Foreground Removal in the Epoch of Reionisation

Dr Emma Chapman
Royal Astronomical Society Fellow
Imperial College London

@DrEOChapman
e.chapman@imperial.ac.uk
dremmachapman.wordpress.com

Imperial College London

ROYAL ASTRONOMICAL SOCIETY QUICQUID NITET NOTANDUM 1820

LOFAR

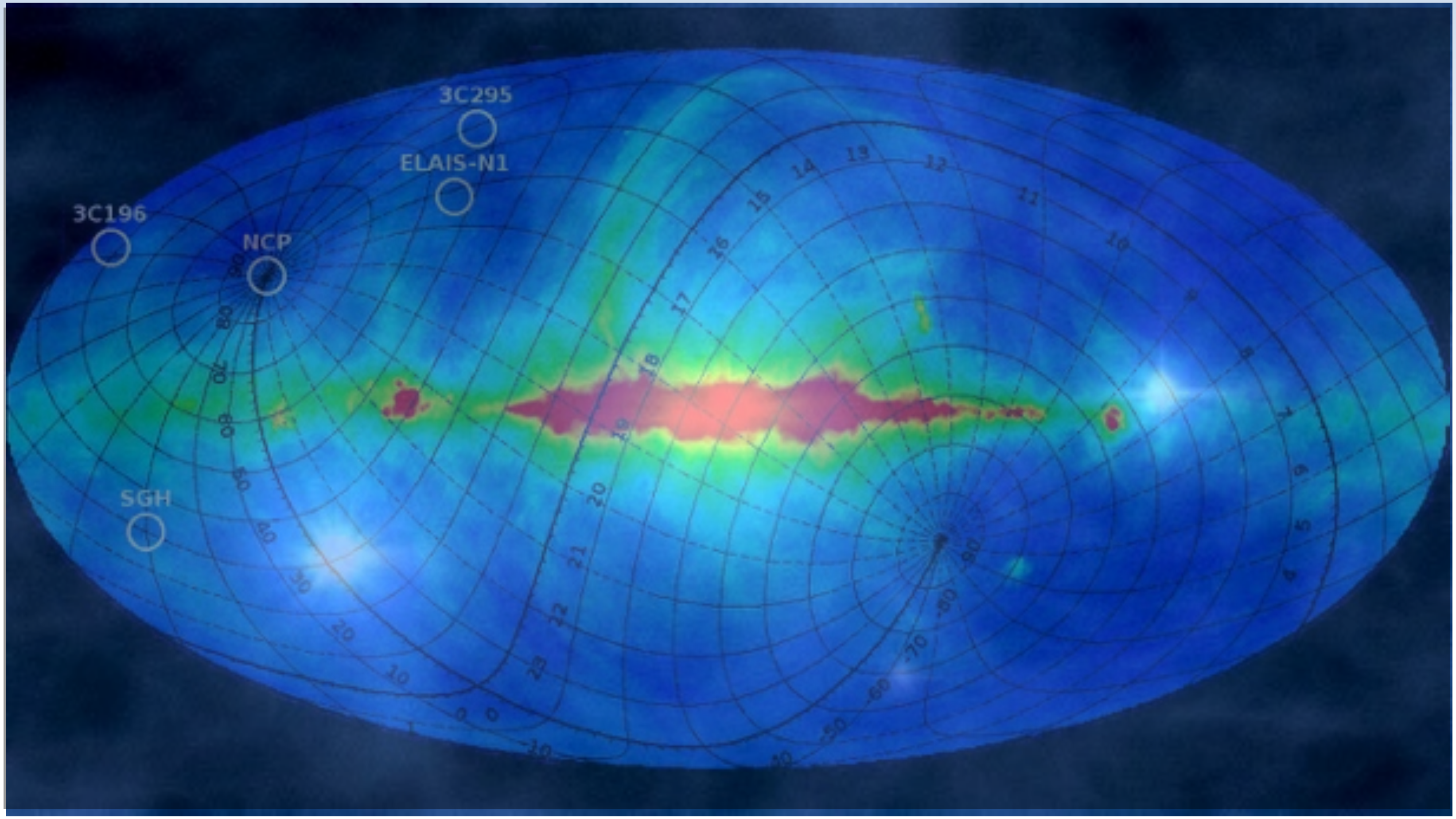
SKA SQUARE KILOMETRE ARRAY

Foreground removal methods

Simulating the data pipeline

Predicting the science

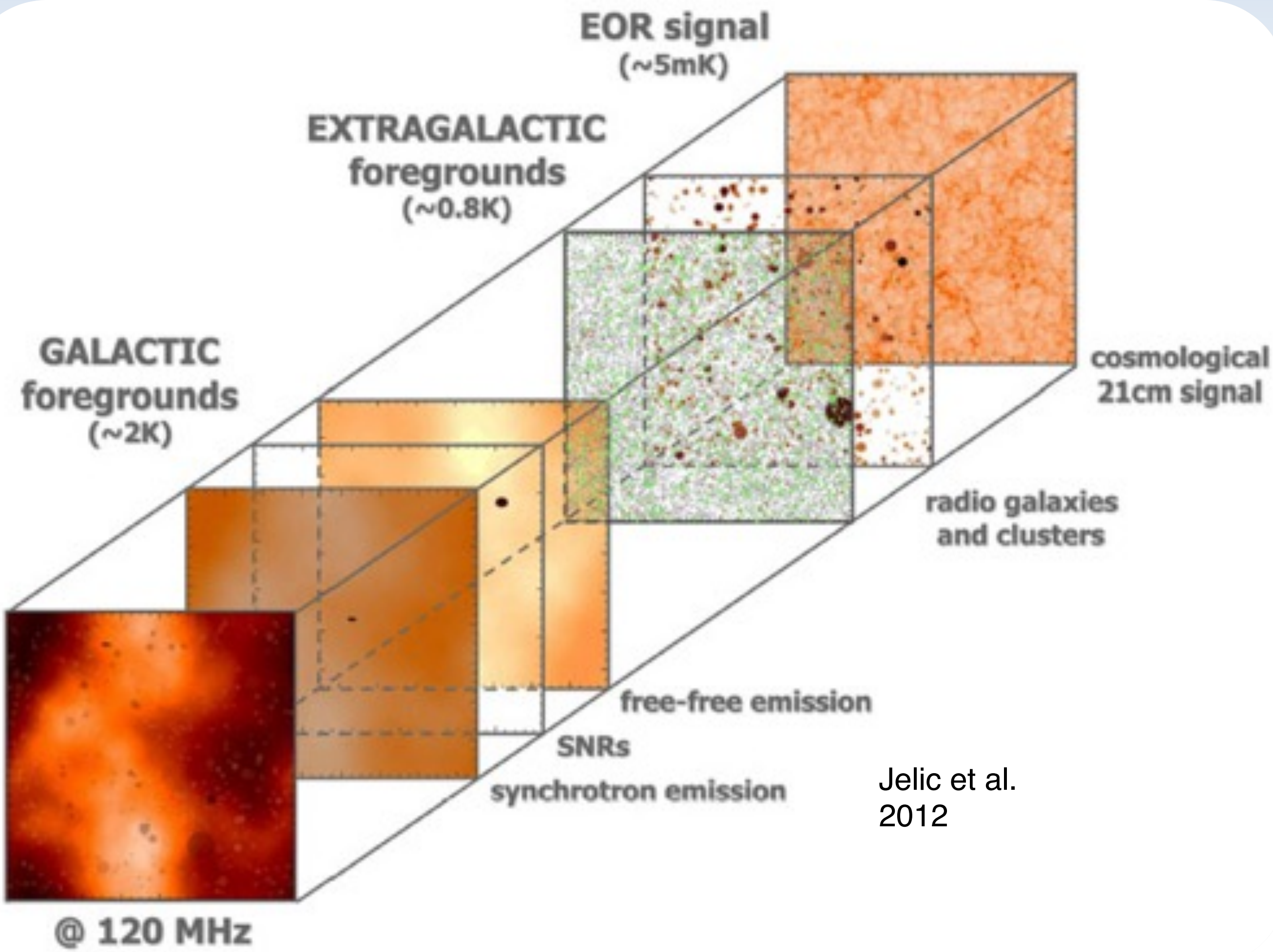
Foreground removal methods



All the stars and galaxies between us and the first stars have to be removed very carefully

