Study of Low Frequency Radio Foregrounds using the uGMRT - Applications to Cosmological HI signal Extraction

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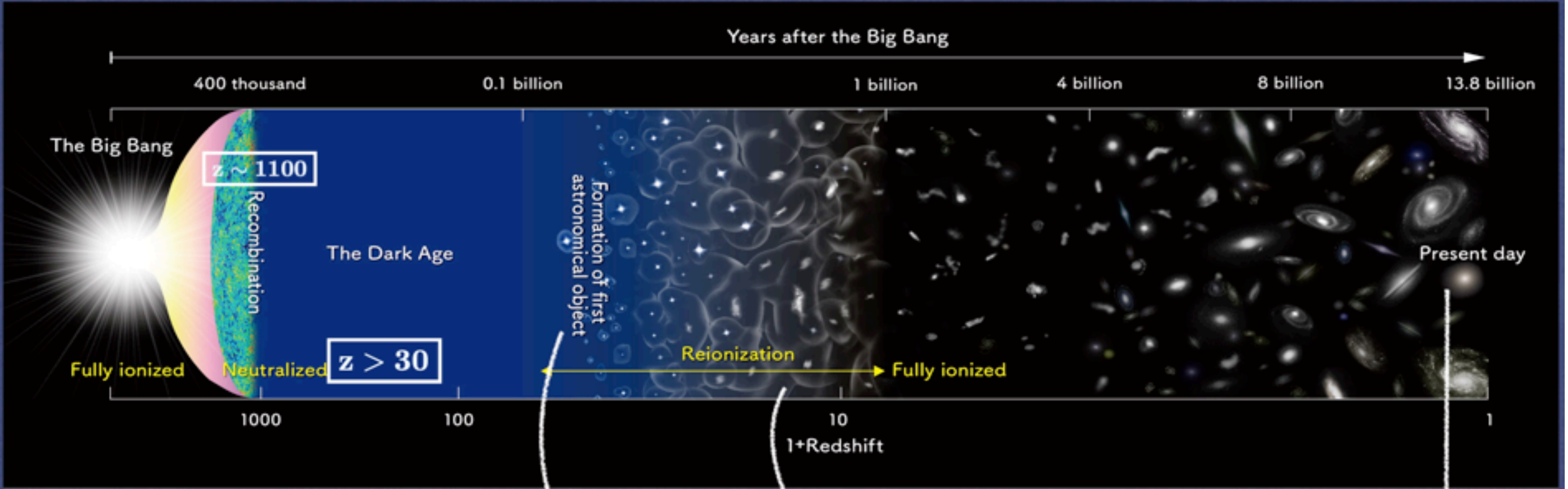
Cosmic Dawn/ Epoch of Reionization



30 > z > 15

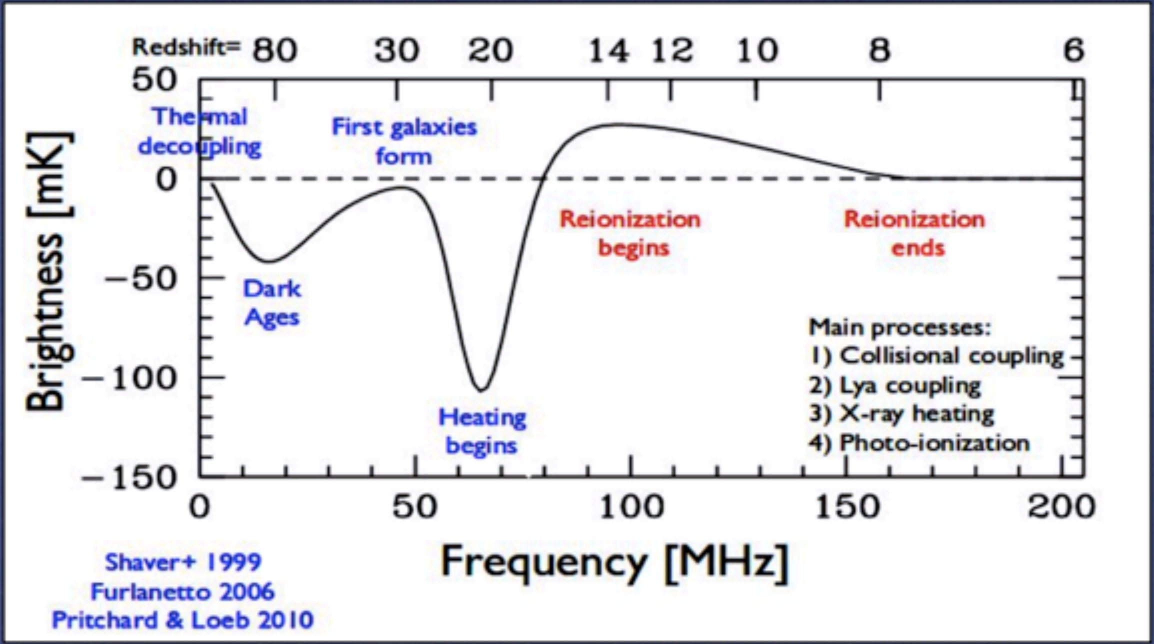
Cosmic Dawn

15 > z > 6

Reionization

Now

The 21-cm Global Signal



$$\delta T_b \approx 27(1 - x_i)\left(\frac{\Omega_{b,0}h^2}{0.023}\right)\left(\frac{0.15}{\Omega_{m,0}h^2}\frac{1+z}{10}\right)^{1/2}\left(1 - \frac{T_\gamma}{T_S}\right)$$

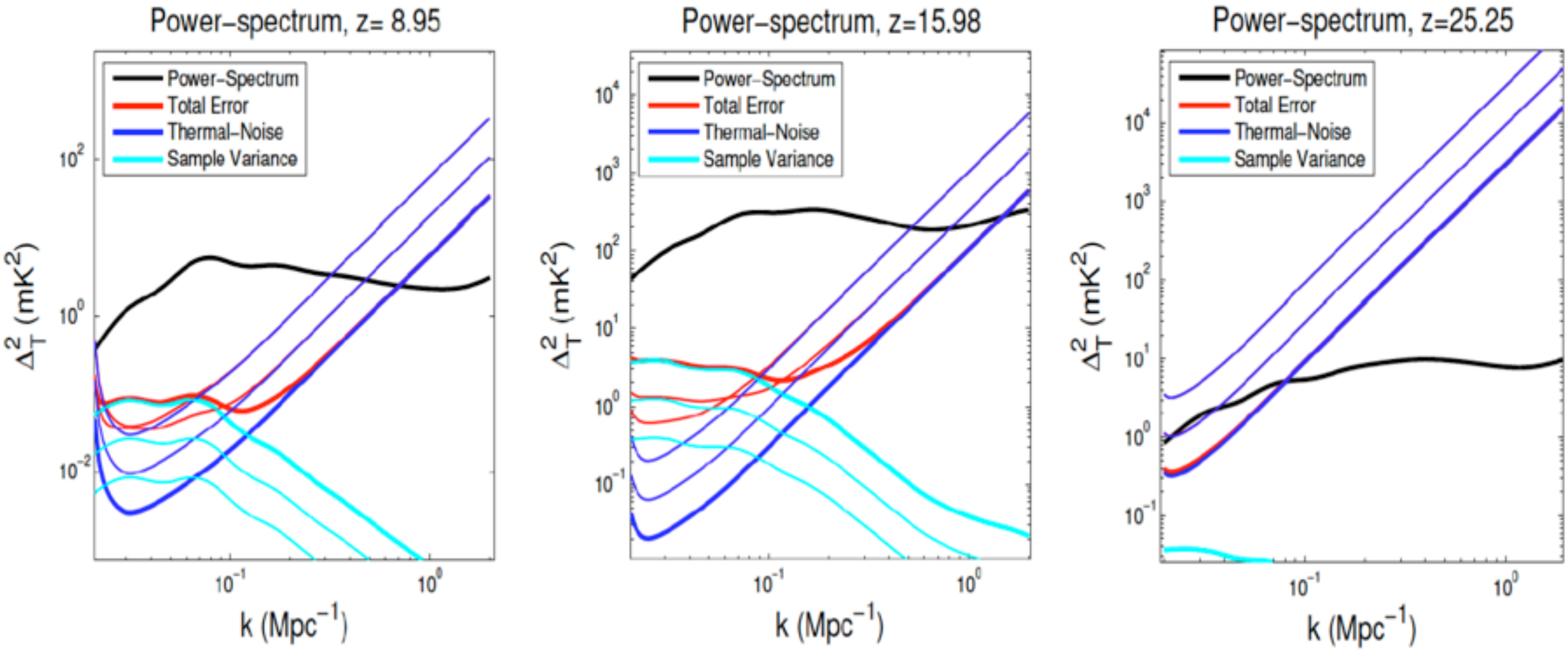
Differential brightness temp.

Ionised fraction

Redshift

CMB temp.

Spin temp.



Differential brightness temp.

$$\delta T_b \approx 27(1 - x_i)\left(\frac{\Omega_{b,0}h^2}{0.023}\right)\left(\frac{0.15}{\Omega_{m,0}h^2}\frac{1+z}{10}\right)^{1/2}\left(1 - \frac{T_\gamma}{T_S}\right)$$

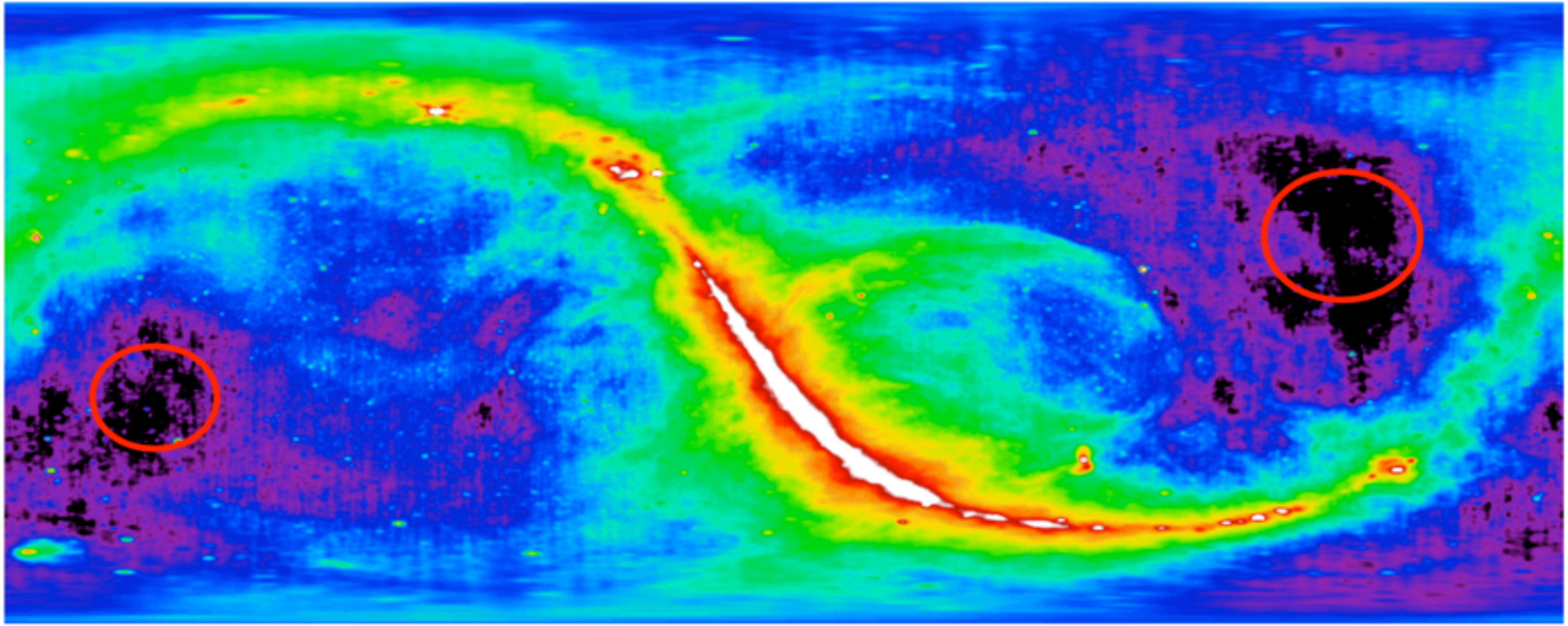
Courtesy: Cath Trott

Ionised fraction

Spin temp.

