Detecting sources of reionization and cosmic dawn using SKA

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Collaborators

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- Garrelt Mellema (Stockholm Univ.)
- Martina Friedrich (Stockholm Univ.)
- Ilian Iliev (Sussex Univ., UK)
- Somnath Bharadwaj (IIT Kharagpur)
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- Himadri Roy (Presidency Univ., Kolkata)

Major approaches

- Global HI 21-cm signal
- Statistical - power spectrum, rms, skewness, kurtosis
- Individual : Targeted observations, blind search, imaging

Three approaches

- Global HI 21-cm signal
- Statistical - power spectrum, rms, skewness, kurtosis
- Individual : Targeted observations, blind search, imaging

Advantages:

- Direct evidence
- Easy to interpret
- probes nature of sources

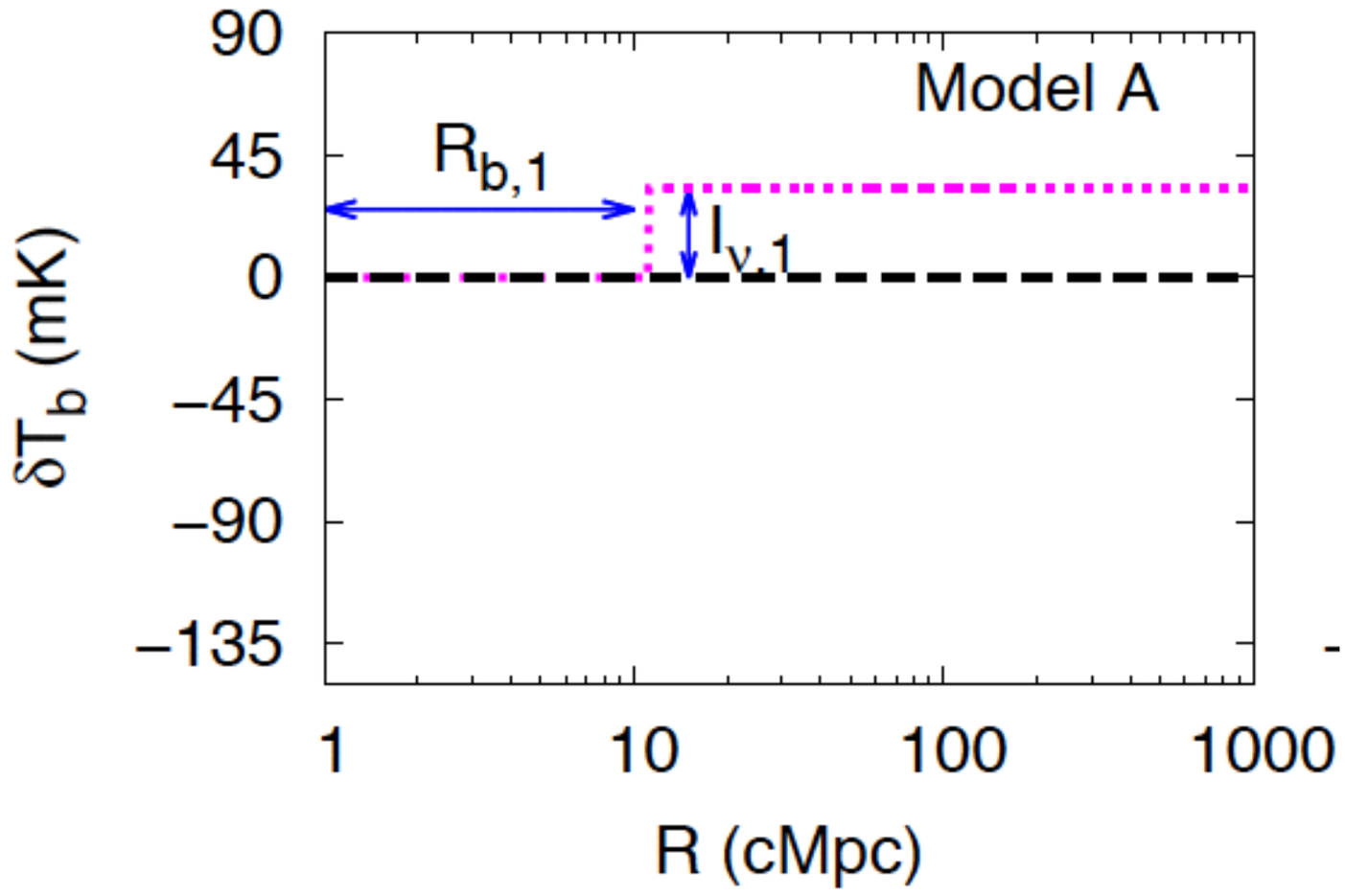
21 cm signal

Differential Brightness temperature

$$\delta T_{\rm b}(\nu_{\rm obs}, \hat{\boldsymbol{n}}) \equiv \delta T_{\rm b}(\boldsymbol{x}) = 27\, x_{\rm H\,I}(z, \boldsymbol{x})[1 + \delta_{\rm B}(z, \boldsymbol{x})] \left(\frac{\Omega_{\rm B} h^2}{0.023}\right) \times \left(\frac{0.15}{\Omega_{\rm m} h^2} \frac{1+z}{10}\right)^{1/2} \left[1 - \frac{T_{\rm CMB}(z)}{T_{\rm S}(z, \boldsymbol{x})}\right] \ {\rm mK},$$

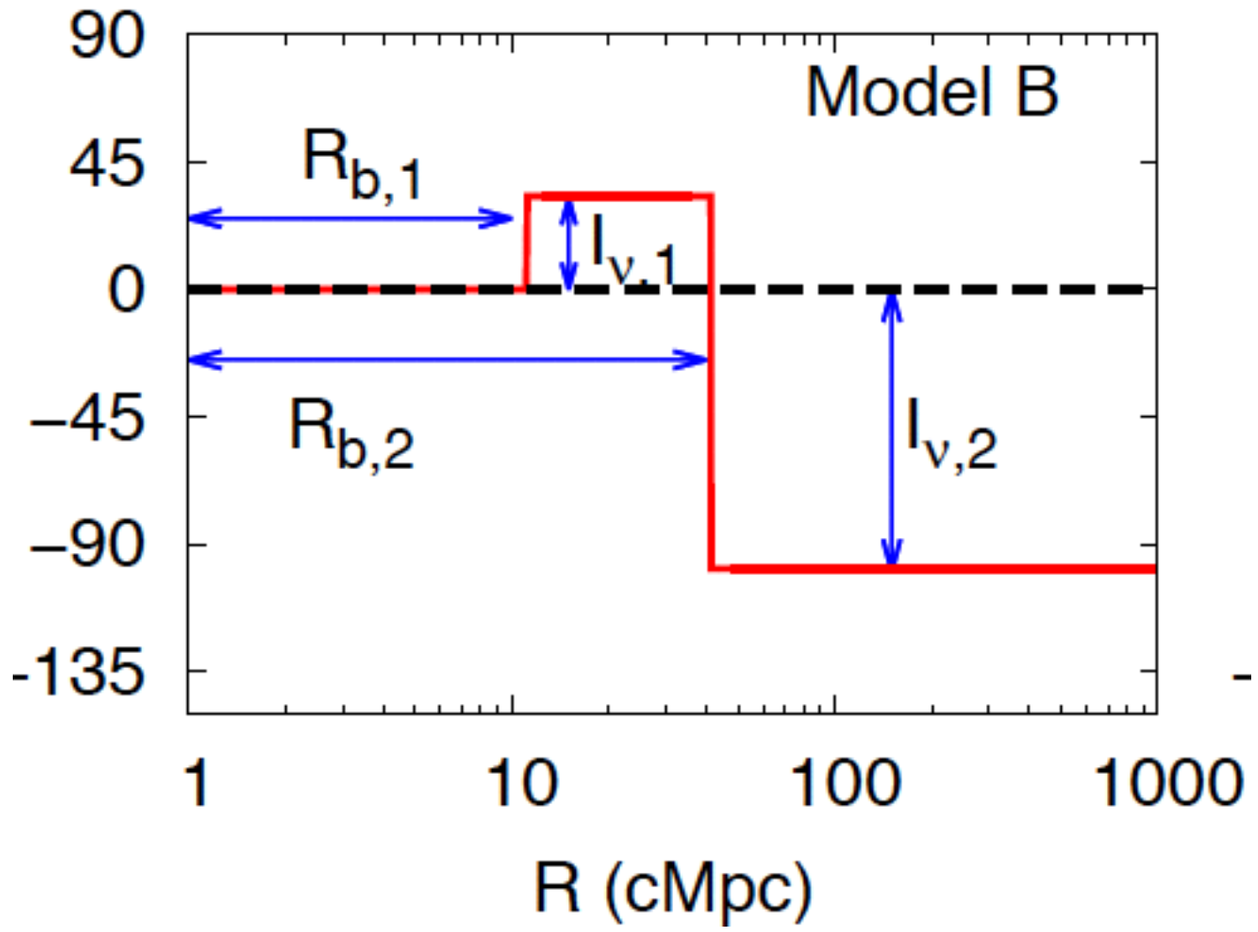
HI 21-cm signal around individual sources

