21-cm signal from Epoch of Reionization

Raghunath Ghara

Dept of Astronomy & Oskar Klein Center,
Stockholm University

Collaborators:
Garrelt Mellema, Tirthankar Roy Choudhury, Kanan K. Datta, Sambit Giri,
Samir Choudhuri, Suman Majumdar

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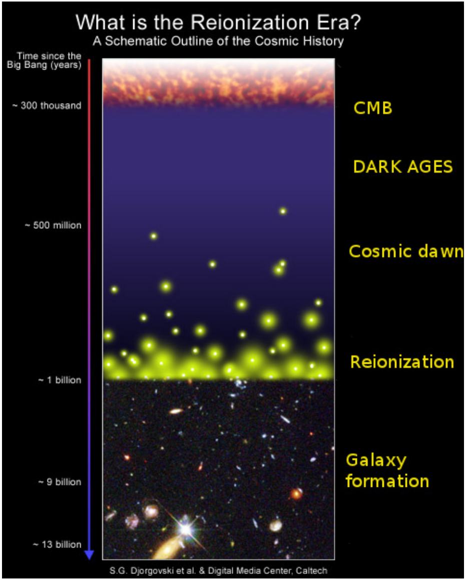
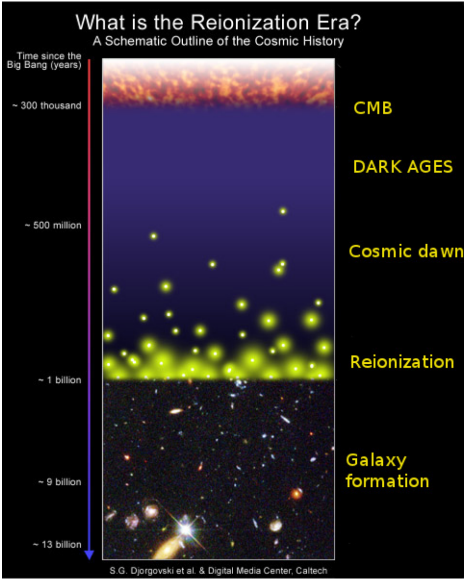
Cosmic dawn and epoch of reionization (EoR)



Cosmic dawn and epoch of reionization (EoR)

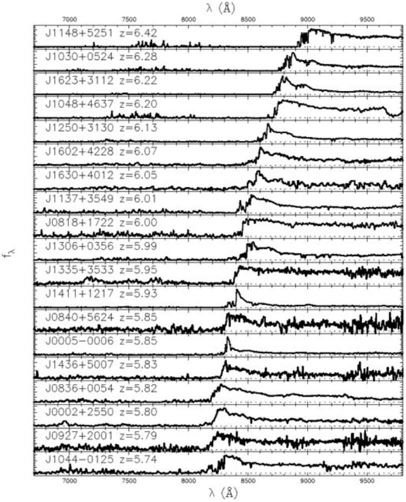


Why is this fascinating?

- When did reionization occur?
- Sources responsible ?
  - Galaxies?
  - Quasars?
- Thermal and ionization state of the IGM ?
- Impact of the reionization process on the structure formation ?

Probes of reionization

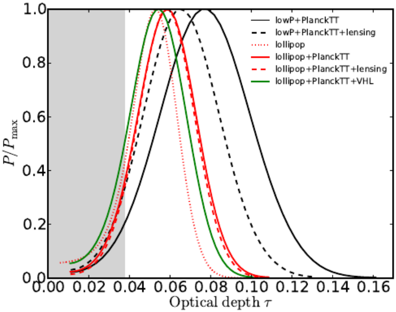
- Quasar absorption spectra ($z_{\mathrm{end}} \sim 6$)



X. Fan, et al. 2006

Probes of reionization

- Quasar absorption spectra ($z_{\mathrm{end}} \sim 6$)
- CMBR observations ($z_{\mathrm{re}} \sim 8.8$)