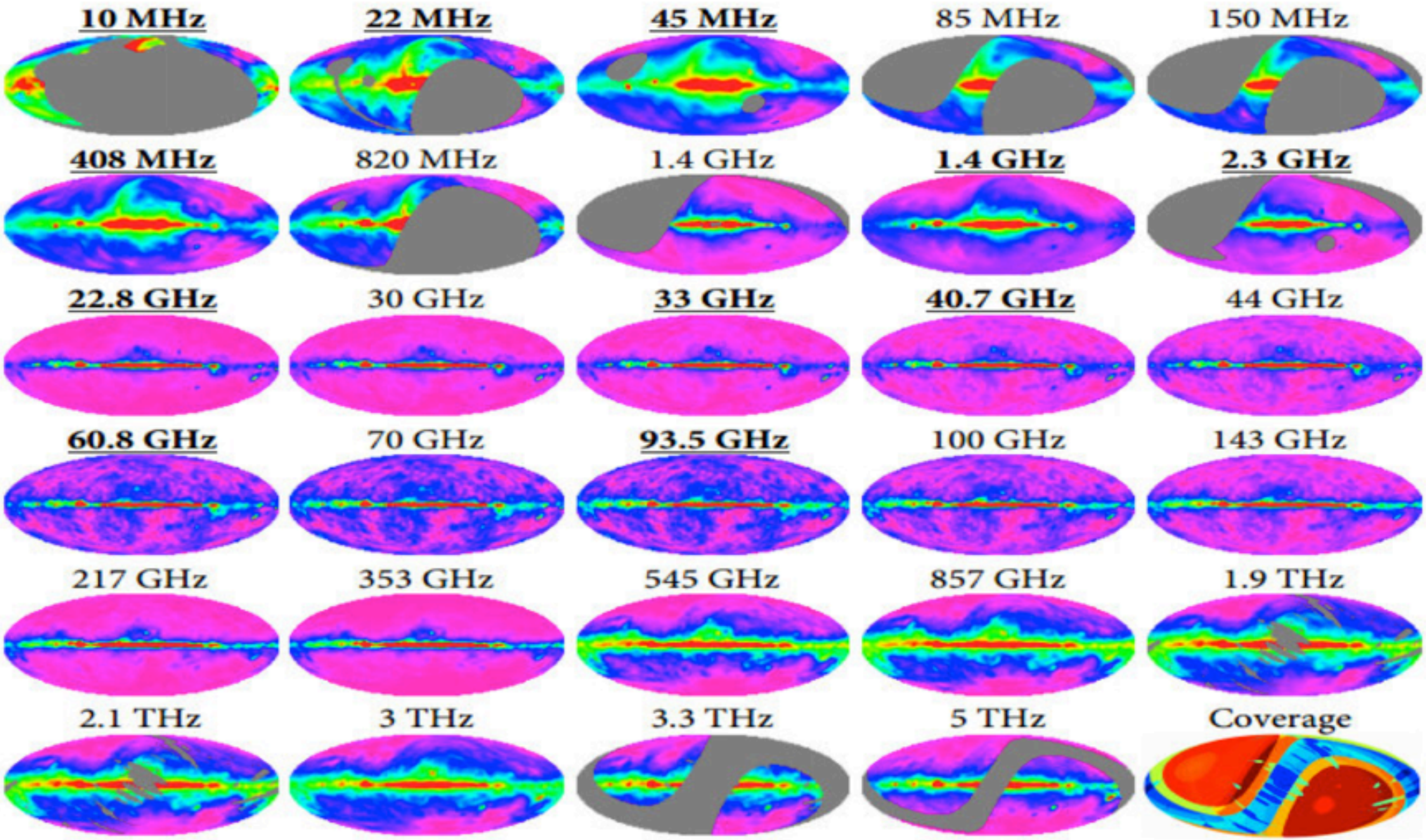
Foregrounds

$T_{sys} = T_{sky} + T_{Receiver}$ At 150 MHz $T_{sky} \sim 200K$

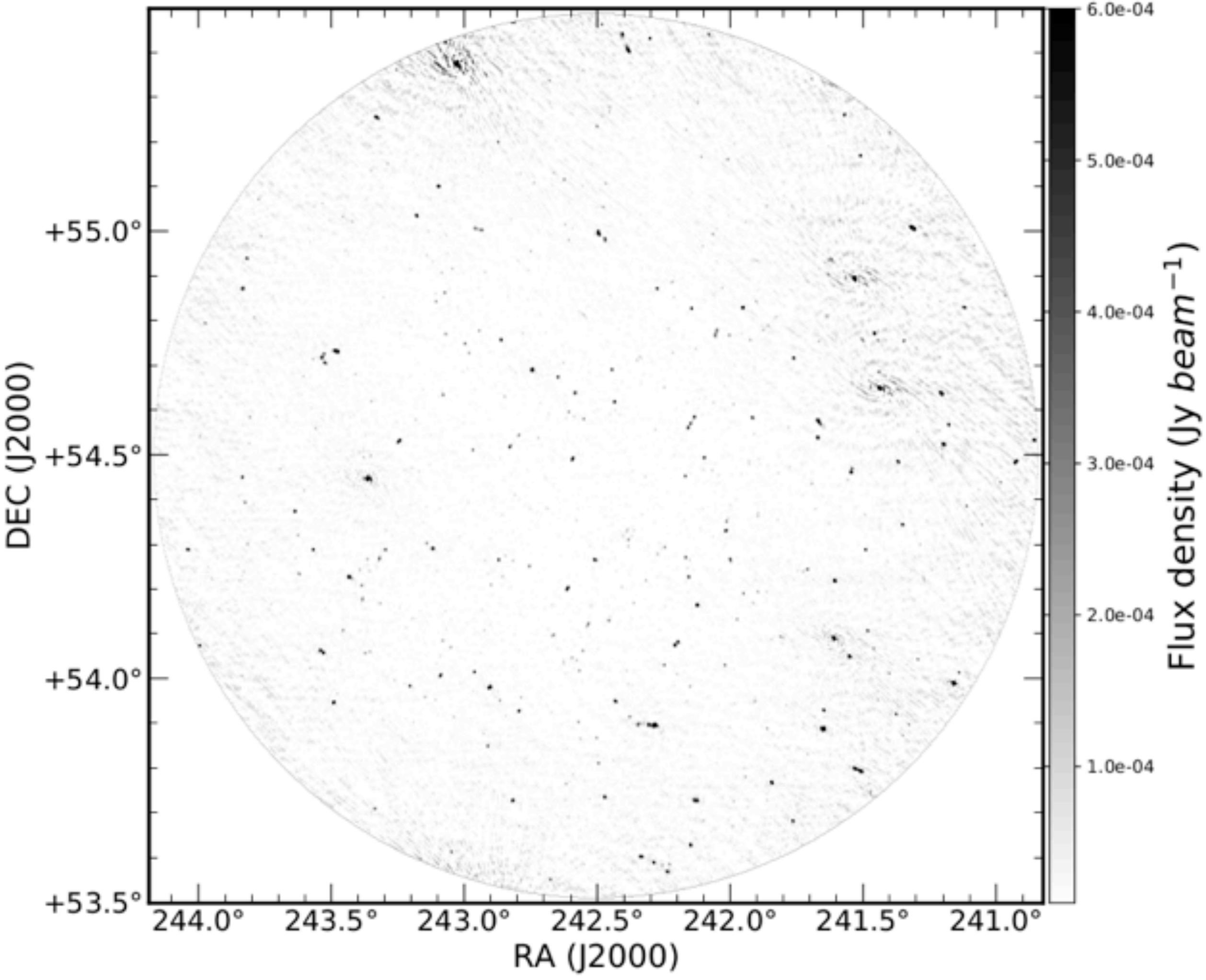


Radio sky at 408 MHz continuum

Haslam et al, 1982



Zheng et al. 2016



uGMRT observations of ELAIS-N1

Single Pointing

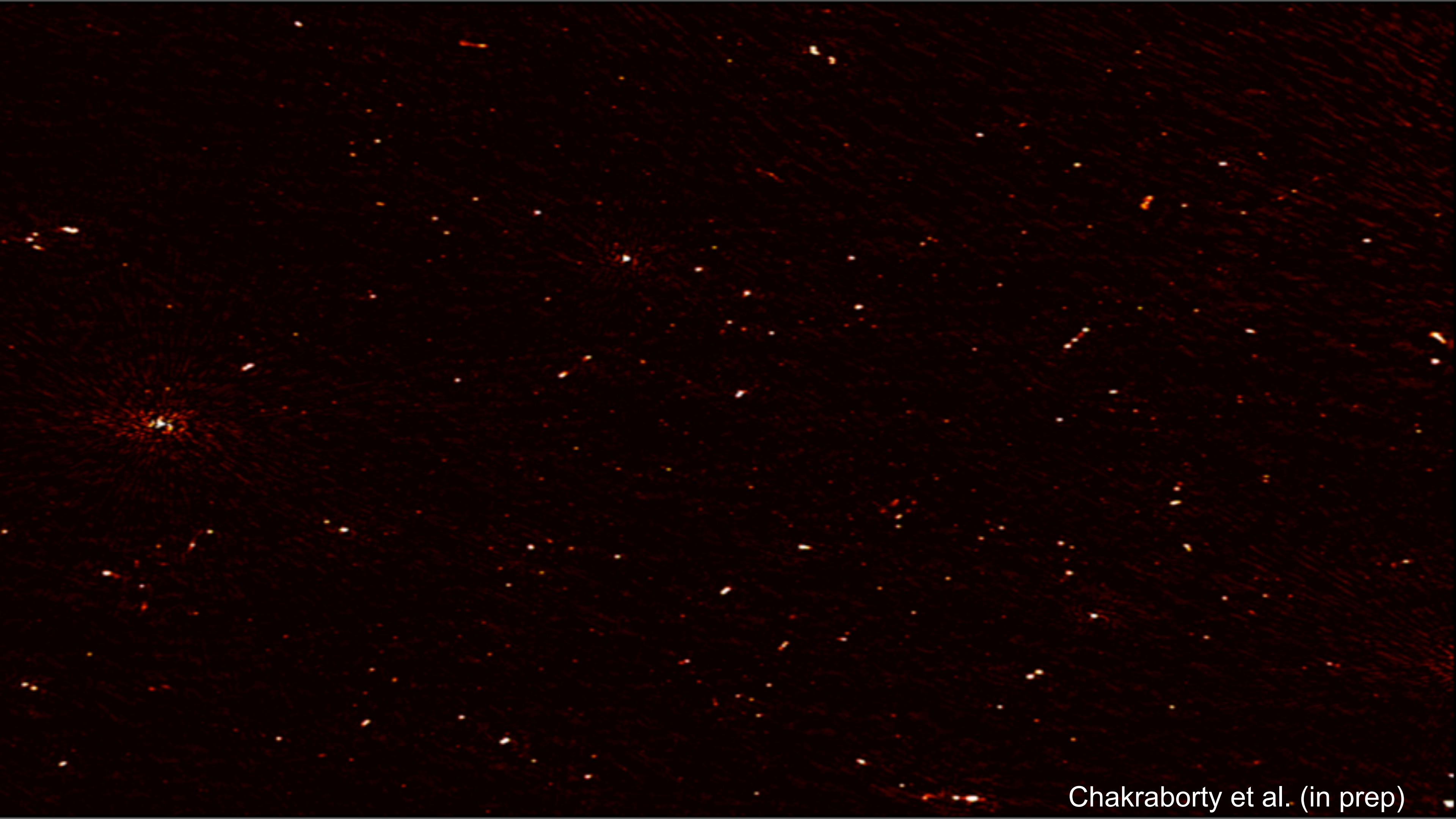
14 hours on-source time

30% data flagged

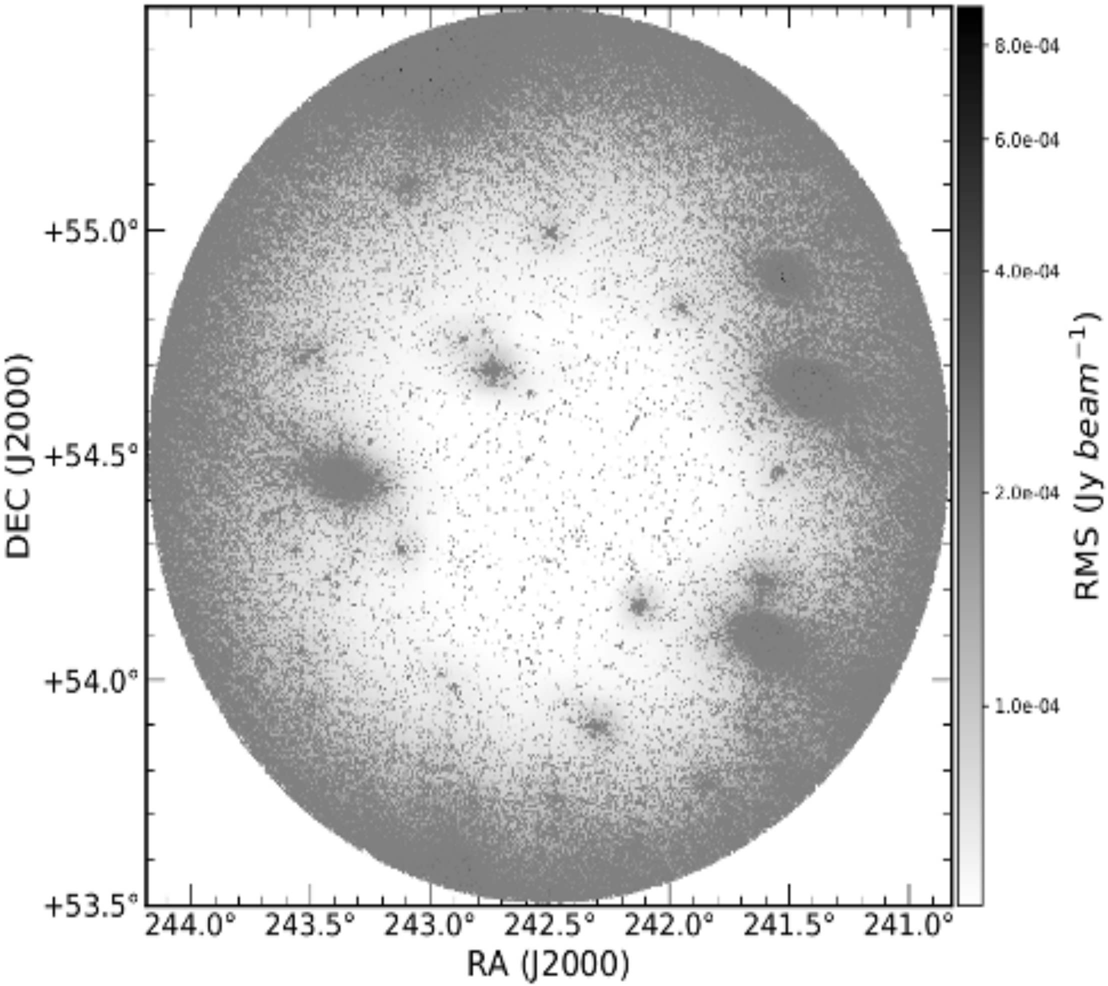
Flagging done by AOFLAGGER + RFLAG

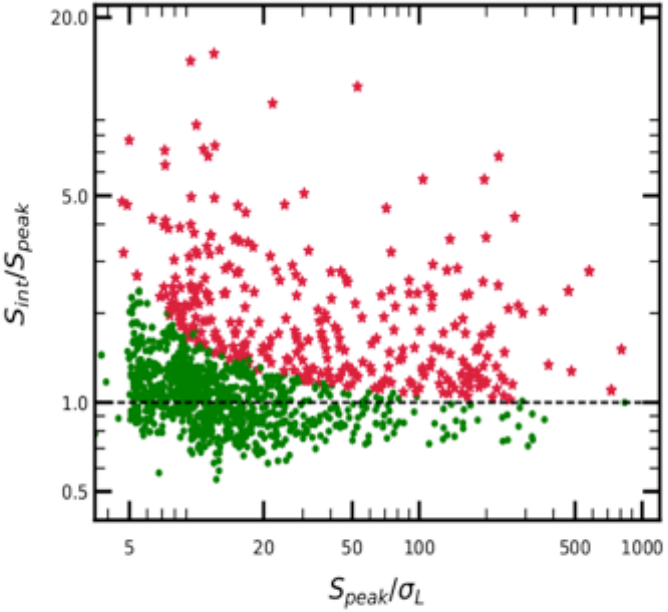