During Re-ionization era ($T_s >> T_{CMB}$)



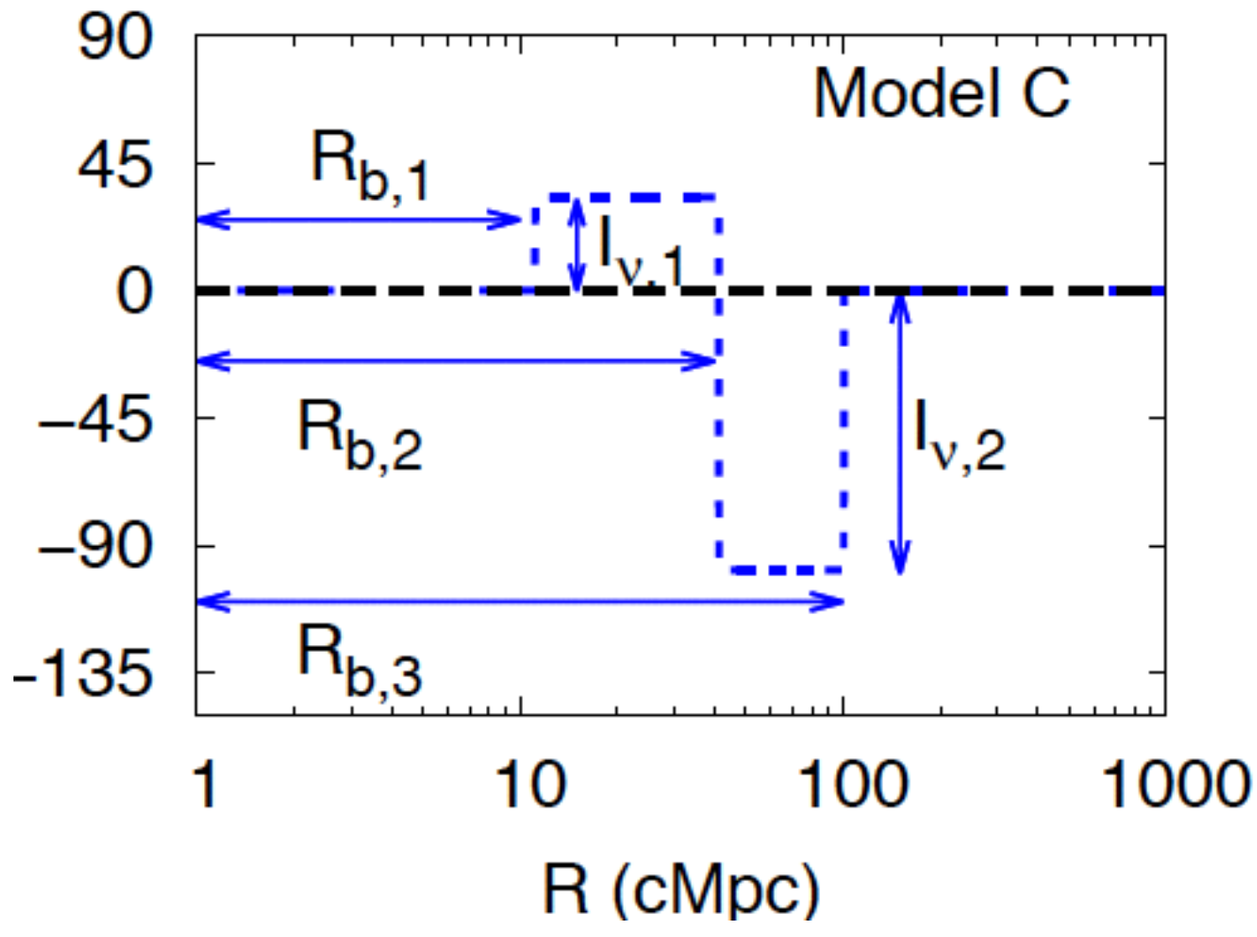
HI 21-cm signal around individual sources

During Cosmic dawn ($T_s \sim T_{kin}$, IGM heating is in progress)