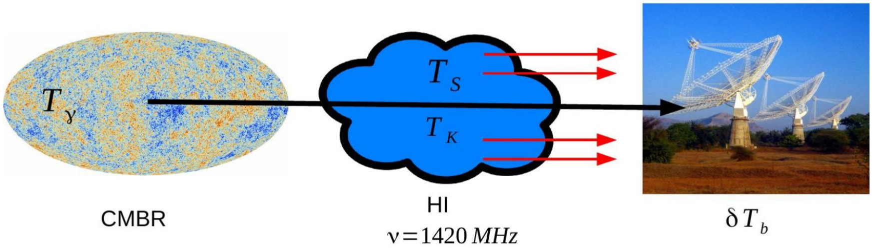


Planck Collaboration, 2016

Probes of reionization

- Quasar absorption spectra
  ($z_{\rm end} \sim 6$)
- CMBR observations
  ($z_{\rm re} \sim 8.8$)
- Others : High-z GRBs, IGM temperature, High-z Galaxies..
- 21-cm line from neutral hydrogen (H I).
  - Most promising probe of EoR.
  - Can be used for imaging the topology of reionization.
  - Probes thermal history of IGM before reionization.
  - Probes various radiation background.

Differential brightness temperature (δT_b)



Density contrast

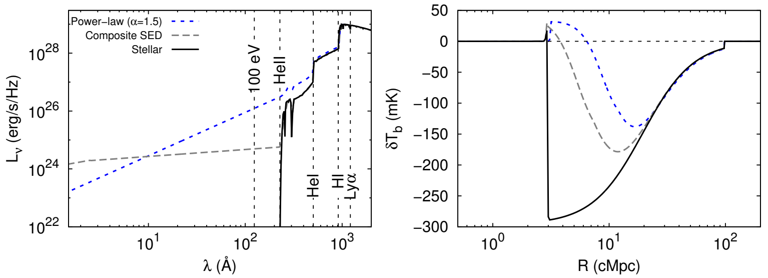
CMBR temperature

$$\delta T_\mathrm{b} = 27\, x_\mathrm{HI}\ (1+\delta_\mathrm{B}) \left(\frac{\Omega_\mathrm{B} h^2}{0.023}\right) \left(\frac{0.15}{\Omega_\mathrm{m} h^2}\frac{1+z}{10}\right)^{1/2} \left[1-\frac{T_\gamma}{T_\mathrm{S}}\right] \mathrm{mK}$$

neutral fraction of hydrogen (Astrophysics)

Spin temperature (Heating & Lyα coupling)

