galaxy formation (feedback).
- When and how it happened provides unique information about structure formation, and early star and black hole formation.
- Redshift: 6 – 20.



Now

The 21cm Signal

- The 21 cm hyperfine transition is a forbidden transition between the two $1^2s_{1/2}$ ground level states of neutral hydrogen.
- For the IGM during the EoR the measurable signal (differential brightness temperature) can be written as

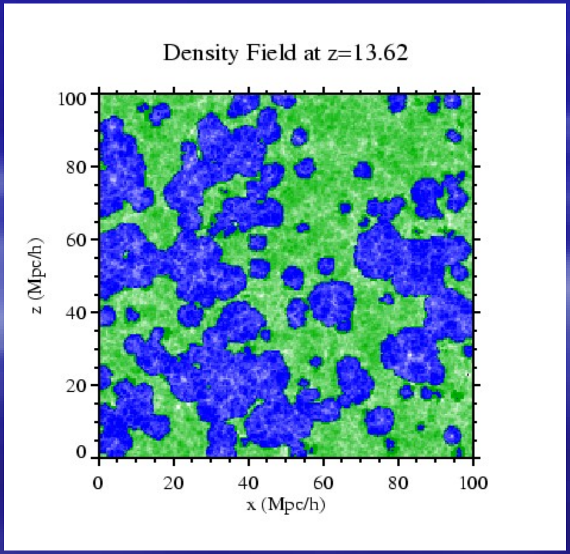
$$\delta T_b \approx 28\mathrm{mK}\,(1+\delta)x_{HI}\frac{T_s - T_{CMB}}{T_s}\frac{\Omega_b h^2}{0.02}\left[\frac{0.24}{\Omega_m}\left(\frac{1+z}{10}\right)\right]^{\frac{1}{2}}$$

$$T_s = \frac{T_{CMB} + y_\alpha T_k + y_c T_k}{1 + y_\alpha + y_c}$$

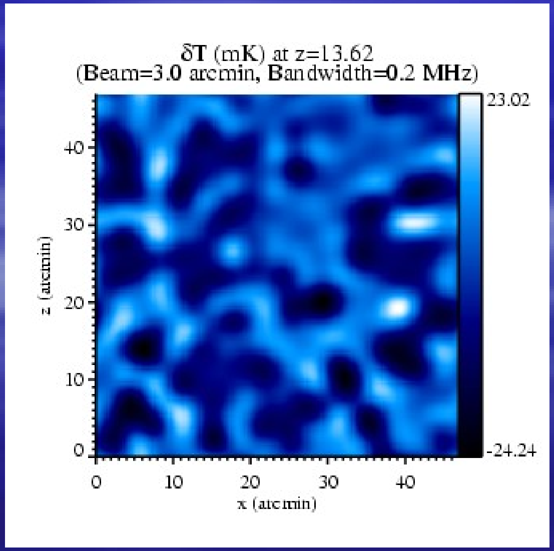
and is found at frequencies below 200 MHz.

The 21cm Sky

- Just as the Cosmic Microwave Background, the redshifted 21cm signal fills the sky. It has fluctuations due to
  - Gas density of the IGM (δ)
  - Appearance of ionized regions (x_{HI})
  - Excitation variations (T_s)