RMS noise ~ 18 uJy
Dynamic range ~ 18000

Chakraborty et al. (in prep)



Chakraborty et al. (in prep)



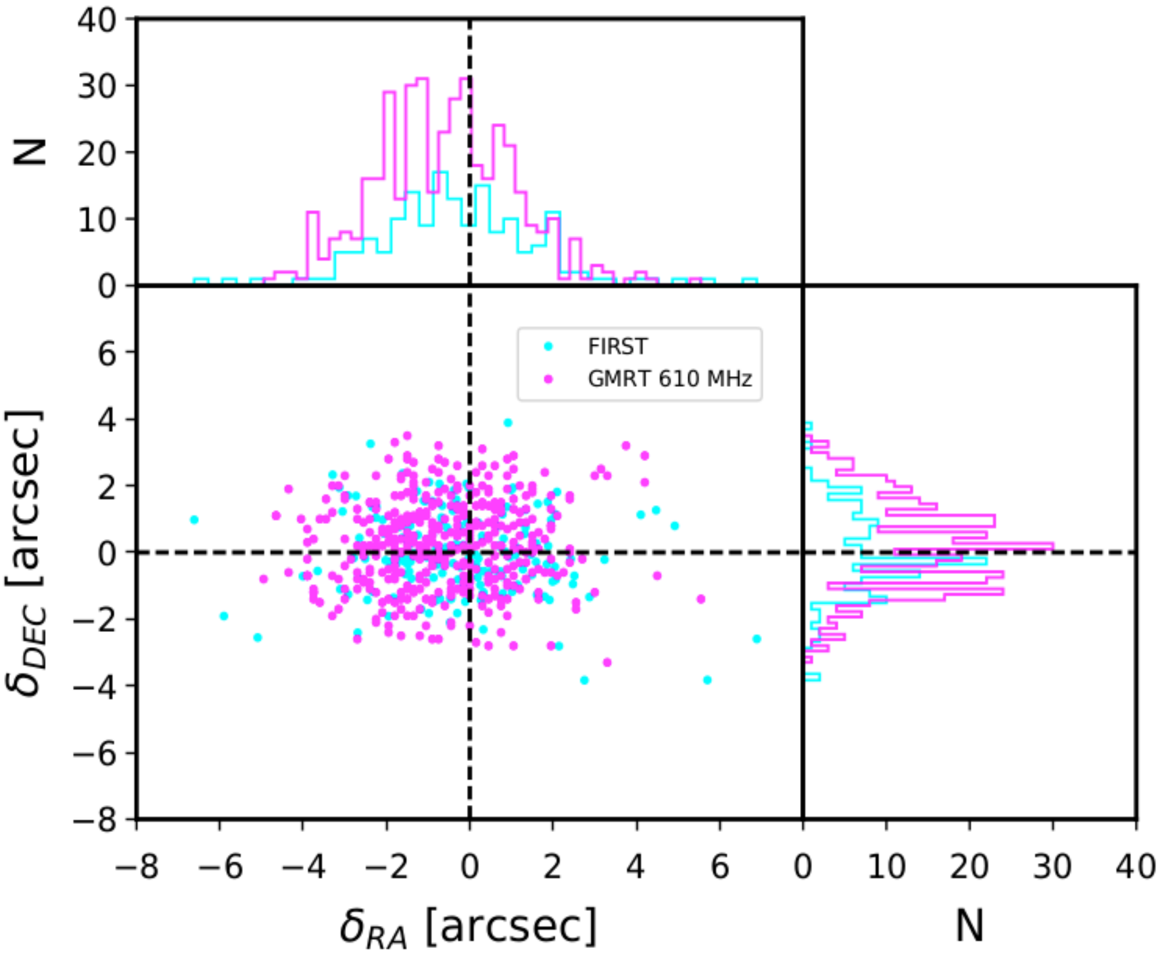


Following GLEAM analysis:

$$ln\left(S_{int}/S_{peak}\right) > 3\sqrt{\left(\frac{\sigma_S}{S}\right)^2 + \left(\frac{\sigma_{S_{peak}}}{S_{peak}}\right)^2}$$

Unresolved sources ~ 1105
Resolved sources ~ 333 (PYBDSF)

Chakraborty et al. (in prep)



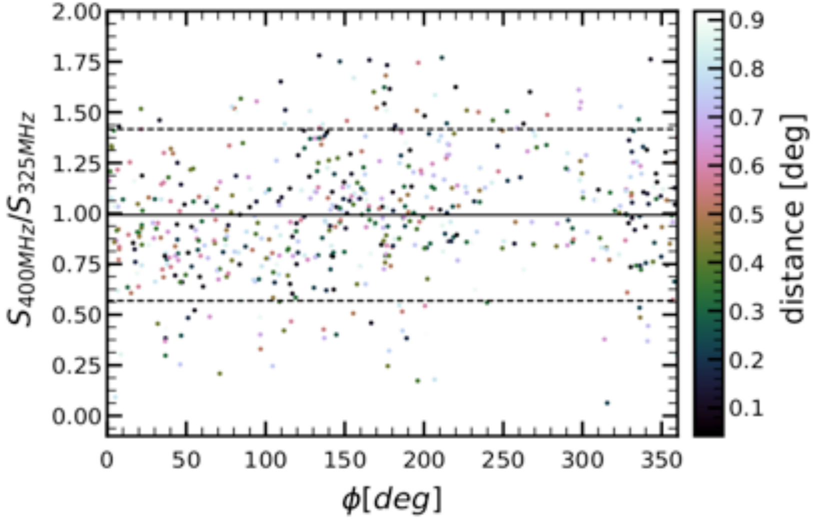
Source selection :