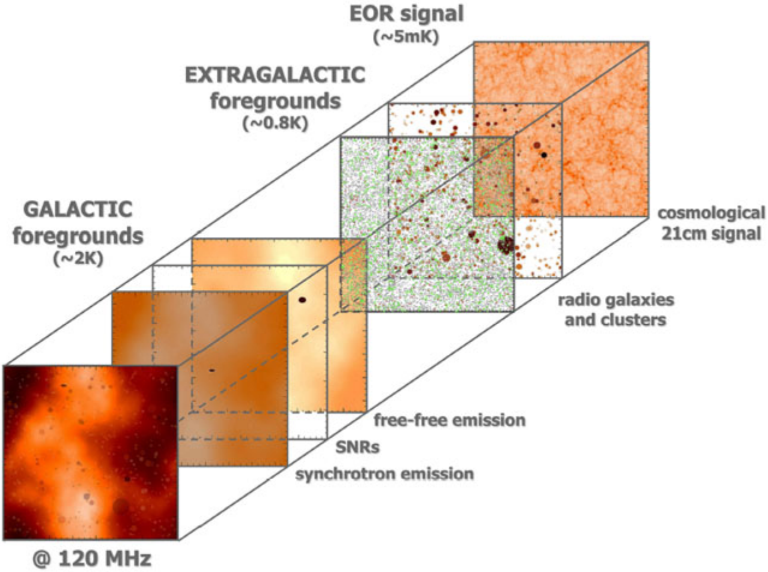
Example / parameters



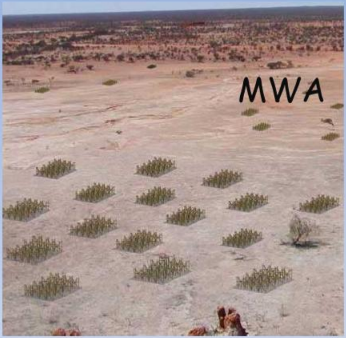
- Sources
  - $M_\star = 10^8\ \mathrm{M}_\odot$ (depends on star-formation efficiency $f_\star$).
  - Mini-QSO spectral index $\alpha = 1.5$
  - Composite SED of HMXBs : $\alpha = 0.24$ at soft X-ray range (5 years observation with MAXI)
  - Ratio of X-ray and UV luminosity $f_\mathrm{X} = 0.05$
  - UV escape fraction $f_\mathrm{esc} = 0.1$
  - $t_\mathrm{age} = 20\ \mathrm{Myr}$

.. in preparation

Problems: Foregrounds, System noise, Ionosphere..