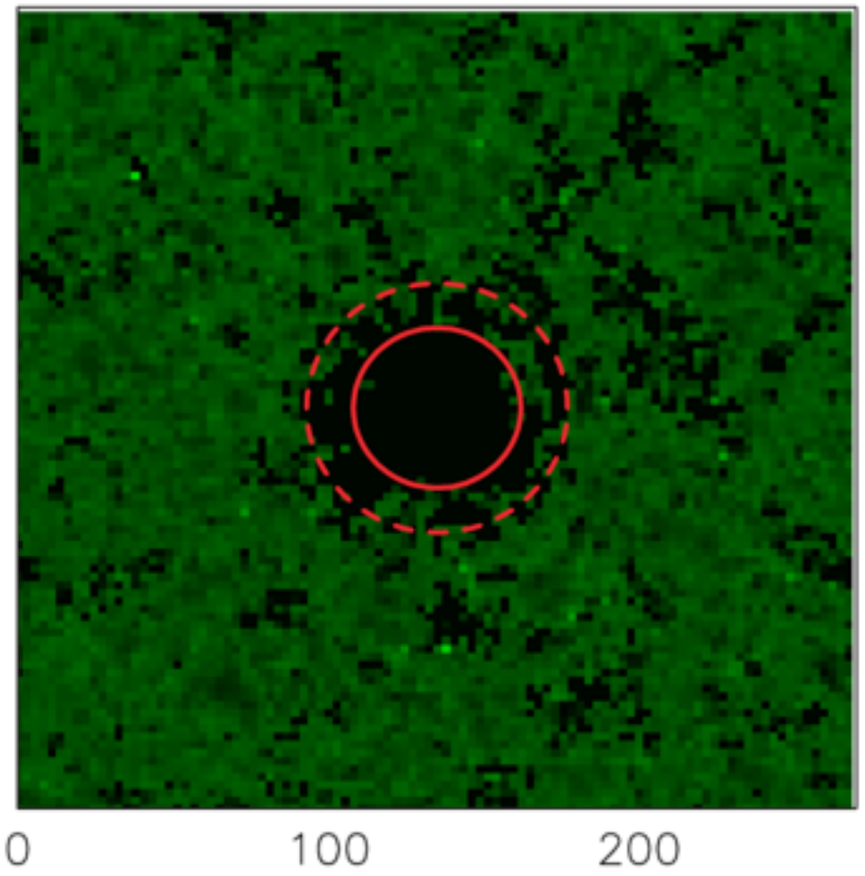


HI 21-cm signal around individual sources

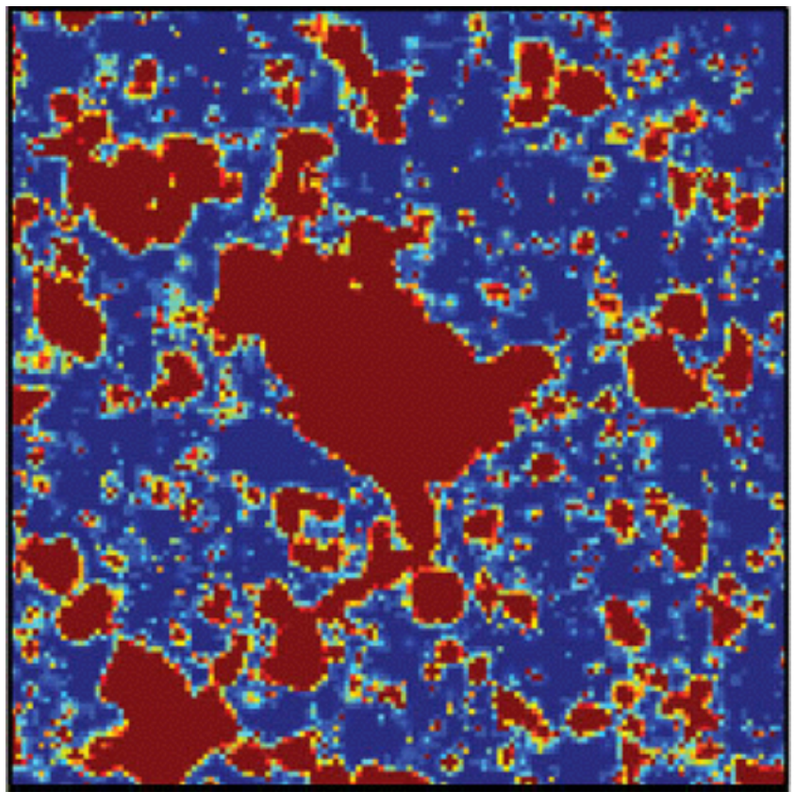
During Cosmic dawn (Both Ly-alpha coupling and IGM heating are in progress)



Ionized regions around bright QSOs during reionization



Using semi-numerical simulations
Datta, Majumdar, Bharadwaj, Choudhury, 2008



$\dot{N}_{\gamma}^{\rm qso}$ (s)=1.4 × 10^{56}

$x_{\rm HI}$ ~0.5

qso age=11.5 Myr

z~7.6

Radiative transfer (C2-Ray)
Datta, Friedrich, Mellema, Iliev, Shapiro, 2012

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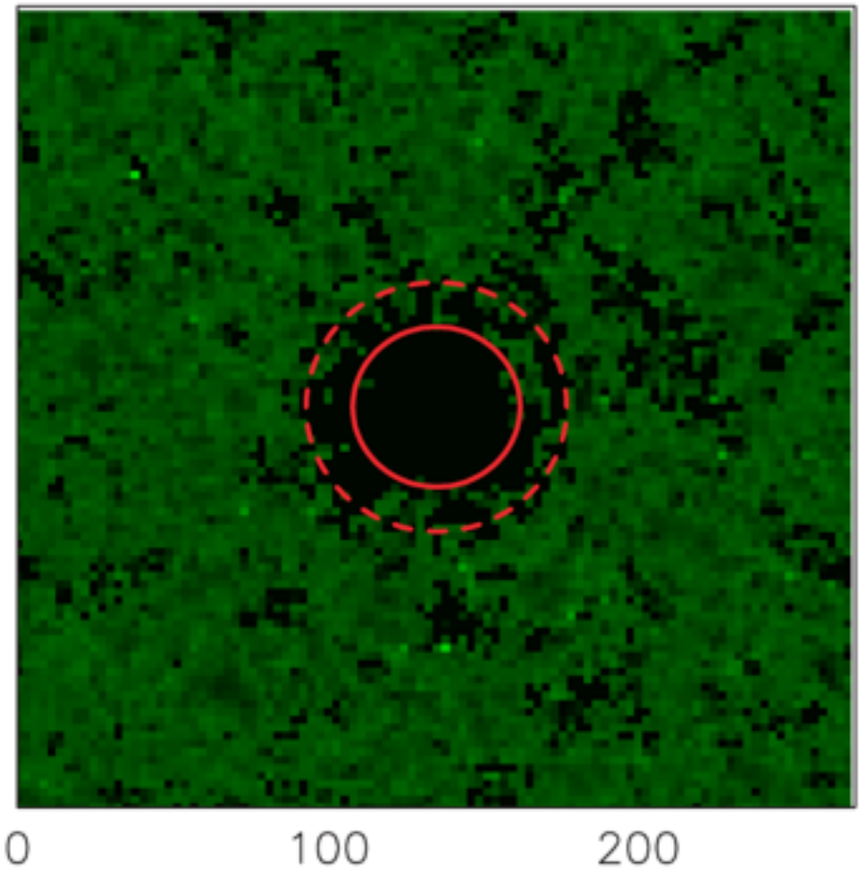

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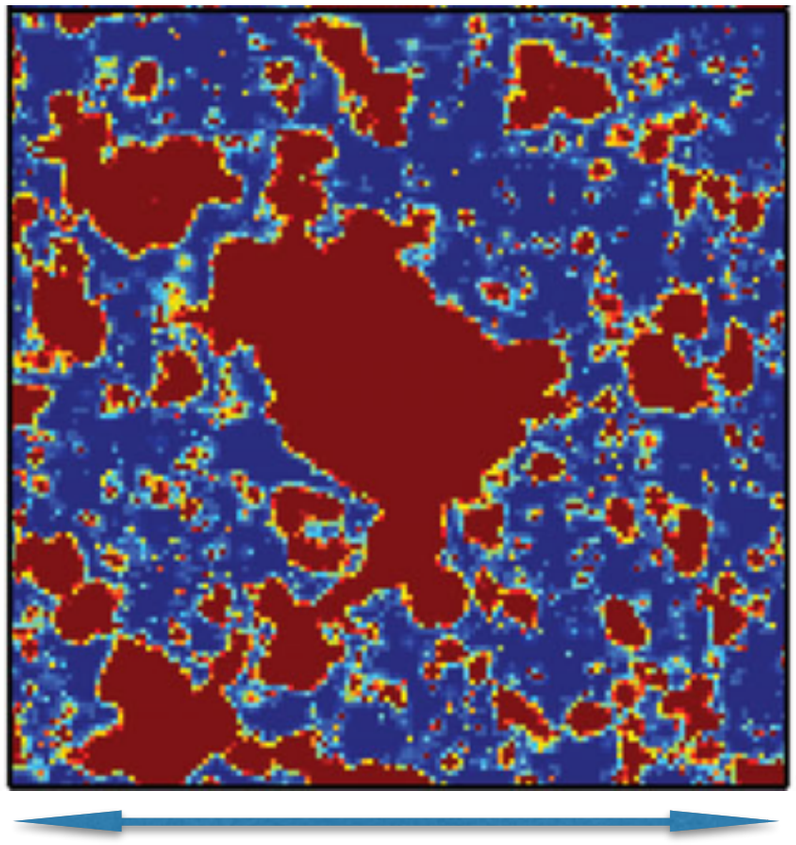