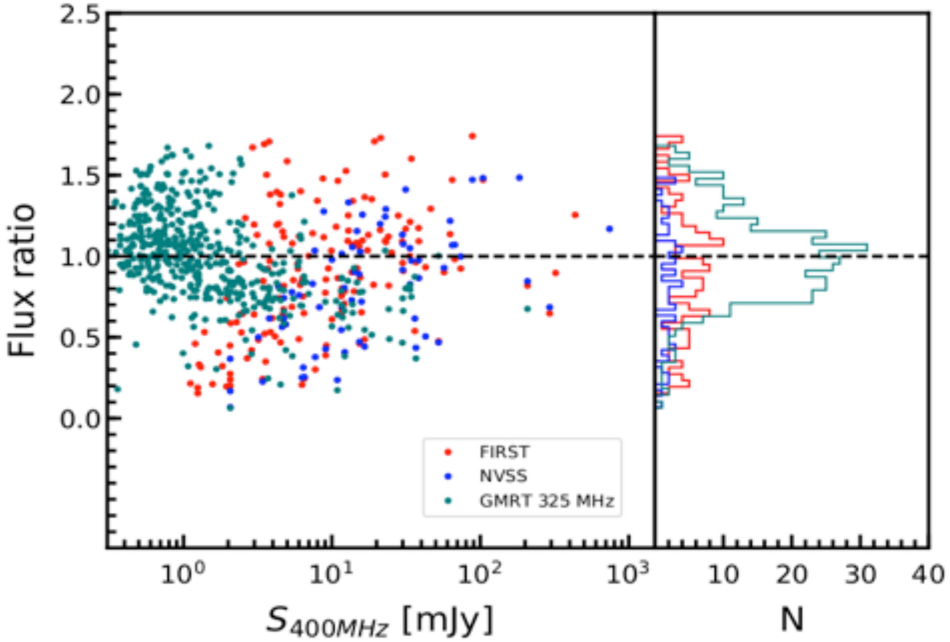
1. Search radius = 6”
2. SNR > 20**σ**
3. Size < 5” (Compact)
4. No sources with 30”

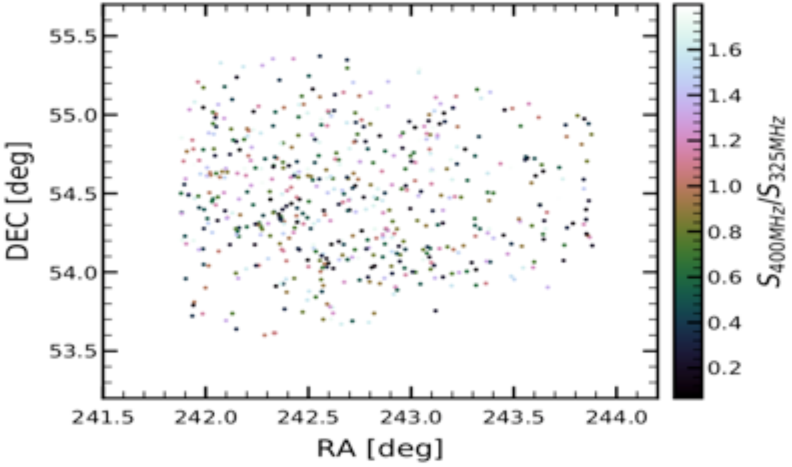
We have used a constant correction factor from FIRST histogram : mean offset in RA = - 0.3 arcsec and in DEC = - 0.003 arcsec

Previous GMRT 610 MHz Observations from Garn et al. 2009

Chakraborty et al. (in prep)







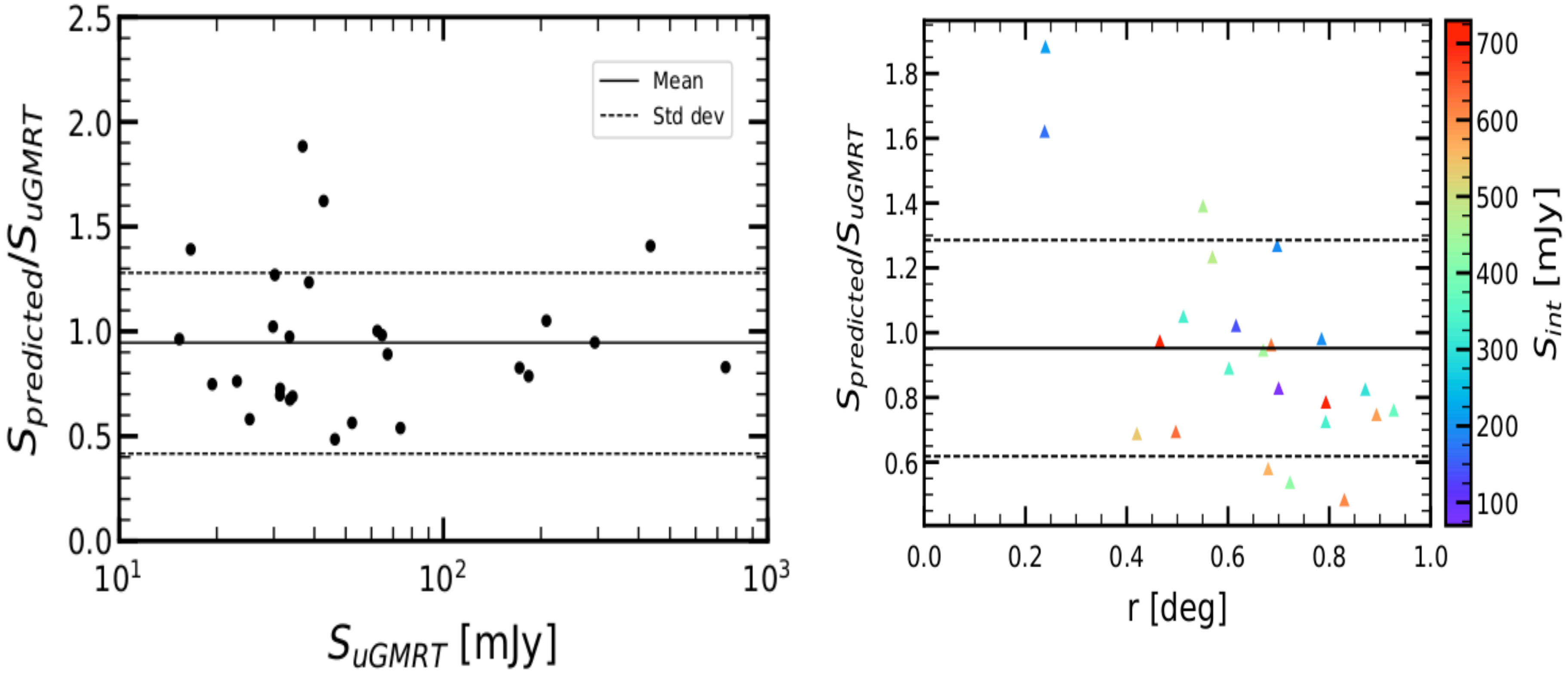
Source selection :

1. Compact sources (size less than the corresponding resolution)

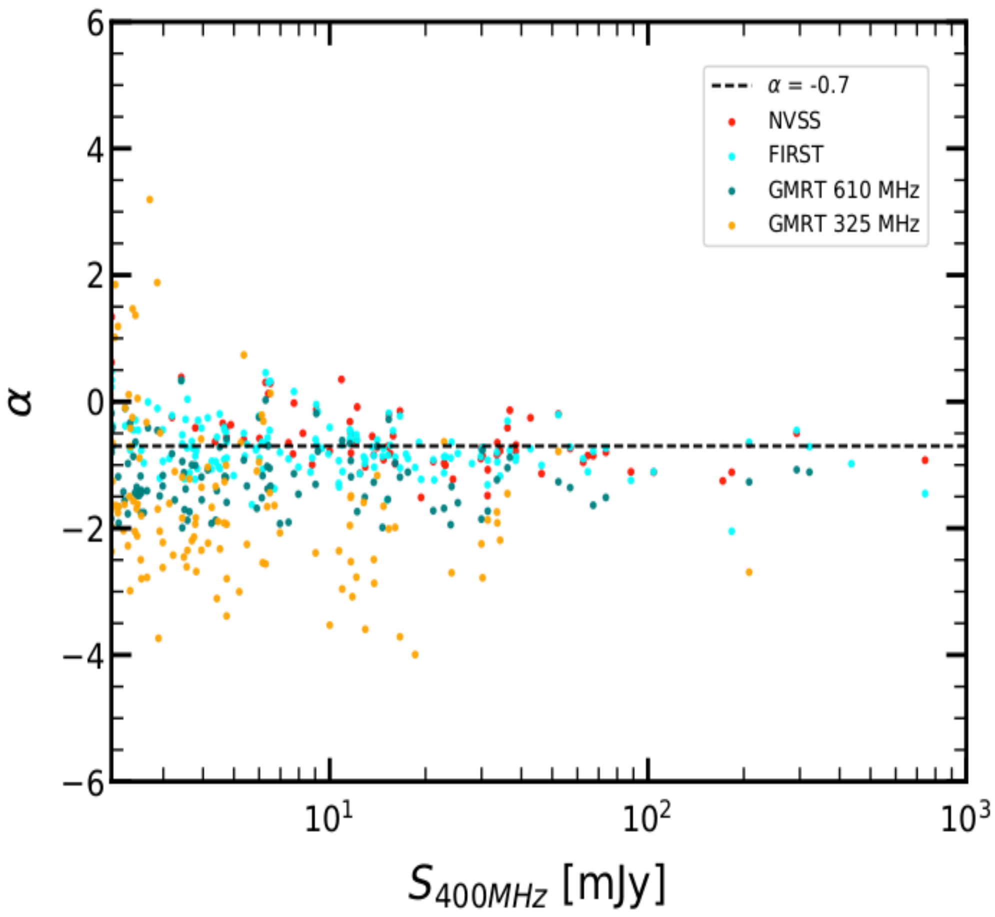
2. High SNR (> 10**σ**)

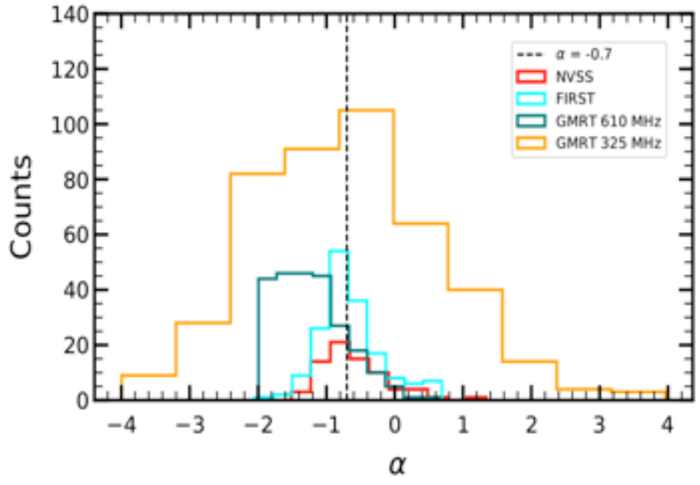
Chakraborty et al. (in prep)