x_{HI}, δ

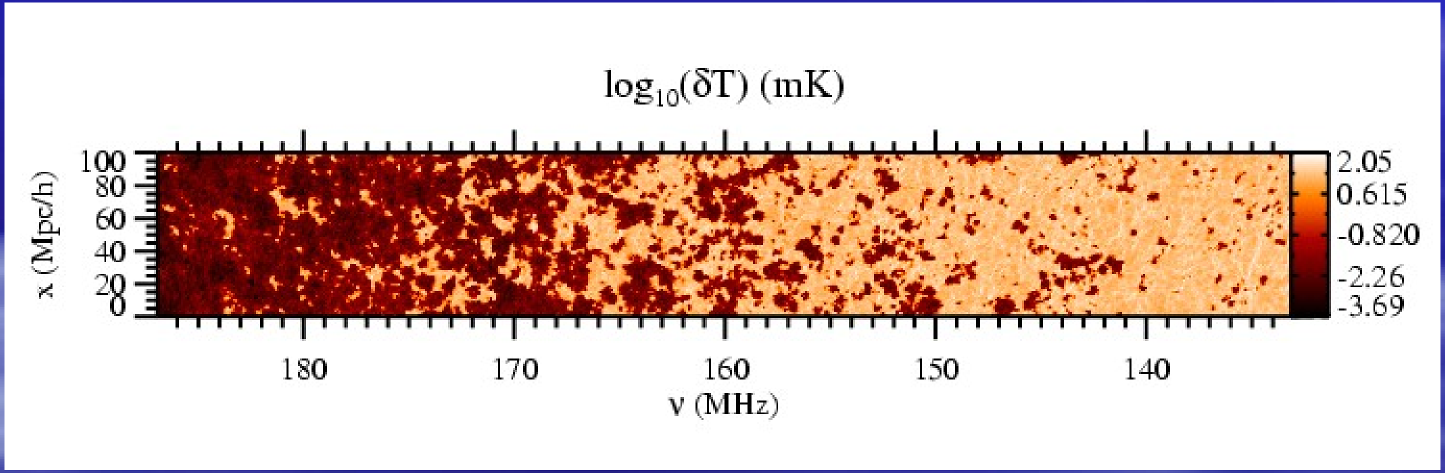


δT_b

Mellema et al. (2006)

The 21cm Depth

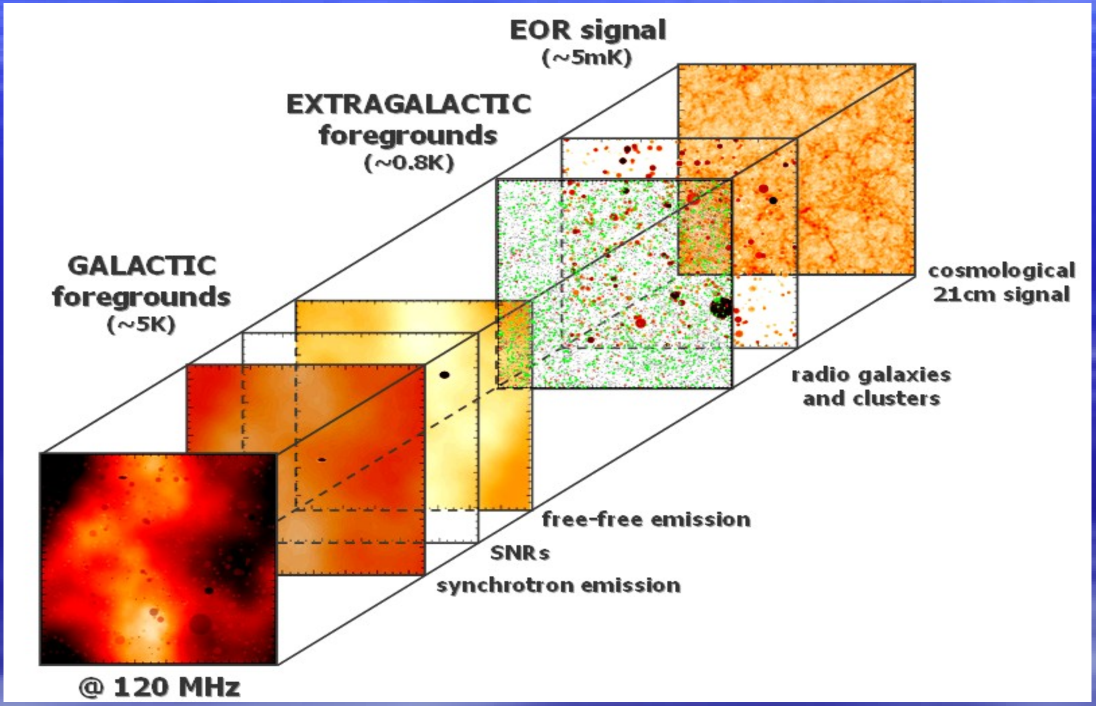
- *Unlike* the CMB, the redshifted 21cm signal also has fluctuations along the ***frequency*** direction.
- These fluctuations carry a rich mix of spatial, temporal and velocity information.



Mellema et al. (2006)

Astrophysical Foregrounds

- Just as the CMB, we need to deal with foreground signals.
- These are however ~3 orders of magnitude brighter than the signal.
- Good news: they have a smooth frequency behaviour.
- Bad news: they have structure/fluctuations in polarized intensity.