$\dot{N}_{\gamma}^{\rm qso}$ (s)=1.4 × 10^{56}

$x_{\rm HI}$ ~0.5

qso age=23.0 Myr

z~7.6

Radiative transfer (C2-Ray)
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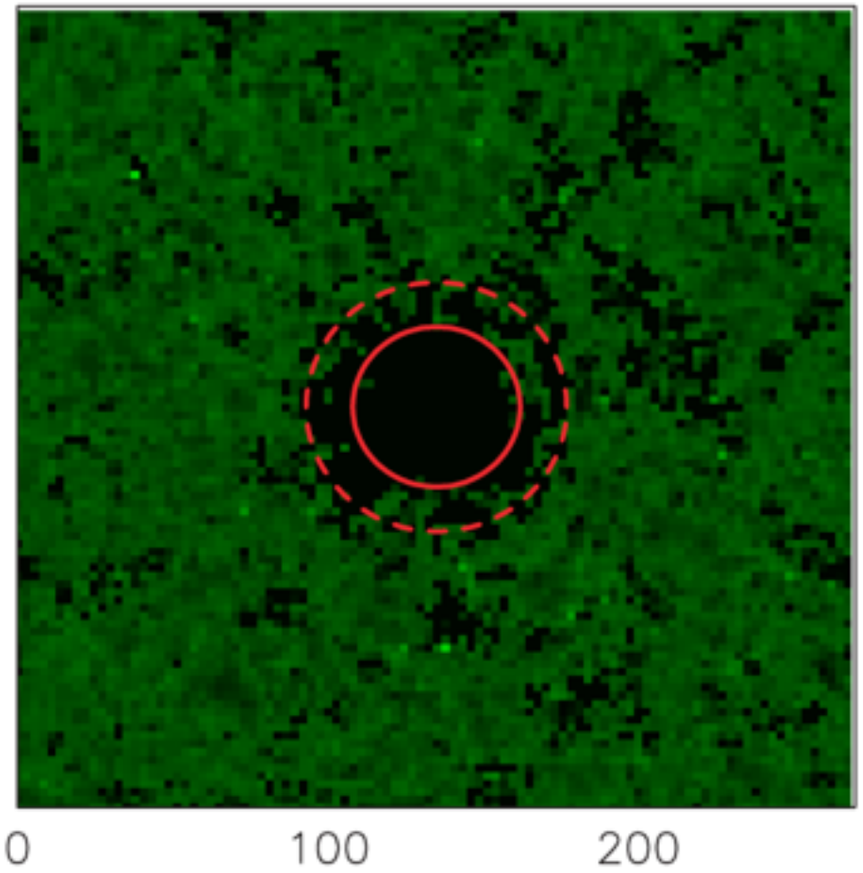
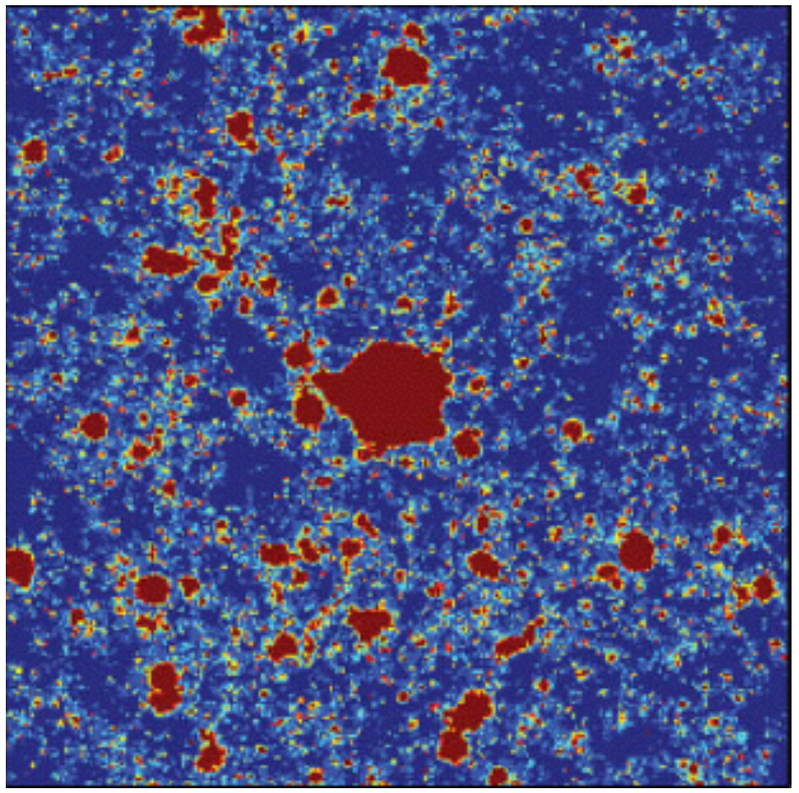
Ionized regions around bright QSOs during reionization



Using semi-numerical simulations
Datta, Majumdar, Bharadwaj, Choudhury, 2008



163 Mpc

$\dot{N}_\gamma^{qso}$ (s)= 3.3×10^{55}

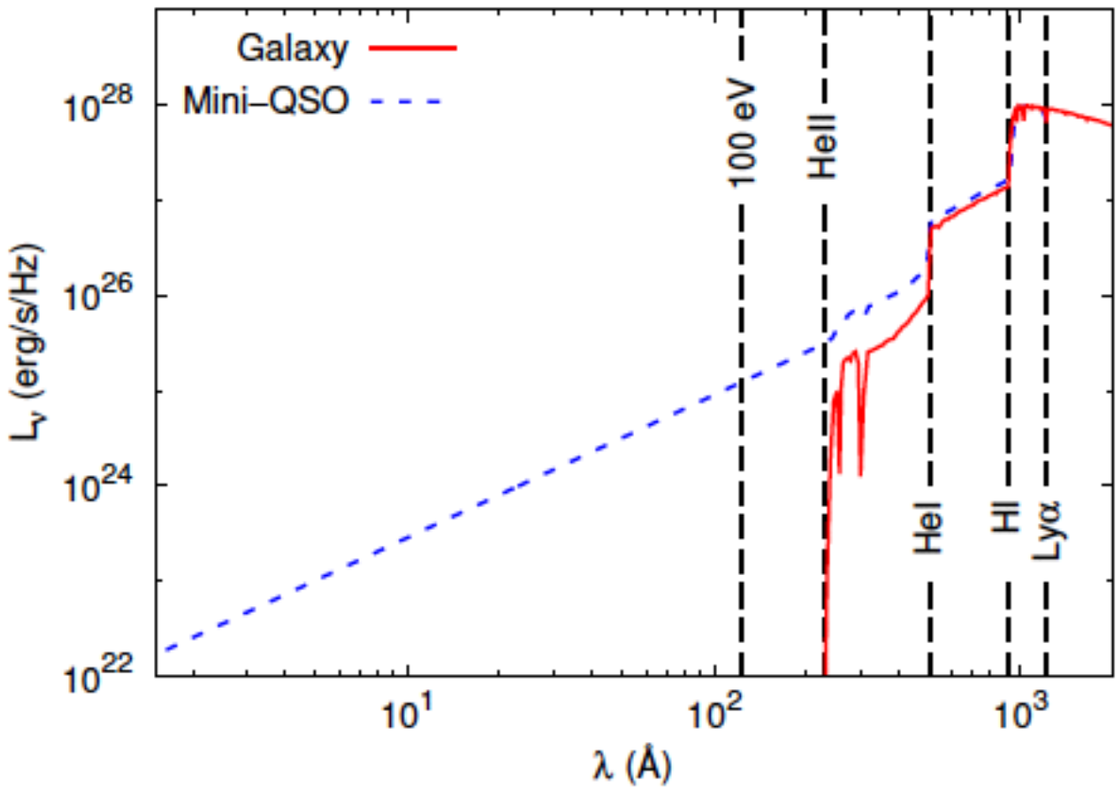
x_{HI} **~0.2**

qso age=23.0 Myr

z~8.4

Radiative transfer (C2-Ray)
Datta, Friedrich, Mellema, Iliev, Shapiro, 2012

Modelling Sources during cosmic dawn



Source parameters

$M_\star = 10^8\ \mathrm{M}_\odot$.