Comparison with NVSS and WENSS catalogs



Chakraborty et al. (in prep)

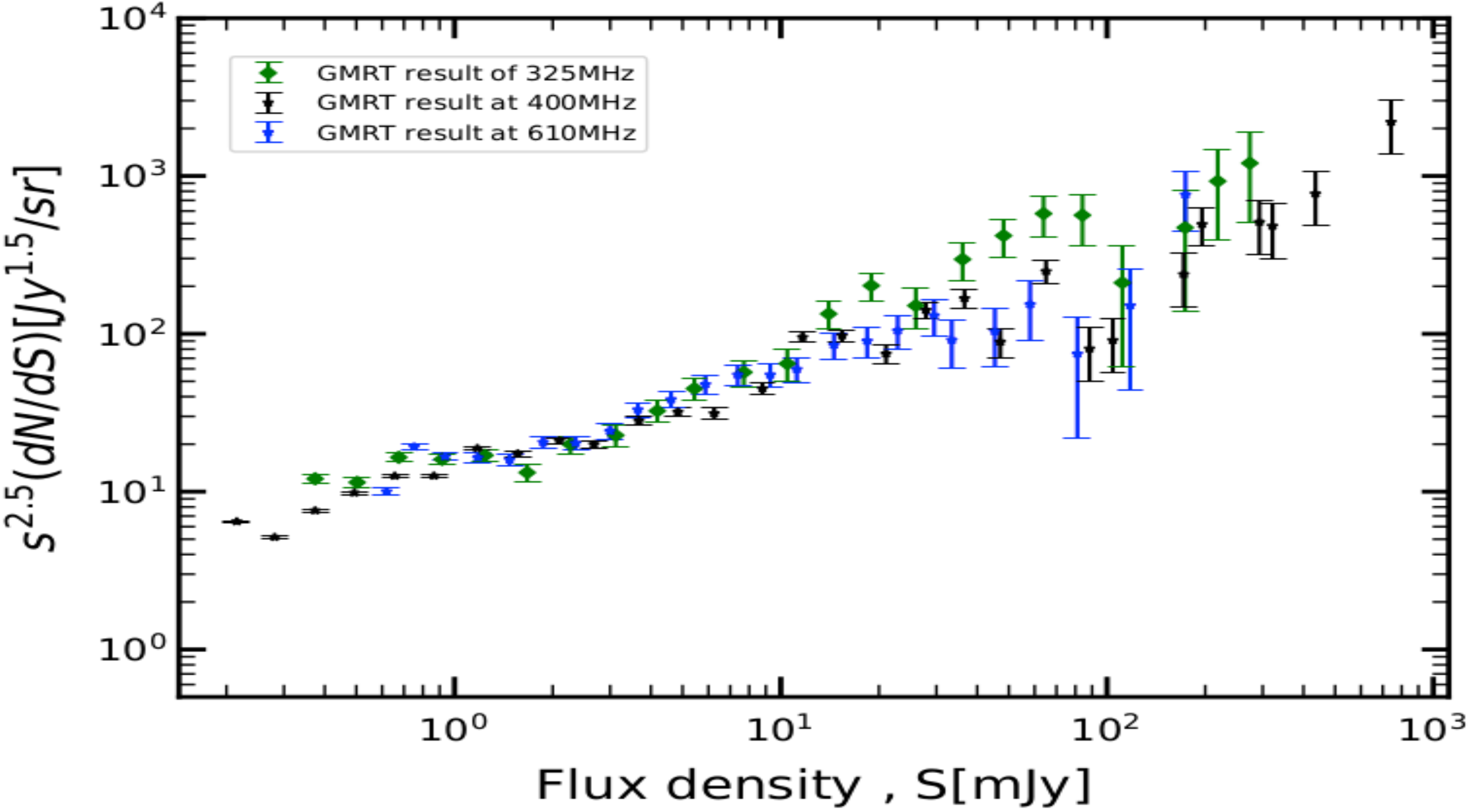




Catalog	Frequency (MHz)	Matches within (5″)	Resolution (arcsec)	α Histogram
NVSS	1.4 GHz	73	45″	-0.68
FIRST	1.4 GHz	166	5.4″	-0.73
GMRT	610 MHz	243	6″	-1.2
GMRT	325 MHz	440	9″	-0.71

Chakraborty et al. (in prep)

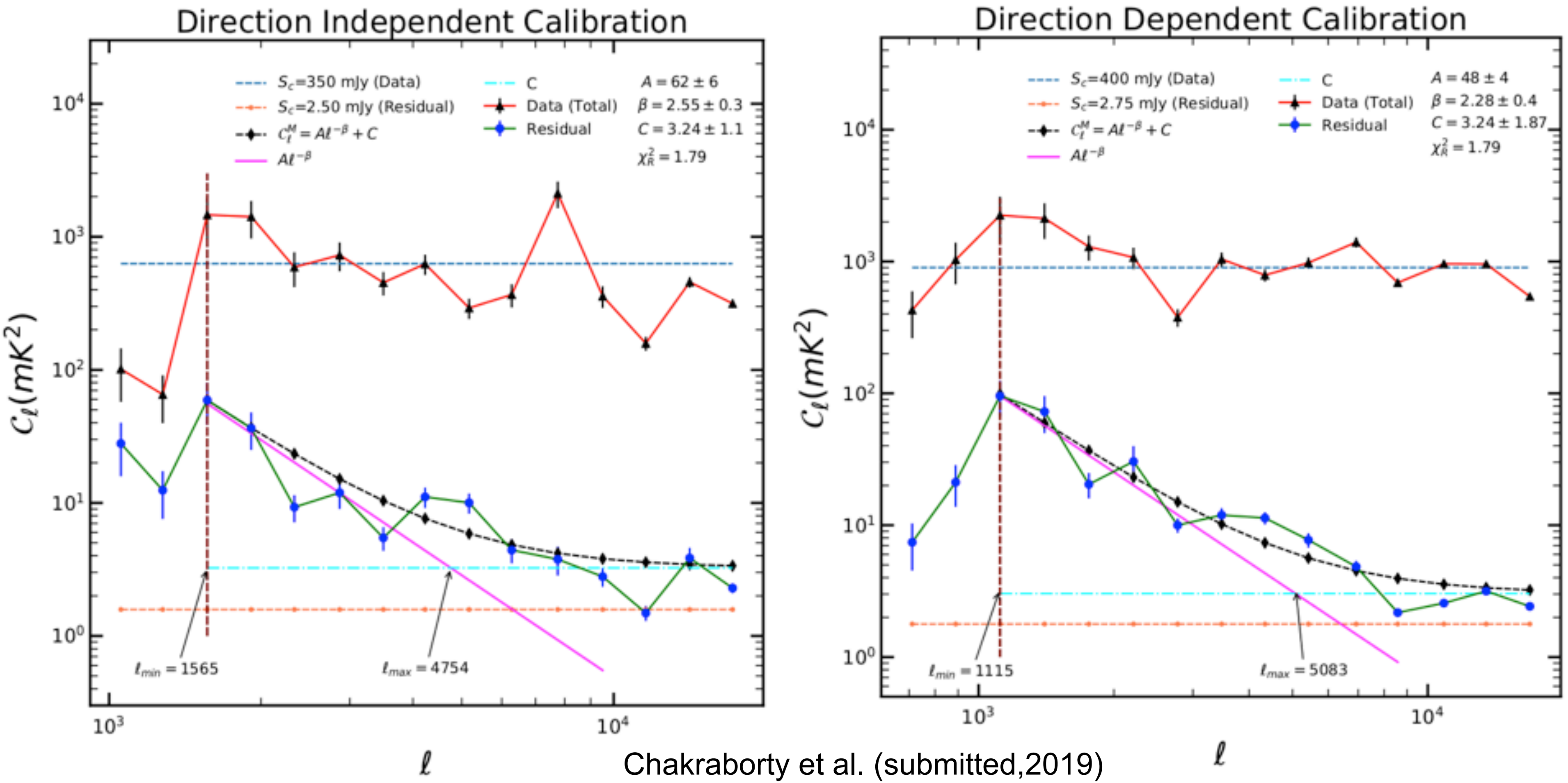
Previous GMRT 325 MHz Observations from Sirothia et al. 2009



Chakraborty et al. (in prep)

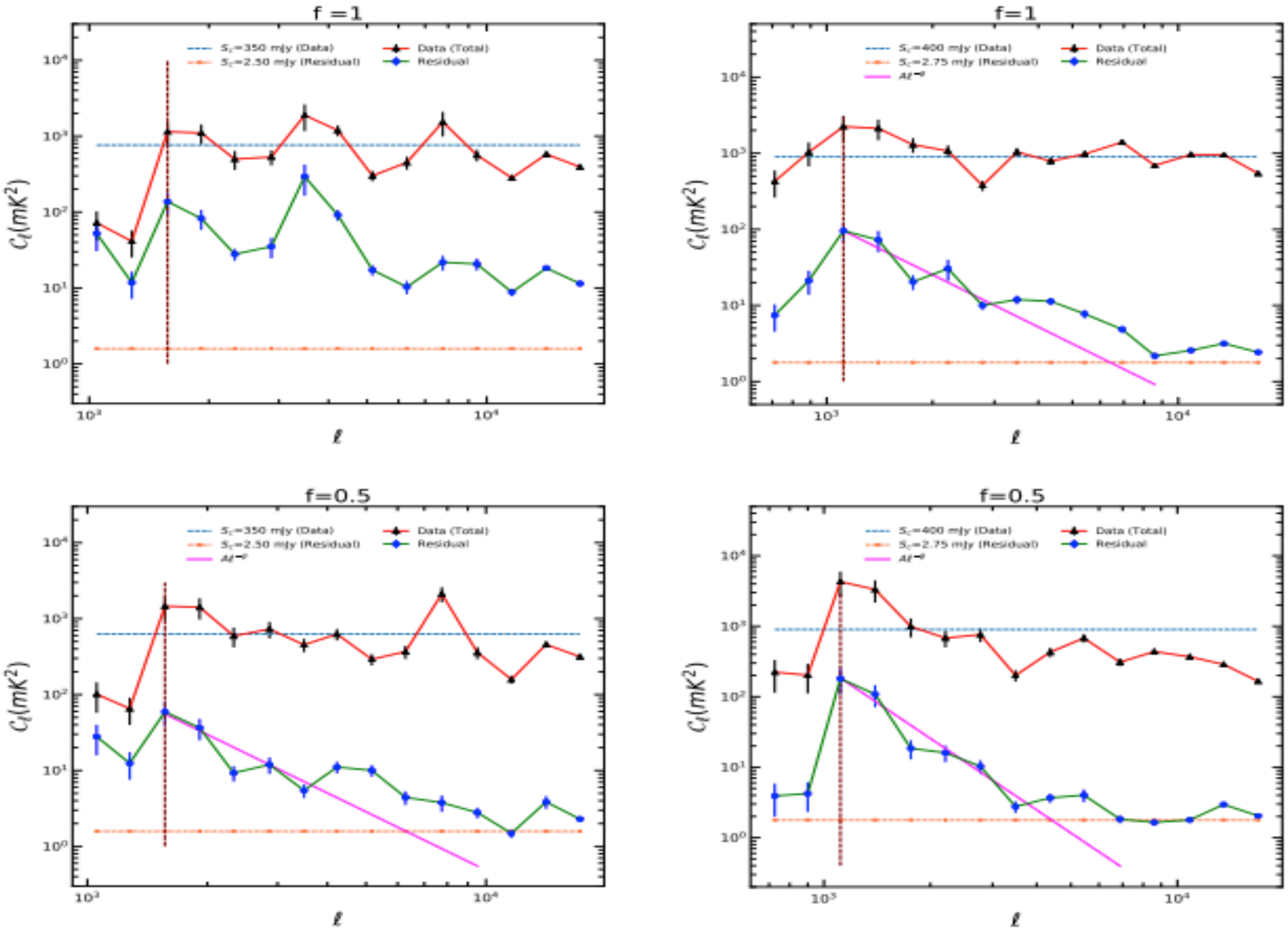
Tappered Gridded Estimator (TGE)