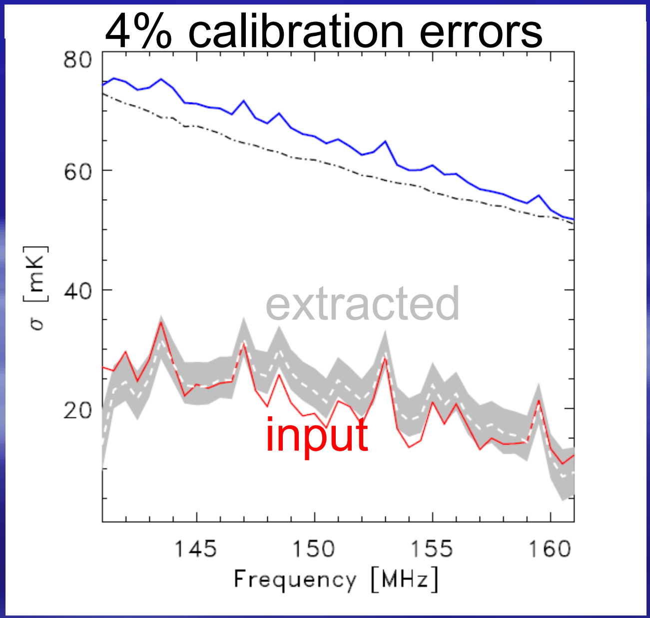


Ionosphere

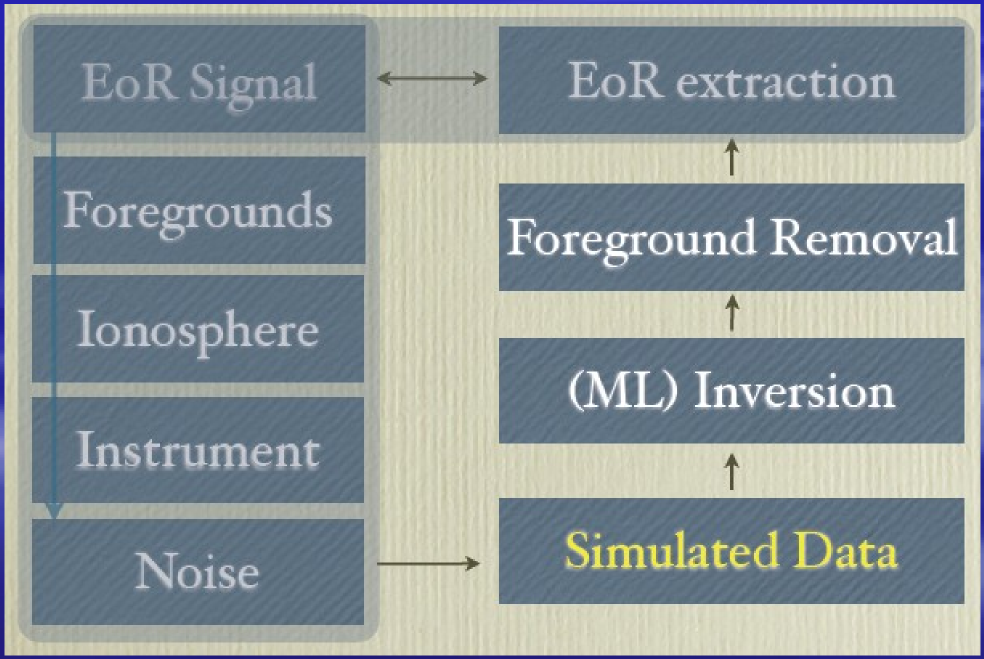
- The Earth's ionosphere
  - Distorts the images (phase errors)
  - Introduces Faraday rotation
- Both effects are frequency dependent and time dependent, and need to be accounted for.
- Frequent 2D mapping of large part of observable ionosphere is thought to be needed; precise procedure still under investigation.

Can We Do It?