Spectral index $\alpha = 1.5$

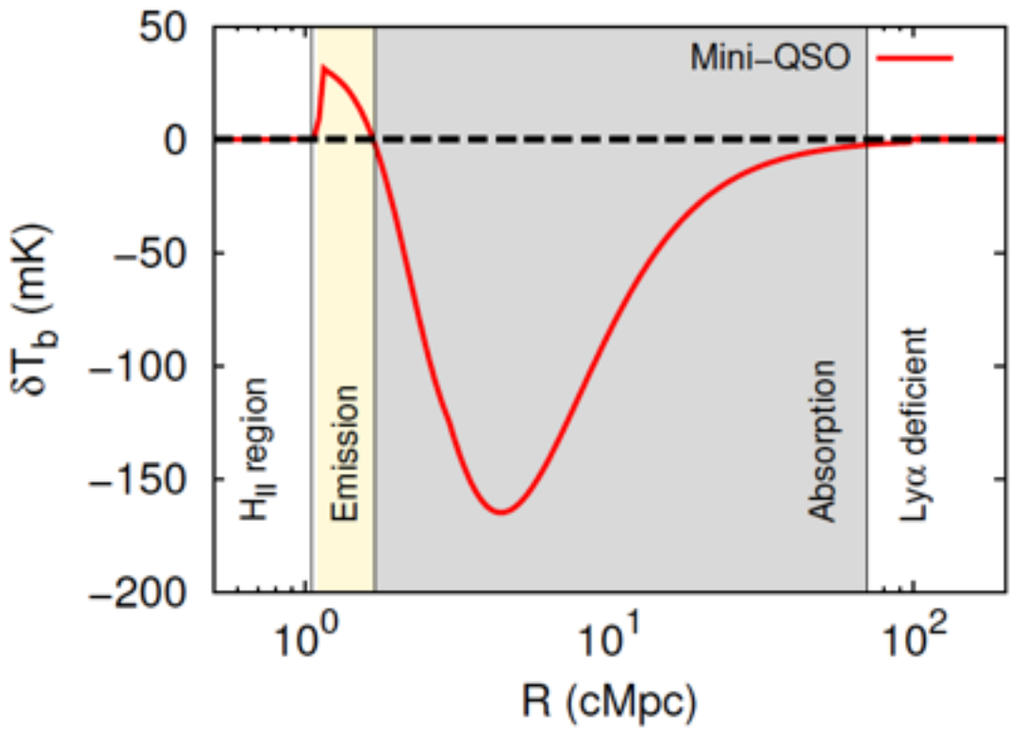
ratio of X-ray and UV luminosity $f_X = 0.05$