Choudhuri et al. 2014, 2016)

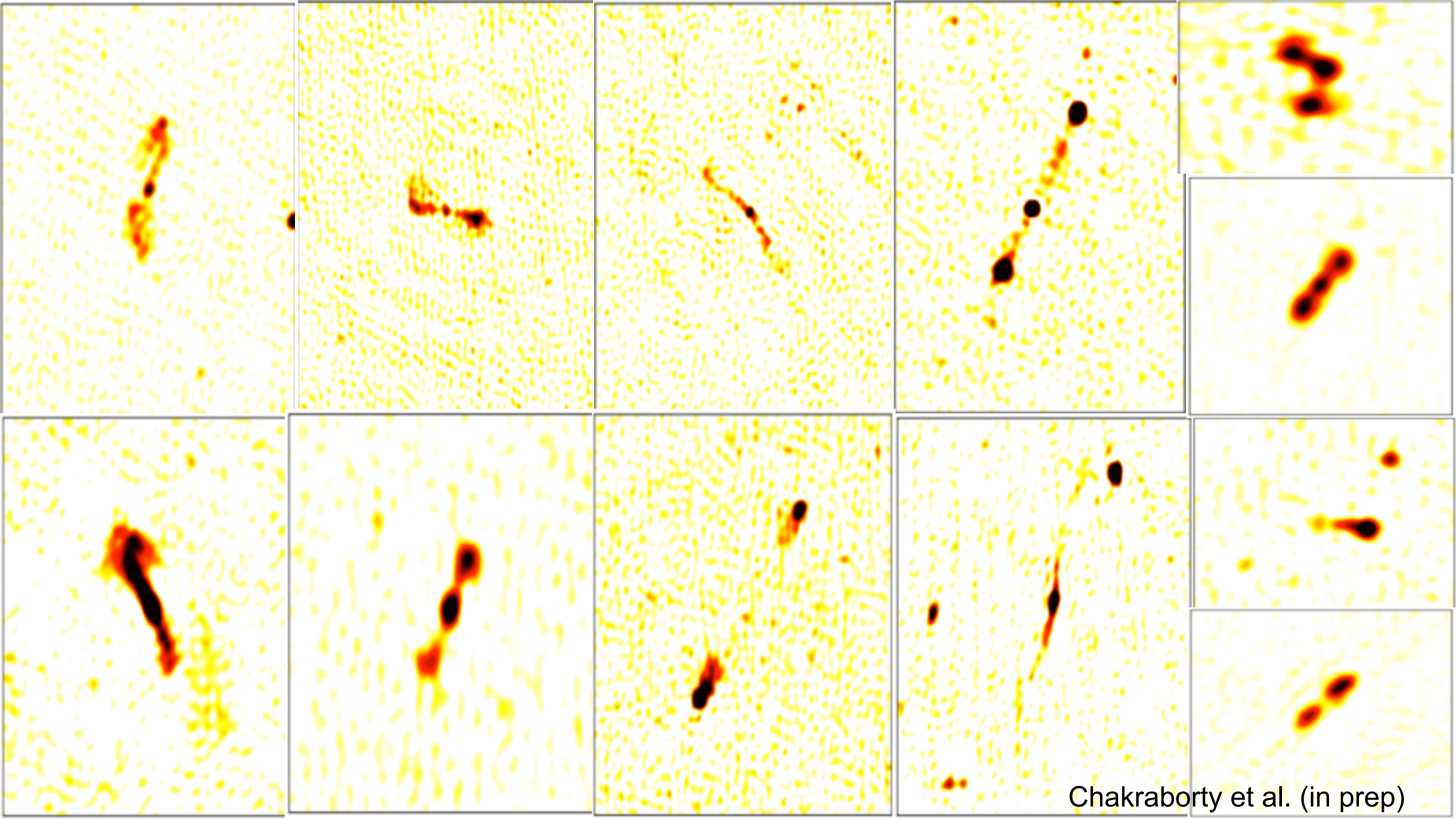


Chakraborty et al. (submitted,2019)

Direction Independent(CASA) Direction Dependent (SPAM)



Chakraborty et al. (submitted,2019)



Chakraborty et al. (in prep)

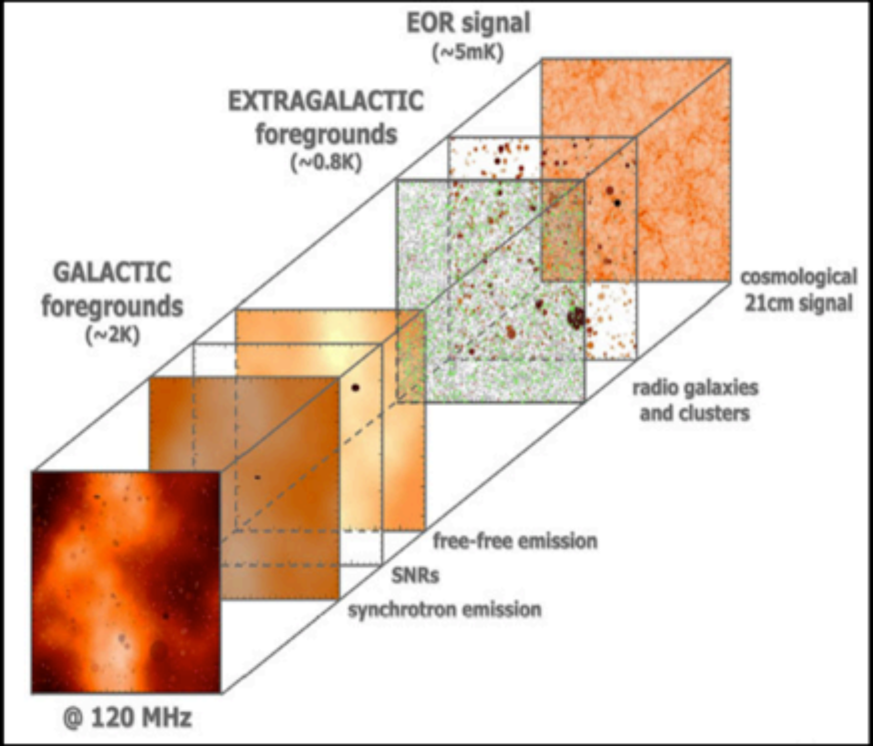
Signal Extraction

A MODEL FOREGROUND

- The foreground model used is of the form:

$$\ln T_{FG} = \ln T_0 + a_1 \ln(\nu/\nu_0) + a_2 \ln(\nu/\nu_0) + a_3 \ln(\nu/\nu_0)$$

- Where, all temperatures are in K, and $\nu_0 = 80\ \mathrm{Hz}$, is an arbitrary reference frequency, which is chosen to lie in the middle of our band.
- The foreground parameters we deal with are : a_0, a_1, a_2, a_3



An Instrument model

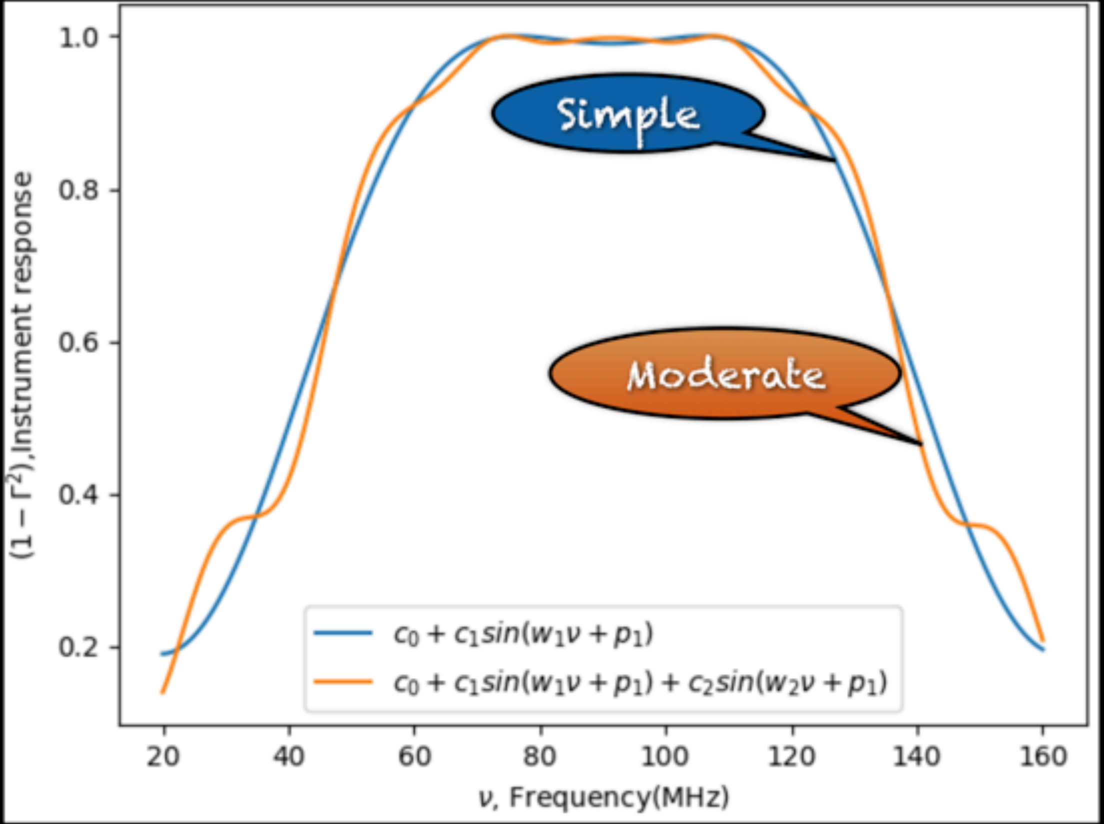
- We have considered two very simple models for the instrument.