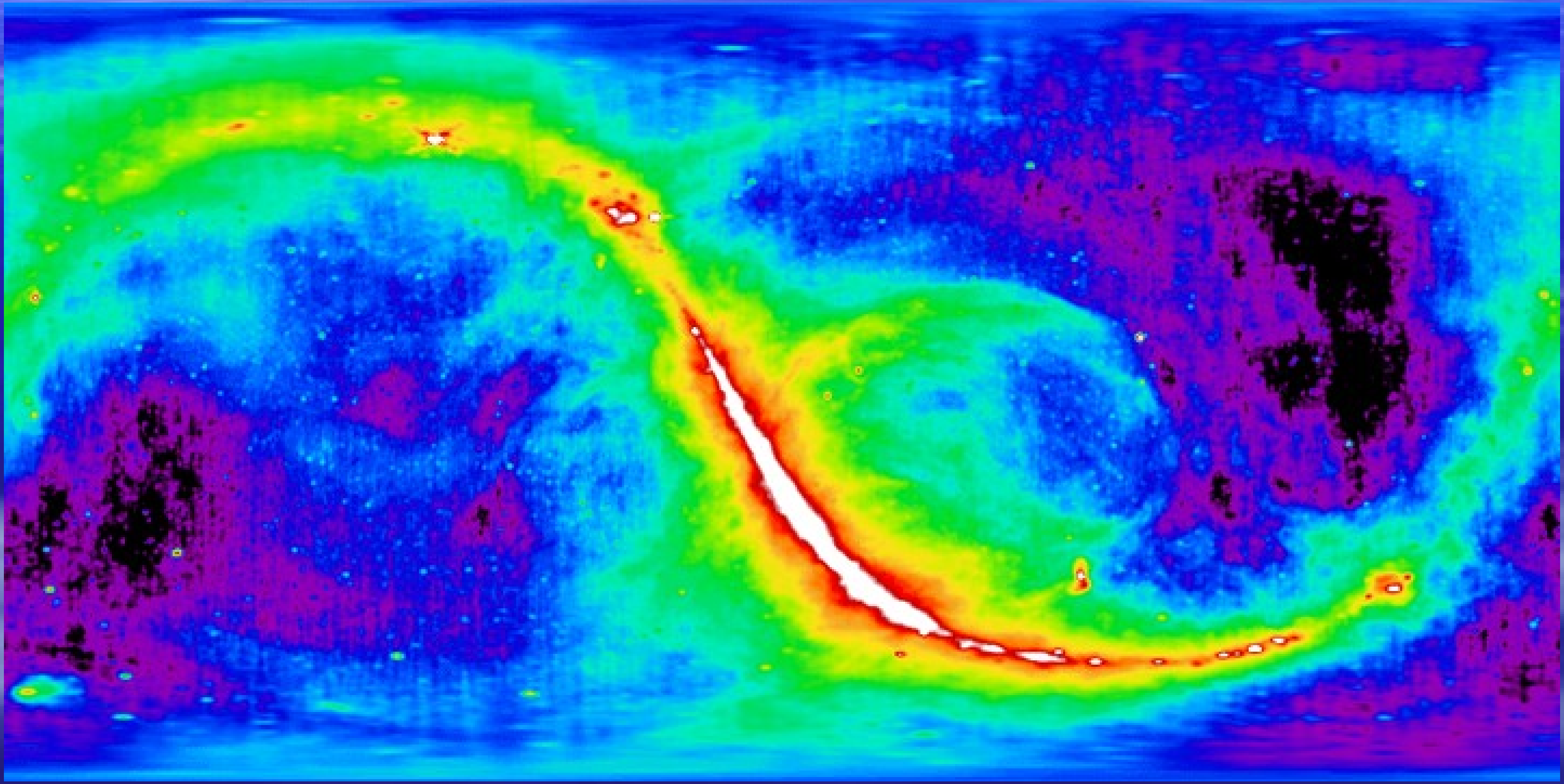
- To prepare for the measurements we have been developing a simulation pipeline in which we introduce all the complications as realistically as possible and try to recover the original signal.



Lambropoulos et al. (2009)



Observing Plan



Haslam map at 408 MHz (1982)

Observing Plan

- Observe five carefully chosen 5° fields with the LOFAR HBA core (plus first ring); angular resolution of ~3', frequency coverage 115-175 MHz and 175-205 MHz.
- Collect ~400 hours of observing to achieve ~50 mK sensitivity per resolution element.
- Limit to night time observing for stablest ionosphere.

- Save data at 10 kHz, 10 sec resolution for reprocessing and adding.

Reprocessing & Data Extraction

- The total amount of raw data will be ~1.5 PB.
- The total requirement in computing time is estimated to be ~1 Zflops (10^{21} flops), mostly in linear operations.
- This requires ~150 days on a 100 Tflop/sec computer.
- No existing infrastructure can provide this, instead we are planning for a dedicated cluster of 50 quadcore CPUs + GPUs (NVidia Tesla). Tests on 3 of such machines show that 100 Tflop/sec is feasible.

128 cores

How Can I Join?

- The frame work for the experiment is largely developed, but for many of the parts contributions are welcome and needed.
- For example:
  - Expertise on ionospheric science, ionospheric modelling
  - Further development of calibration / reprocessing algorithms
  - Software development (e.g., GPUs)
  - Analysis of foregrounds
  - Etc...

Summary

- The LOFAR EoR KSP will carry out extremely deep observations in the frequency range 115-200 MHz with the main aim of statistically detecting the signature of reionization.
- Calibration and extraction of the signal are extremely challenging, both scientifically and technologically, making it the most ambitious radio-astronomy project to date.
- No 'sure thing' but will no doubt explore "where no man has gone before".