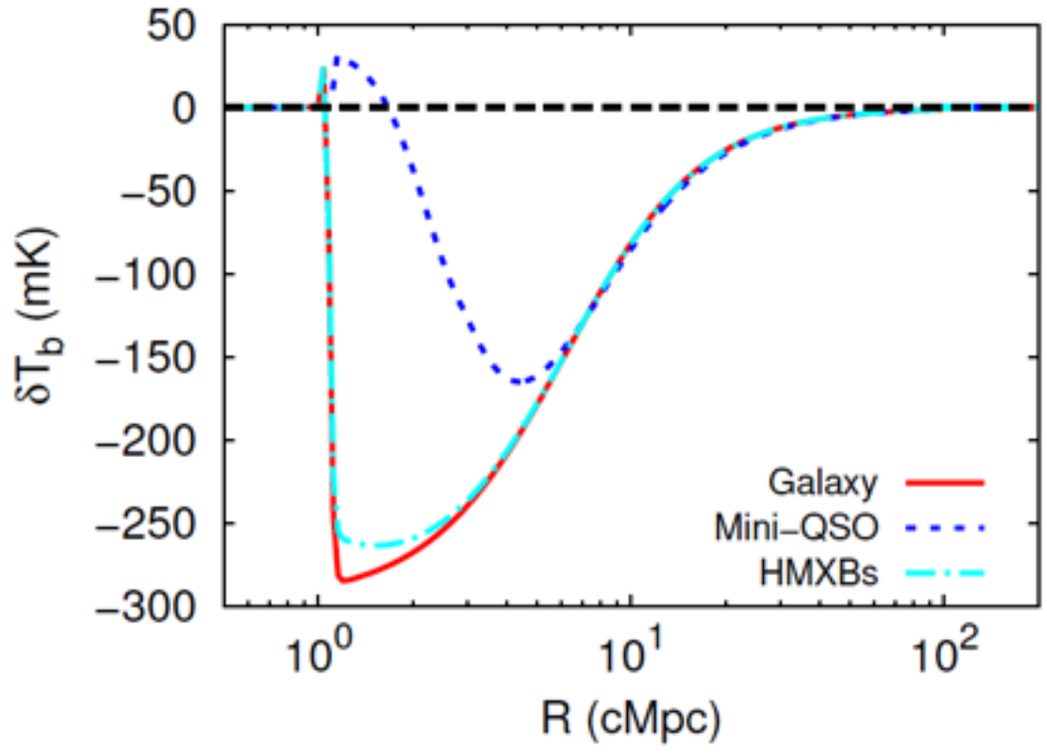
$f_{\mathrm{esc}} = 0.1$

$t_{\mathrm{age}} = 20\ \mathrm{Myr}$

Density contrast $\delta = 0$

HI 21-cm profile during cosmic dawn

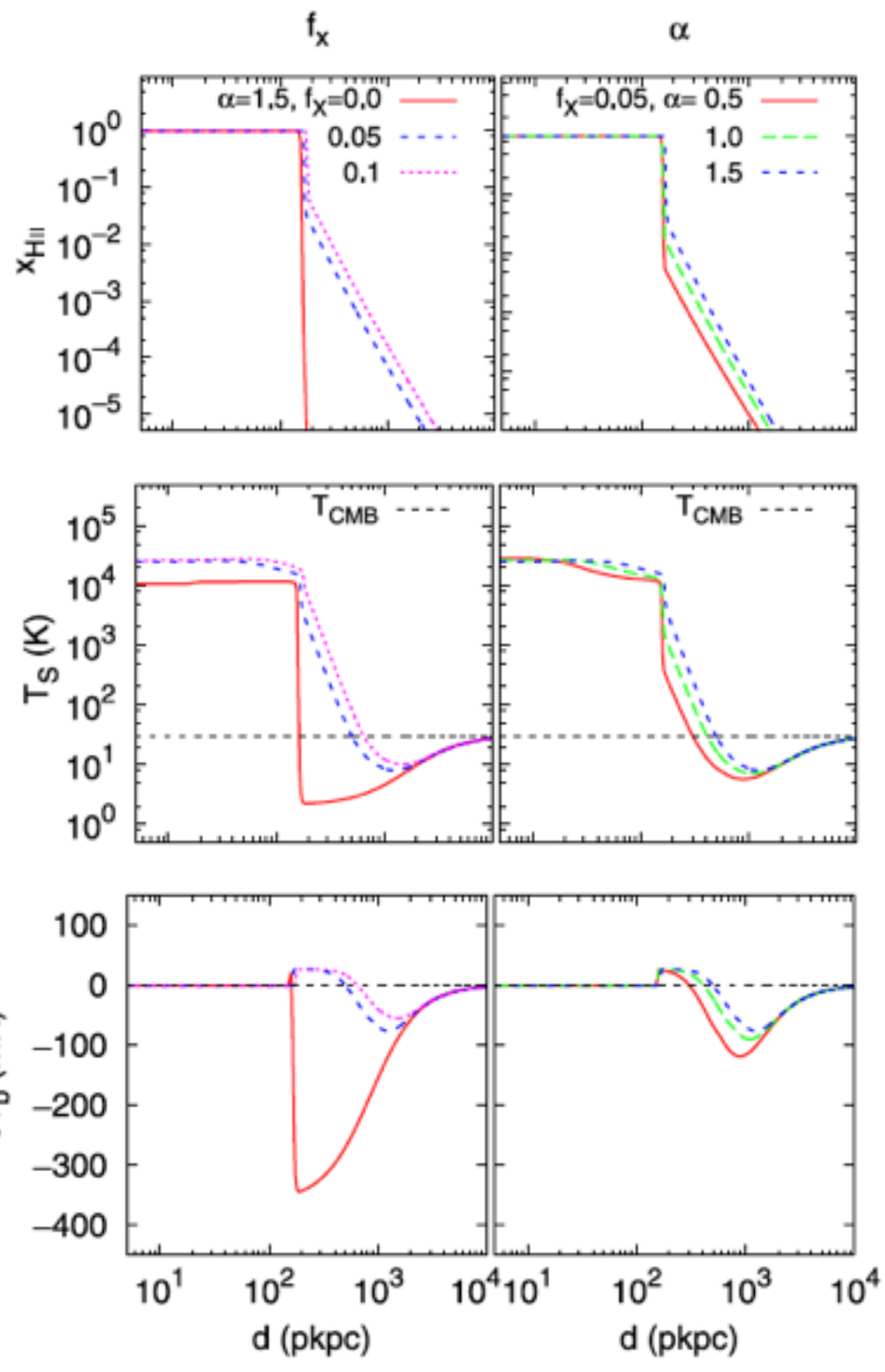




$M_\star = 10^7\ \mathrm{M}_\odot,\ \delta = 0,\ \alpha = 1.5,\ f_X = 0.05,\ t_{\mathrm{age}} = 20\ \mathrm{Myr}$

Ghara, Choudhury, Datta, Choudhuri, 2016

Signal profile around mini-QSOs



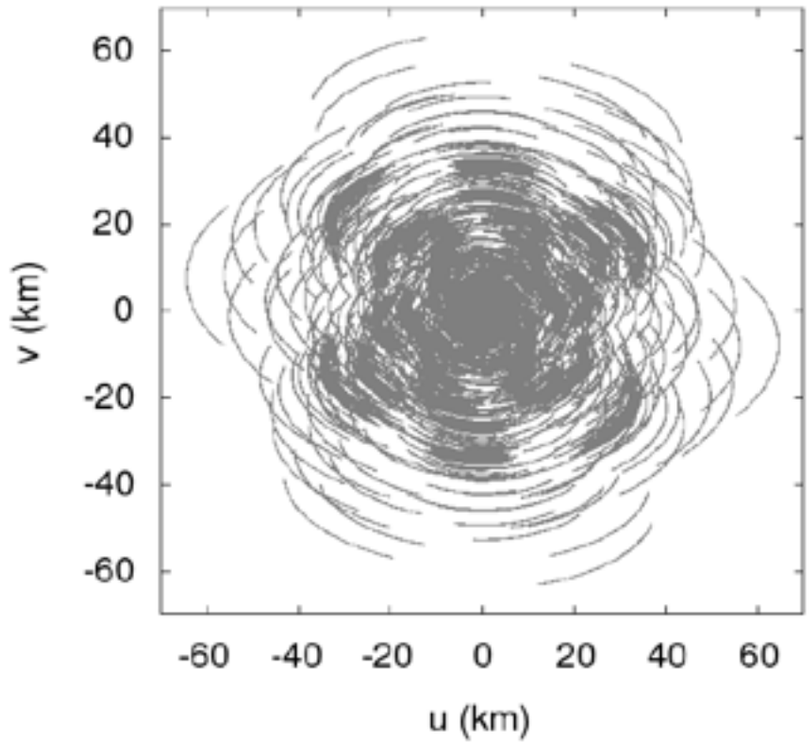
$$M_\star = \ 10^8\,\mathrm{M}_\odot$$

$$t_{\rm age} = 10\ \mathrm{Myr}$$

Ghara, Choudhury, Datta, MNRAS, 2015

SKA1 -low

Parameters	Values
Redshift (z)	15
Central frequency (ν_c)	88.75 MHz
Band width (B_ν)	16 MHz
Frequency resolution ($\Delta\nu_c$)	100 kHz
Observational time ($t_{\rm obs}$)	2000 h
System temperature ($T_{\rm sys}$)	$60 \times (300\ {\rm MHz}/\nu_c)^{2.55}$ K
Number of antennae ($N_{\rm ant}$)	564
Effective collecting area ($A_{\rm eff}$)	962 m^2



Baseline coverage for 4 hrs observations at -30 degree declinations

Visibility based matched filter methods

Estimator

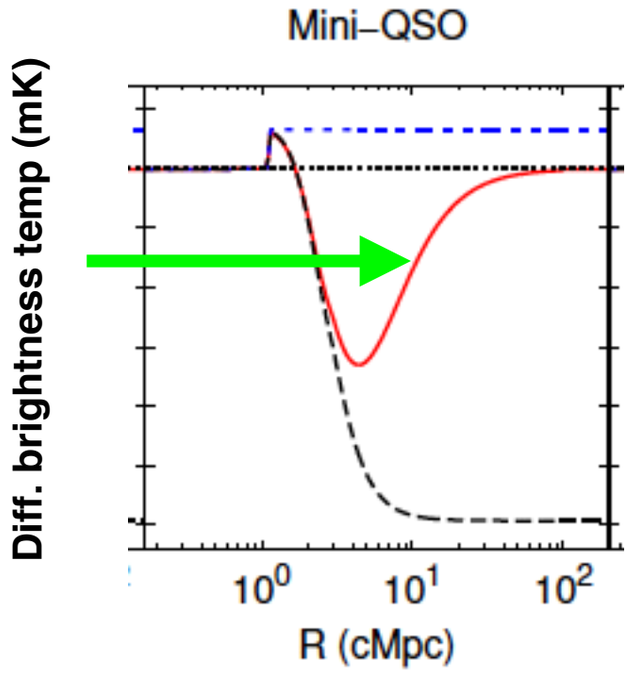
$$\hat{E} = \left[\sum_{a,b} S_f^*(\boldsymbol{U}_a, \nu_b)\hat{V}(\boldsymbol{U}_a, \nu_b)\right] \Big/ \left(\sum_{a,b} 1\right)$$