- The instrument response is given by:

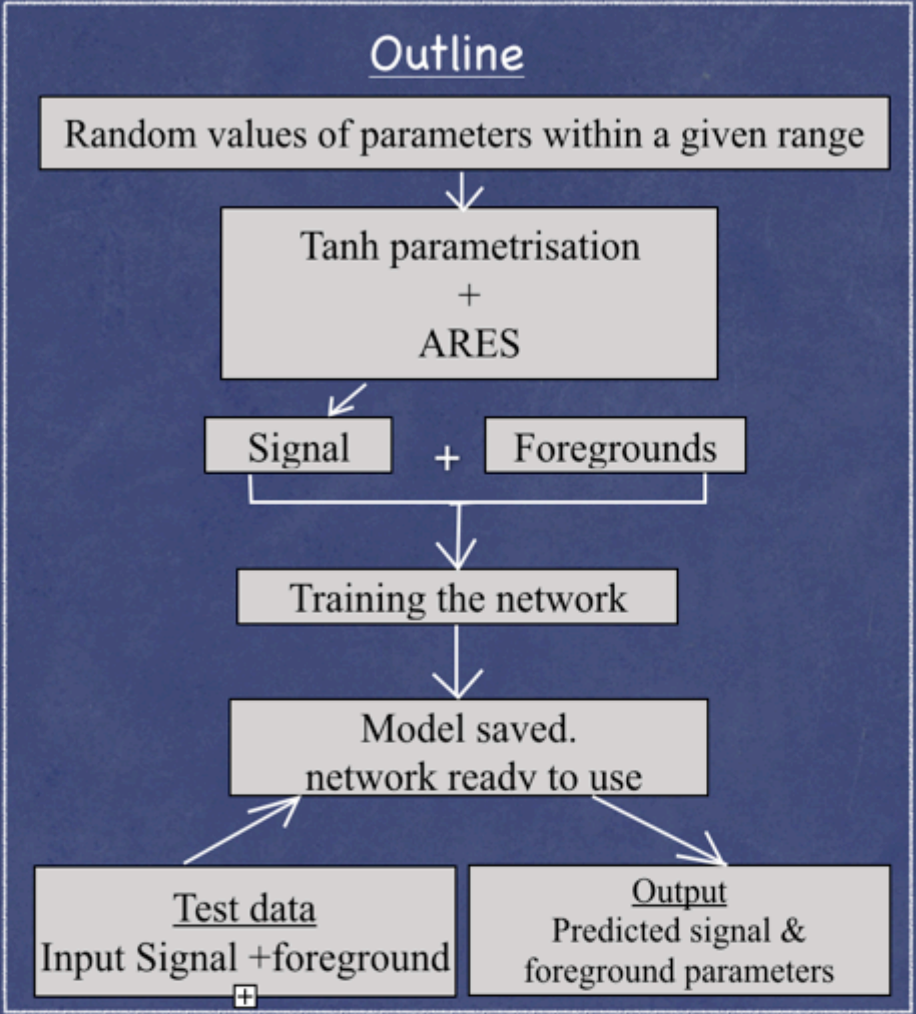
$$G(\nu) = |1 - \Gamma^2|$$

Antenna reflection coefficient

[DARE Radiometer calibration, R.Bradley, 2012]



Choudhury et al,2018 (in prep)



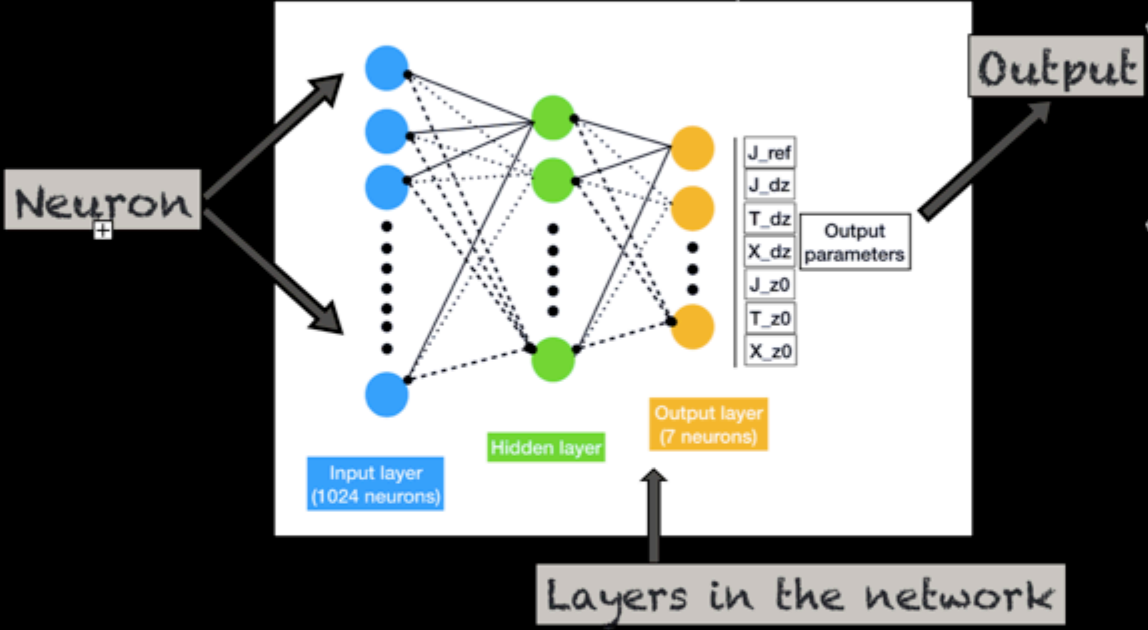
Choudhury et al (in prep)

Building the training dataset

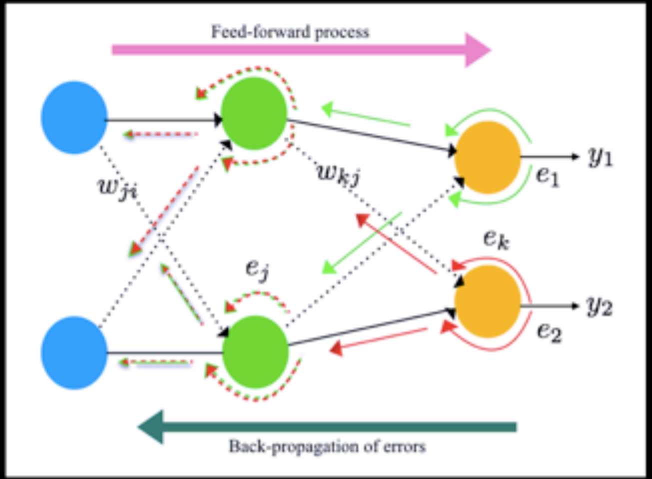
We need to simulate

- A model 21cm signal
- A model foreground
- Other conditions to make the simulation realistic

Basic architecture of the network



- The ANN constructs functions, which associates the input with the output data.
- The basic neural network model is described by a series of functional transformations

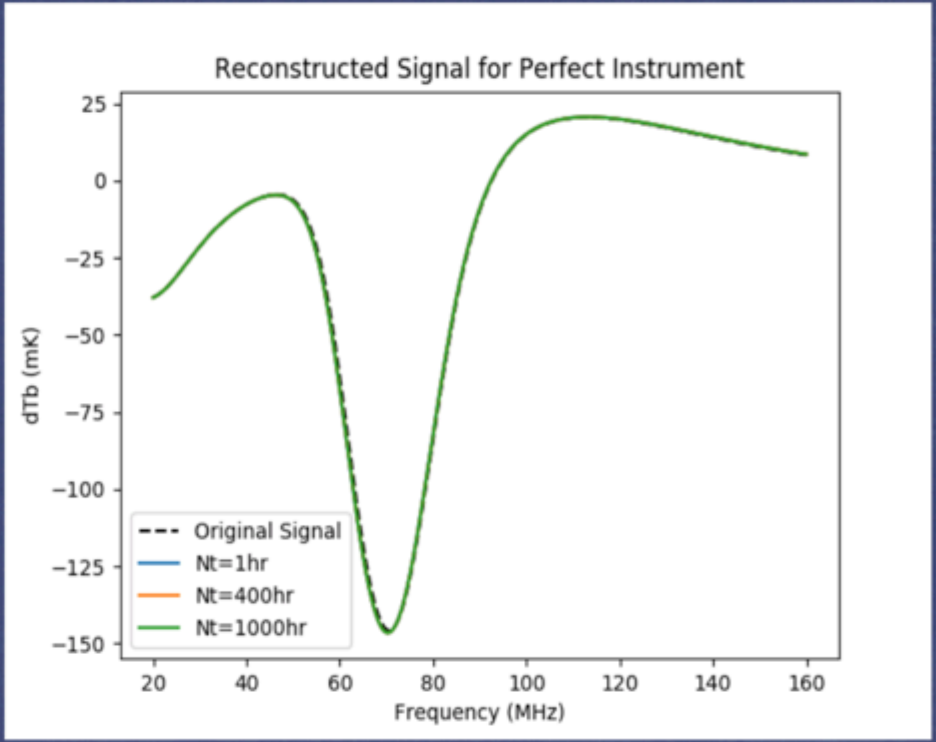


Choudhury et al (in prep)

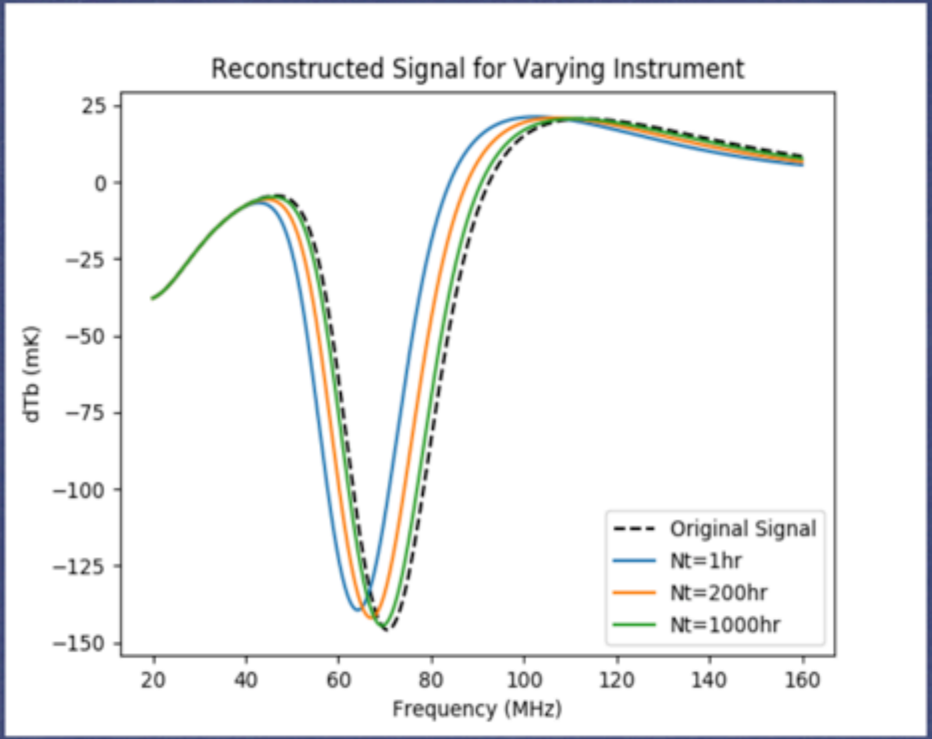
Cost function being minimized

$$\sqrt{\frac{1}{N_{train}}\sum^{N}\left(\frac{y_{pred}-y_{ori}}{y_{ori}}\right)^2}$$