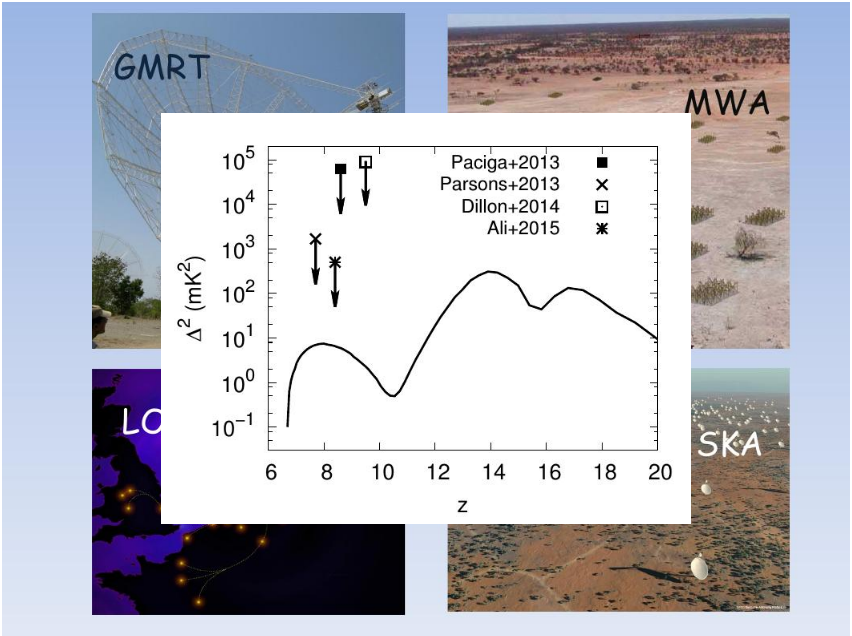



GMRT


MWA


LOFAR


SKA

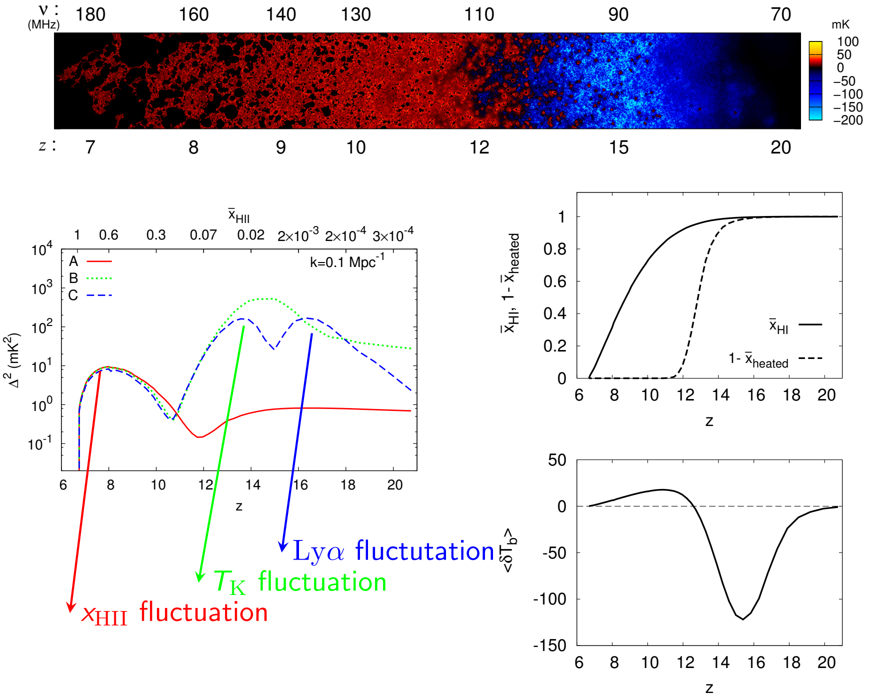

GMRT
MWA
SKA
Paciga+2013
Parsons+2013
Dillon+2014
Ali+2015
Δ^2 (mK^2)
10^5
10^4
10^3
10^2
10^1
10^0
10^{-1}
6 8 10 12 14 16 18 20
z

What Simulations can do?

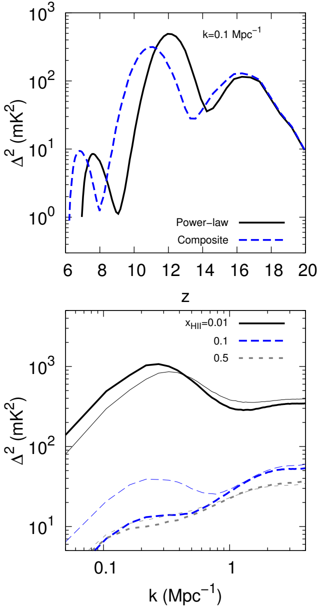
- Detection of the signal is itself challenging.
  - Foregrounds
  - system noise
  - ionosphere
  - calibration
  - signal extraction schemes
- Better understanding of the signal properties.
- For developping better calibration, signal extraction schemes.
- Simulations of 21-cm signal is necessary to make observational strategies.
- Extract information about the sources, IGM etc.
- Need faster simulations to cover huge parameter space ($f_\star$, n_γ, $f_{\rm esc}$, f_X, α, ..).

Different approaches

- Analytical : Reionization model based on excursion set principle
  - Furlanetto et al 2004
- Semi analytical : ionization based on excursion set principle
  - 21cmFAST (Mesinger et al 2007)
  - SimFAST21 (Santos et al 2010)
  - Choudhury et al 2009
  - ...
- Numerical : ionization using 3D radiative transfer
  - C^2-RAY (Mellema et al 2006)
  - CRASH (Ciardi et al 2001)
  - ...
- **Using 1D radiative transfer**
  - BEARS (Thomas et al 2009)
  - GRIZZLY (-BEARS) (Ghara et al 2015)


ν : (MHz) 180 160 140 130 110 90 70
mK 100 50 0 −50 −100 −150 −200
z : 7 8 9 10 12 15 20
x̄HII
1 0.6 0.3 0.07 0.02 2×10^-3 2×10^-4 3×10^-4
A
B
C
k=0.1 Mpc^-1
Δ^2 (mK^2)
z
Lyα fluctutation
T_K fluctuation
x_HII fluctuation
x̄HI, 1- x̄heated
x̄HI
1- x̄heated
<δT_b>
z

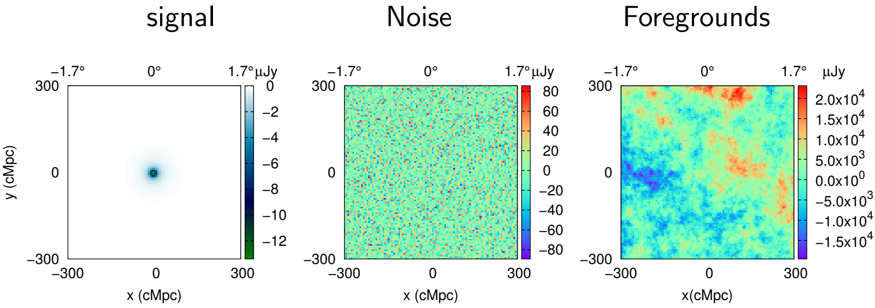
21-cm signal for Mini-QSO and HMXBs model sources