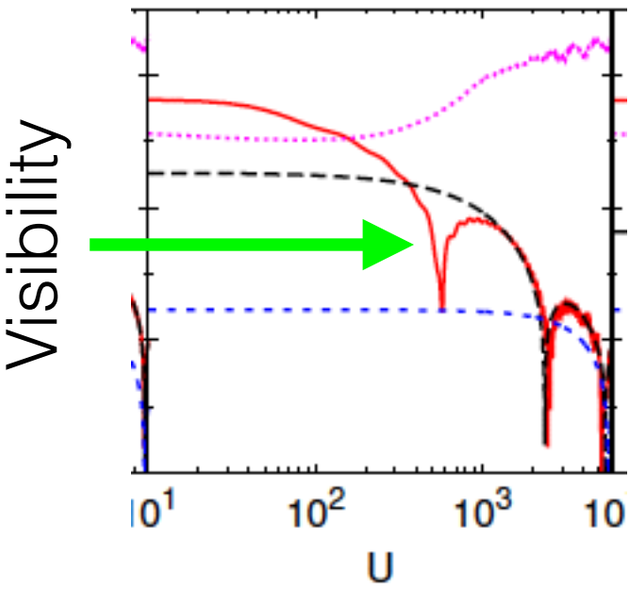
Variance

$$\langle(\Delta\hat{E})^2\rangle_{\rm NS} = \sigma^2 \int \mathrm{d}^2U \int \mathrm{d}\nu\, \rho_N(\boldsymbol{U}, \nu)\, |S_f(\boldsymbol{U}, \nu)|^2$$

Matched Filter

$$S_{\rm f}(\boldsymbol{U},\ \nu) = \left(\frac{\lambda_{\rm c}}{\lambda}\right)^2 [S(\boldsymbol{U},\ \nu) - \frac{\Theta(1 - 2\mid \nu - \nu_{\rm c}\mid /B')}{B'} \int_{\nu_{\rm c}-B'/2}^{\nu_{\rm c}+B'/2} S(\boldsymbol{U}, \nu')\,\mathrm{d}\nu']$$