Case 1: Perfect Instrument

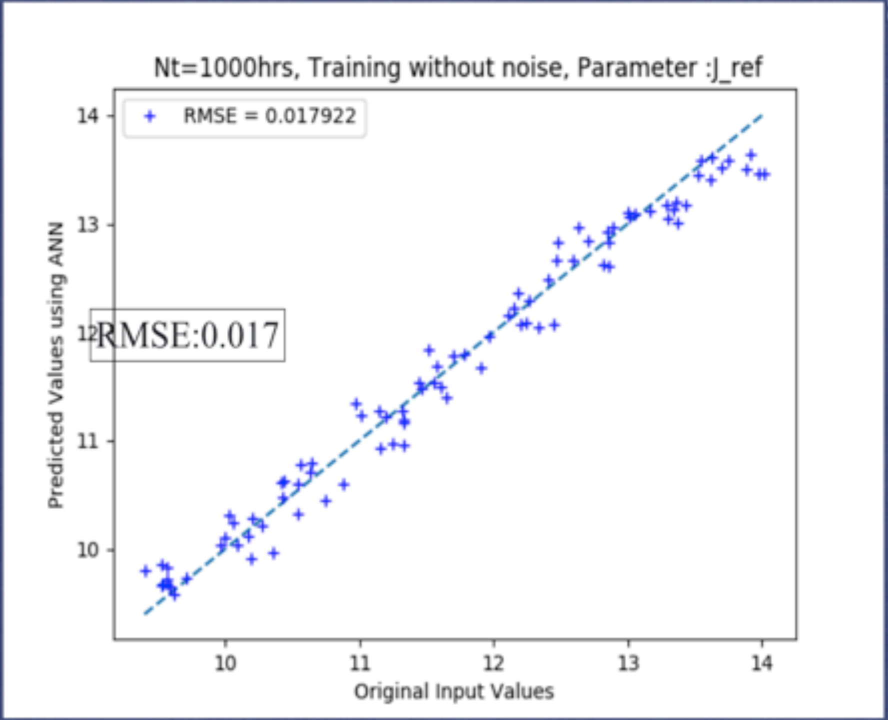


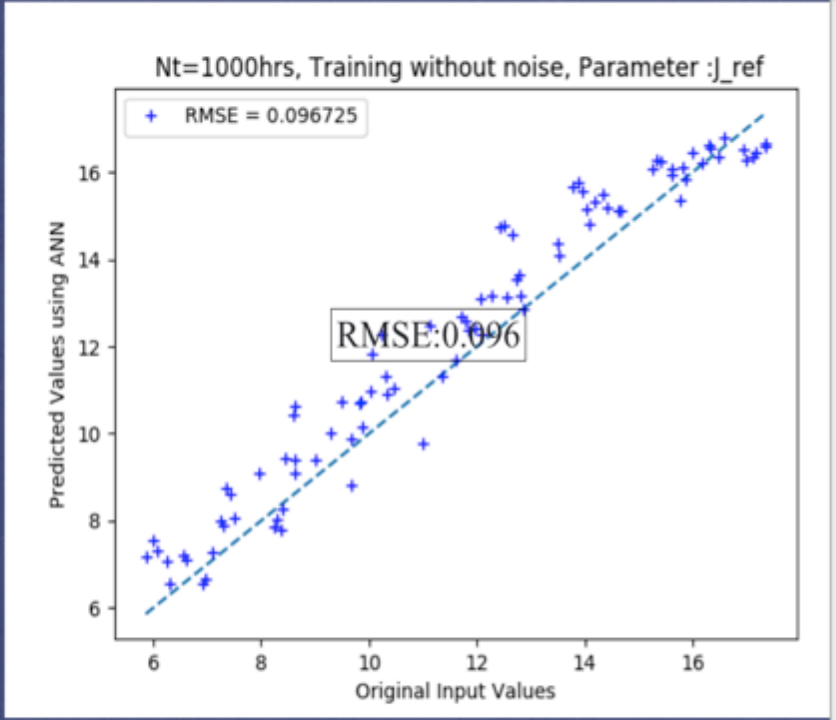
Case 3: Imperfect Instrument



Choudhury et al. (in prep)

A comparision





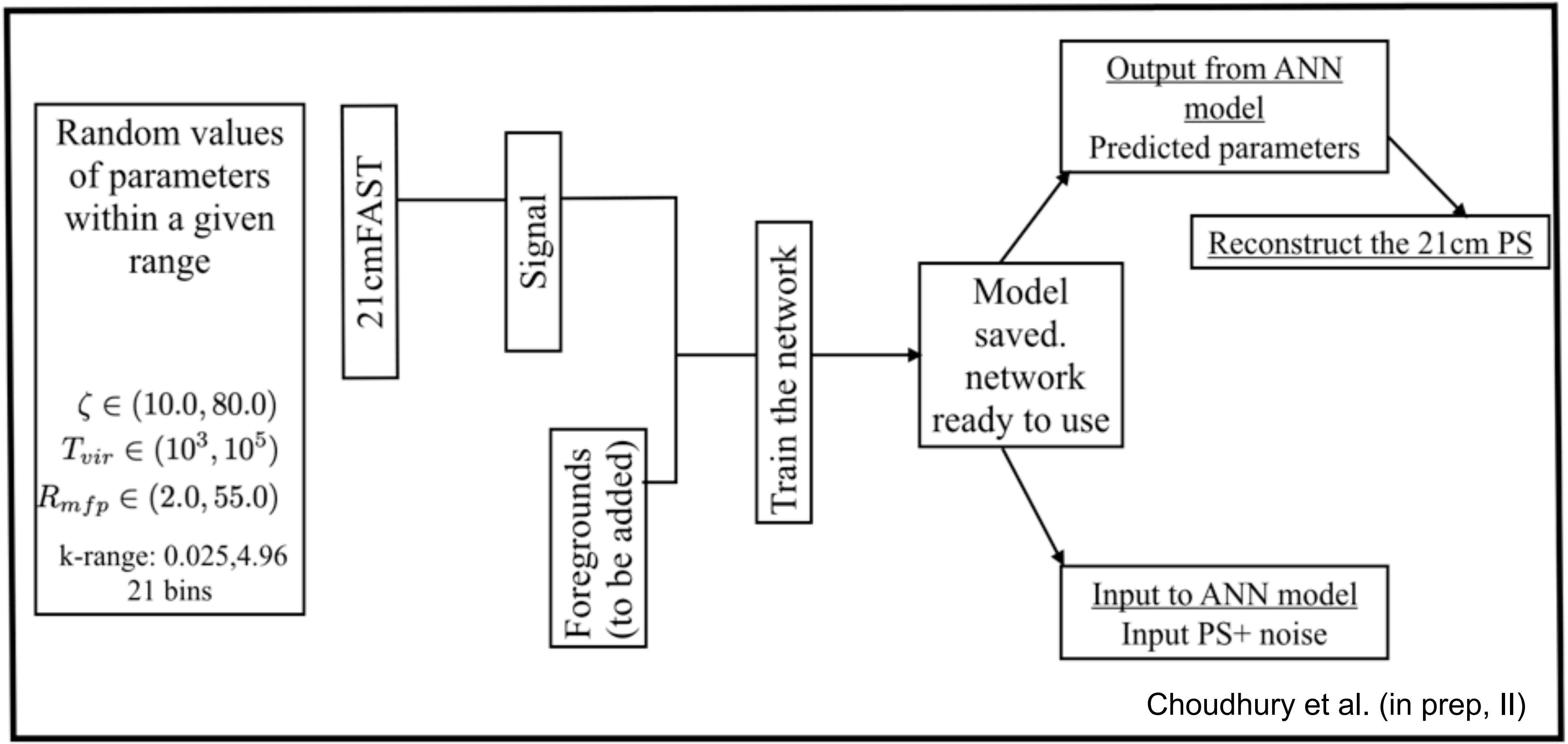
No effect of instrument

Imperfect instrument, varying

RMSE increases with more complexity of the dataset, but is still considerably small. In other words, we get very good prediction of the parameters.

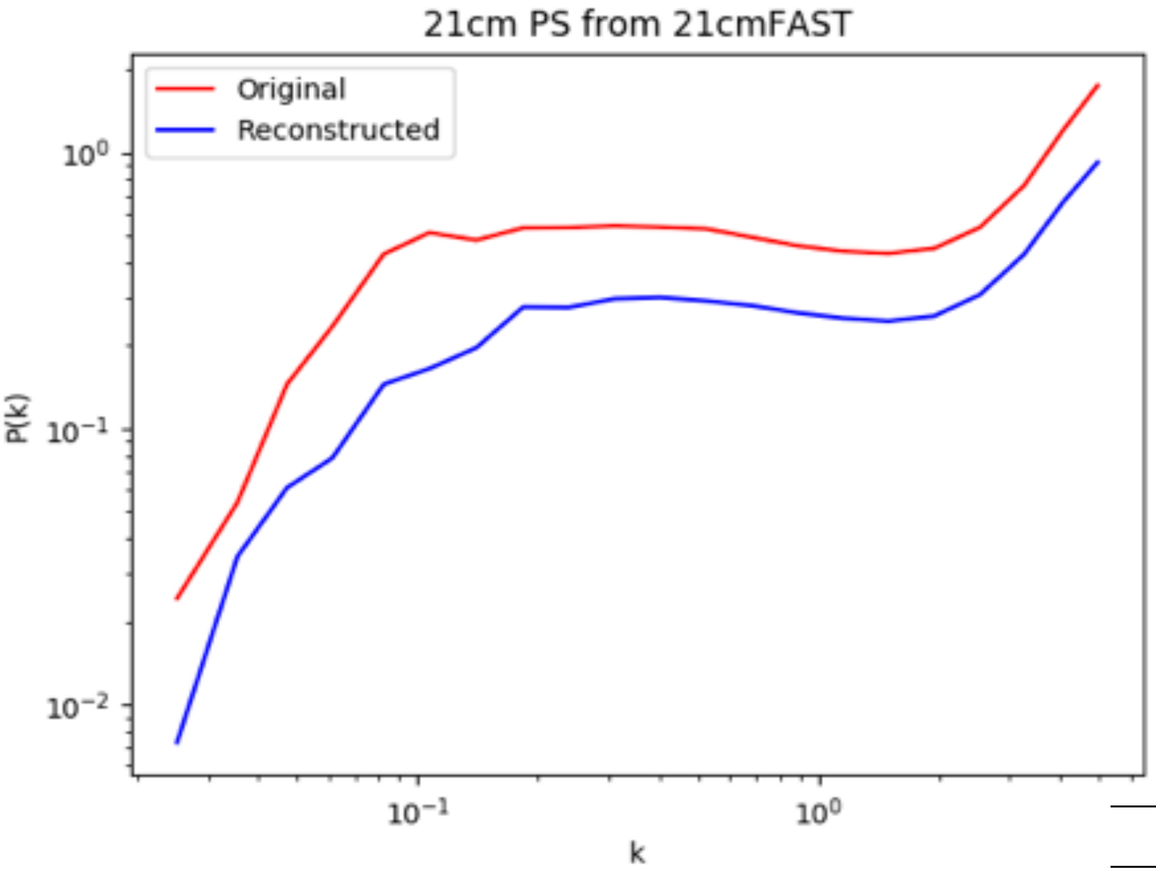
Choudhury et al. (in prep)

Power Spectrum Detection – Using ANN



Choudhury et al. (in prep, II)

RESULTS



–	ζ	R_{mfp}	T_{vir}
Original	50.0	35.0	5000
Predicted	41.8	25.0	6114

Choudhury et al. (in prep, II)

ROAD AHEAD

- Further analysis of the ELAIS-N1 data at Band 3
- uGMRT data at Band 2 on ELAIS-N1 field
- ANN analysis extended to Power Spectrum with Foregrounds + Systematics
- Application of Wide-band Direction Dependent Calibration algorithms.
- More DEEP fields…..