- Composite spectrum do heating less inhomogeneously than the mini-QSOs.
- Heating peak amplitude is less for composite spectrum.
- More partial ionization by soft X-rays in mini-QSOs results in early end of reionization.
- bump around $k \sim 0.2\ \mathrm{Mpc}^{-1}$ at redshift 11.96 (mini-QSO) corresponds to $\mathrm{R}_{\mathrm{heat}} \sim 12\ \mathrm{cMpc}$

.. in preparation

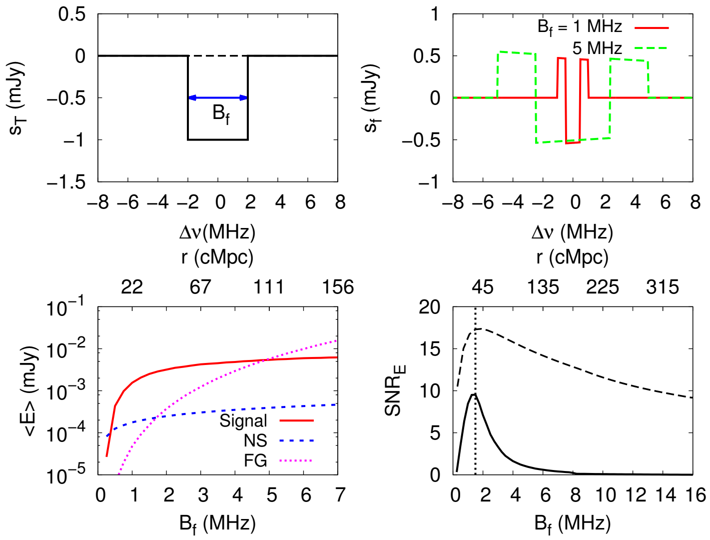
Isolated source detection using SKA1-low Ghara et al., 2016, MNRAS, 460, 827



- Source : Mini-QSO ($M_{\star} = 10^7$ $\mathrm{M}_{\odot}$, $\alpha = 1.5$, $f_{\mathrm{X}} = 0.05$, $f_{\mathrm{esc}} = 0.1$, $t_{\mathrm{age}} = 20$ Myr)
- Noise : SKA1-low, $z = 15$, $\mathrm{t_{obs}} = 2000$ h, Frequency resolution = 100 kHz, band width =16 MHz.
- Foregrounds :Galactic Synchrotron radiation, Unresolved extragalactic point sources

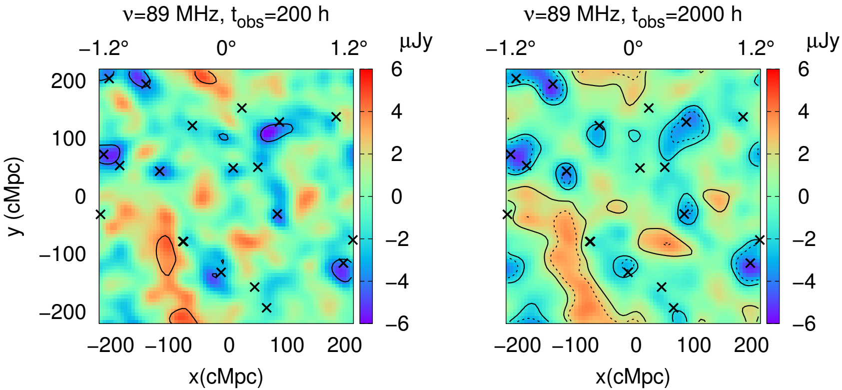
Using filters (Matched filter?)

Ghara et al 2016, MNRAS, 460, 827



Imaging?

Ghara et al 2017, MNRAS, 464, 2234



- '$\times$' marks: θ_x, θ_y positions of the sources.
- SNR : 4.8, 14.2
- Resolution : 30 arcmin

Summary

- Fast simulations of the 21-cm signal are important for parameter estimations, predicting new observation strategies etc.
- One-dimensional radiative transfer can be efficiently used for generating 21-cm maps from the Cosmic dawn and EoR.
- SKA should be able to detect the sources in 21-cm signal even from the cosmic dawn. Images can be used for parameter estimation.
- Matched filtering method can be efficiently used for detecting the sources in cosmic dawn.

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Thank you