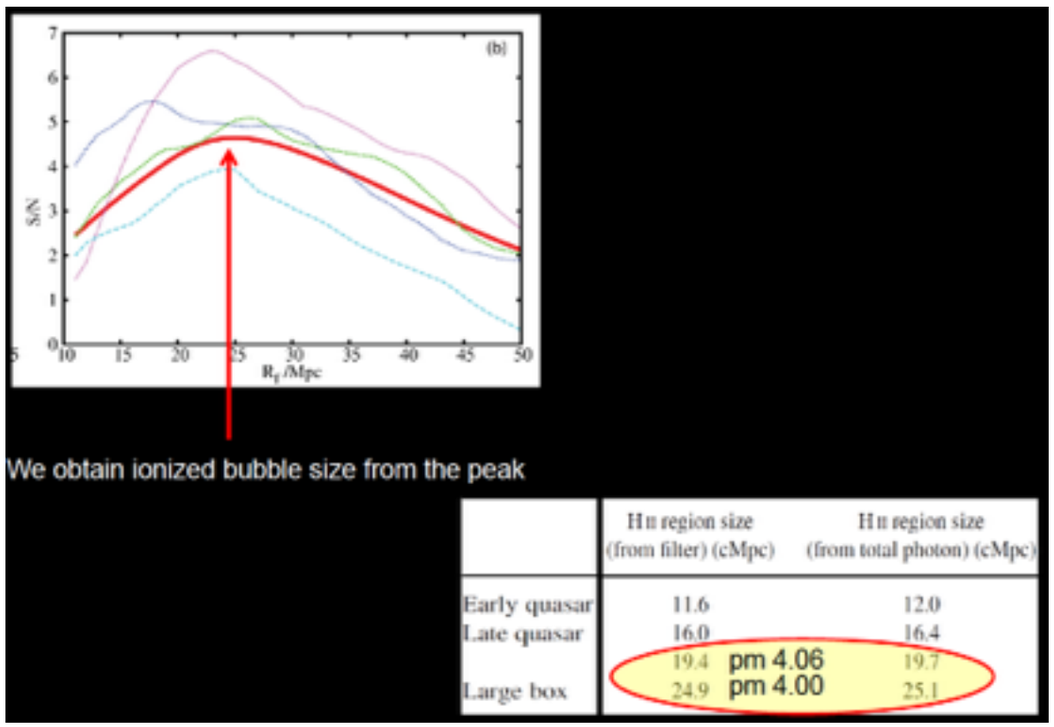




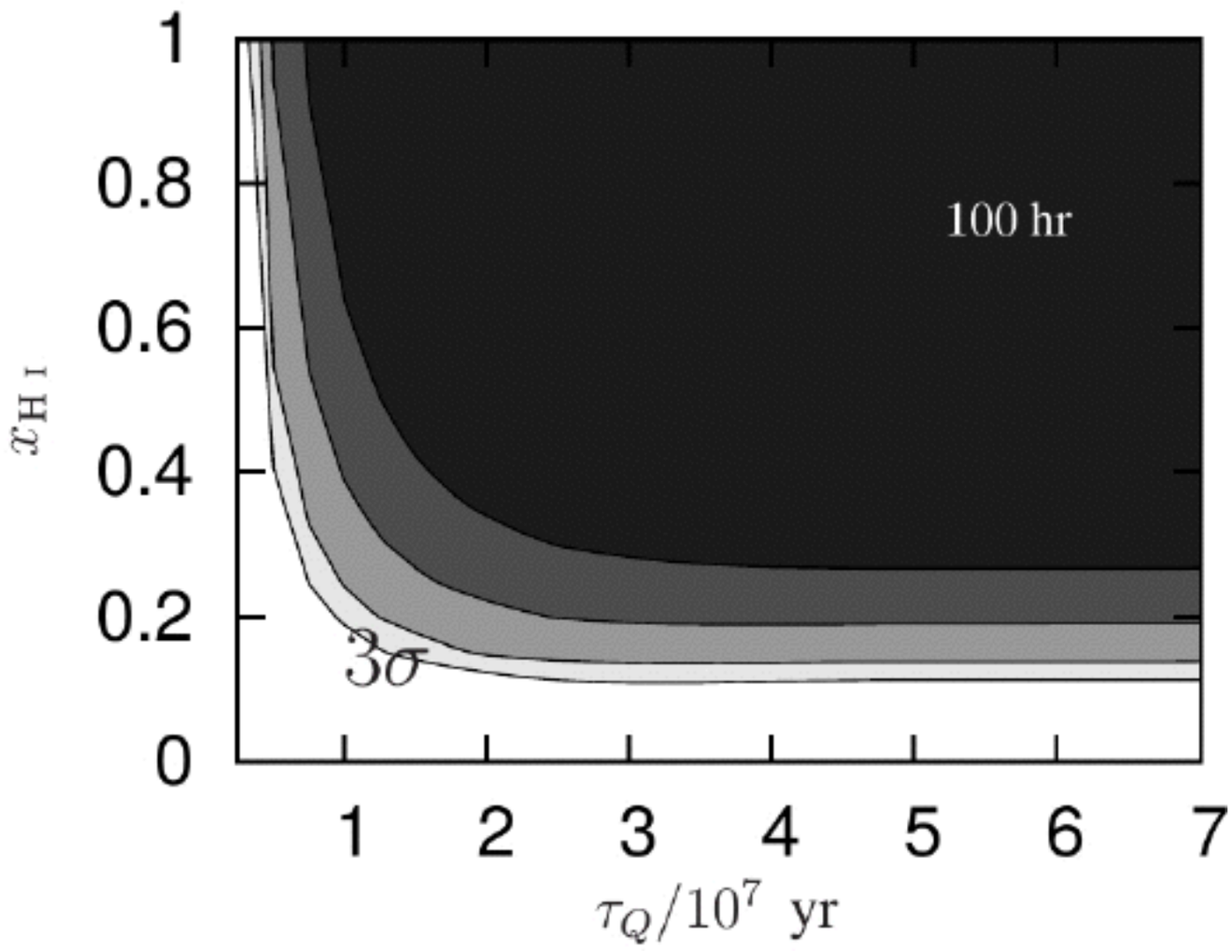
Ghara, Choudhury, Datta, MNRAS, 2016

Detectability : Targeted Search

LOFAR



Datta, Friedrich, Mellema et al
2012, MNRAS

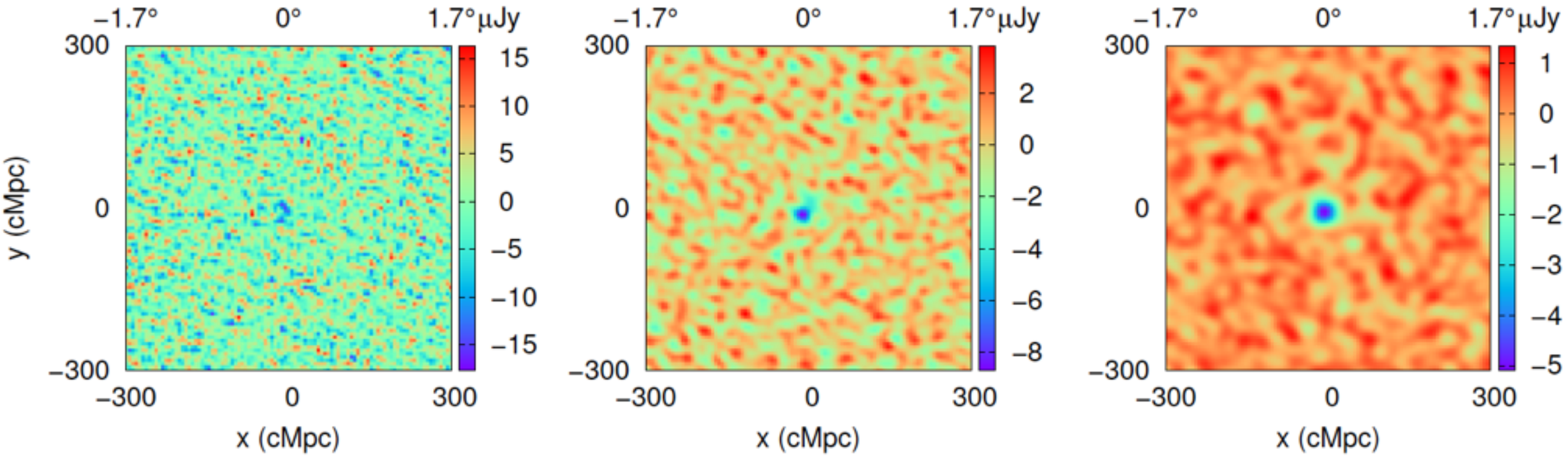


Observing ULASJ1120+0641 (Mortlock et al. 2011) like QSOs with SKA1-low

Datta K, Ghara, Majumdar, Choudhury, Bharadwaj, Roy, Datta A, 2016

Imaging sources during cosmic dawn with SKA1-low

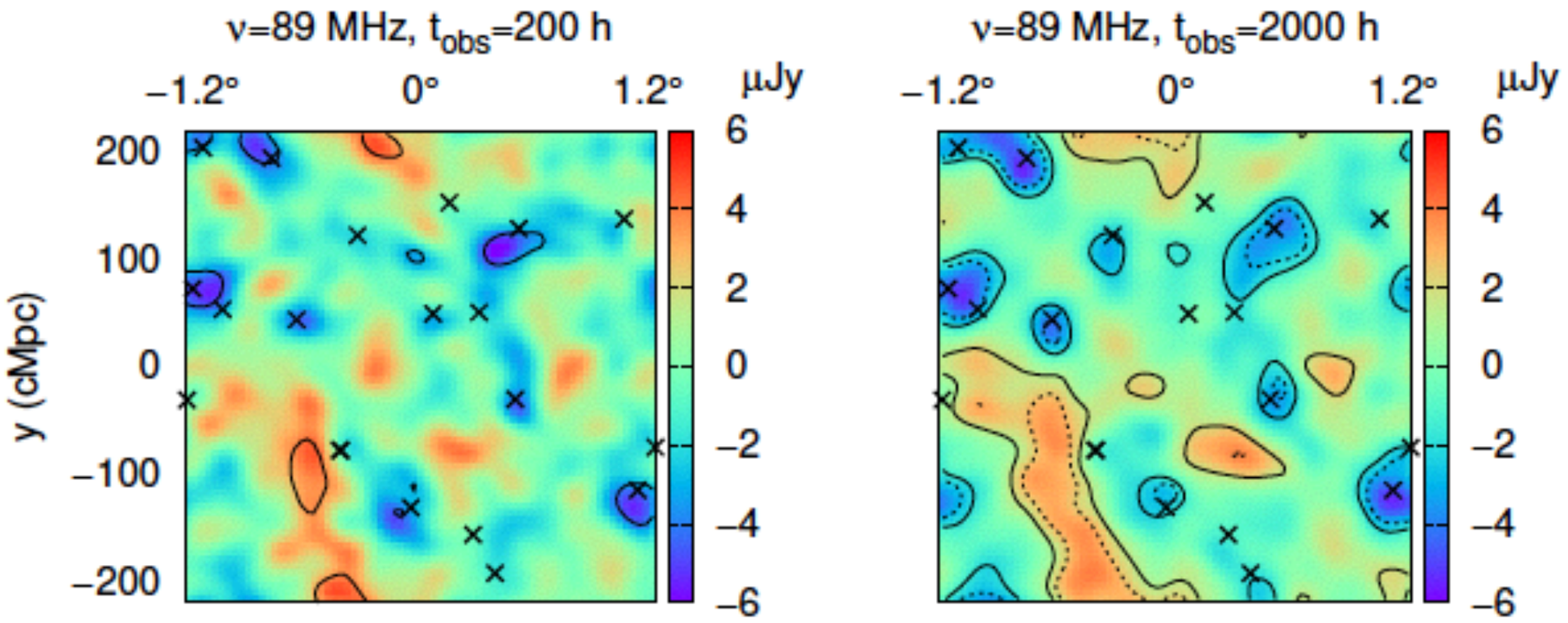
Gaussian smoothing



- z=15, 2000 hrs, 564 antennae, 100 KHz
- 10-20 sigma detection at z=15 for 30’ beam

Ghara, Choudhury, Datta, Choudhuri, 2016

Imaging sources during cosmic dawn with SKA1-low



Source recovery after foreground subtraction and smoothing with 30’ beam

Ghara, Choudhury, Datta, Choudhuri, 2016

Summary

- Detection of 21-cm signal around individual sources is a direct approach to probe EoR. It is also easy to interpret.

- Matched filter technique is a promising technique for detecting ionised bubble around bright objects.

- SKA1-low should be able to image HI around **known bright** QSOs, galaxies with several hundred hrs of observations.

- SKA -low should be able to image HI 21-cm signal around the sources during cosmic dawn with 1000 hrs of observations

- Various source parameters such as the mass, age and IGM density can be probed using such observations

Thanks