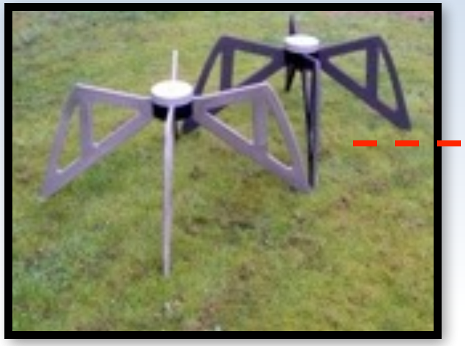
Credit: NASA / WMAP Science Team; Haslam 408MHz map with LOFAR fields superimposed

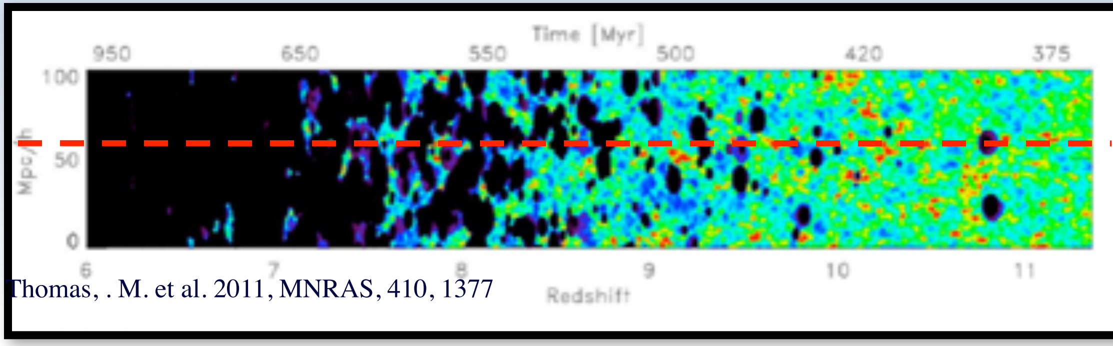
Foregrounds



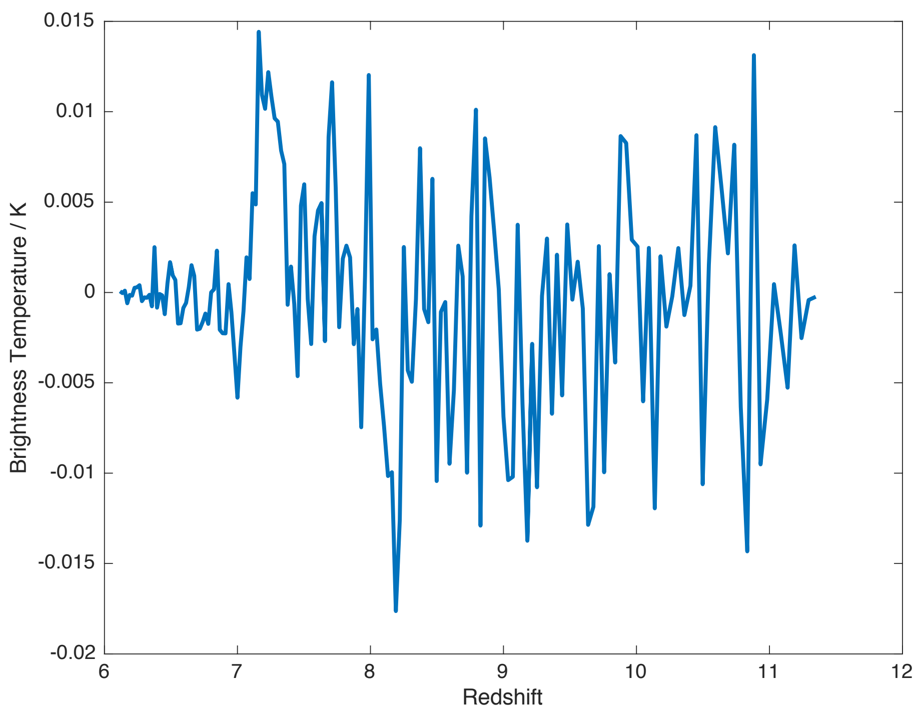
Jelic et al.
2012

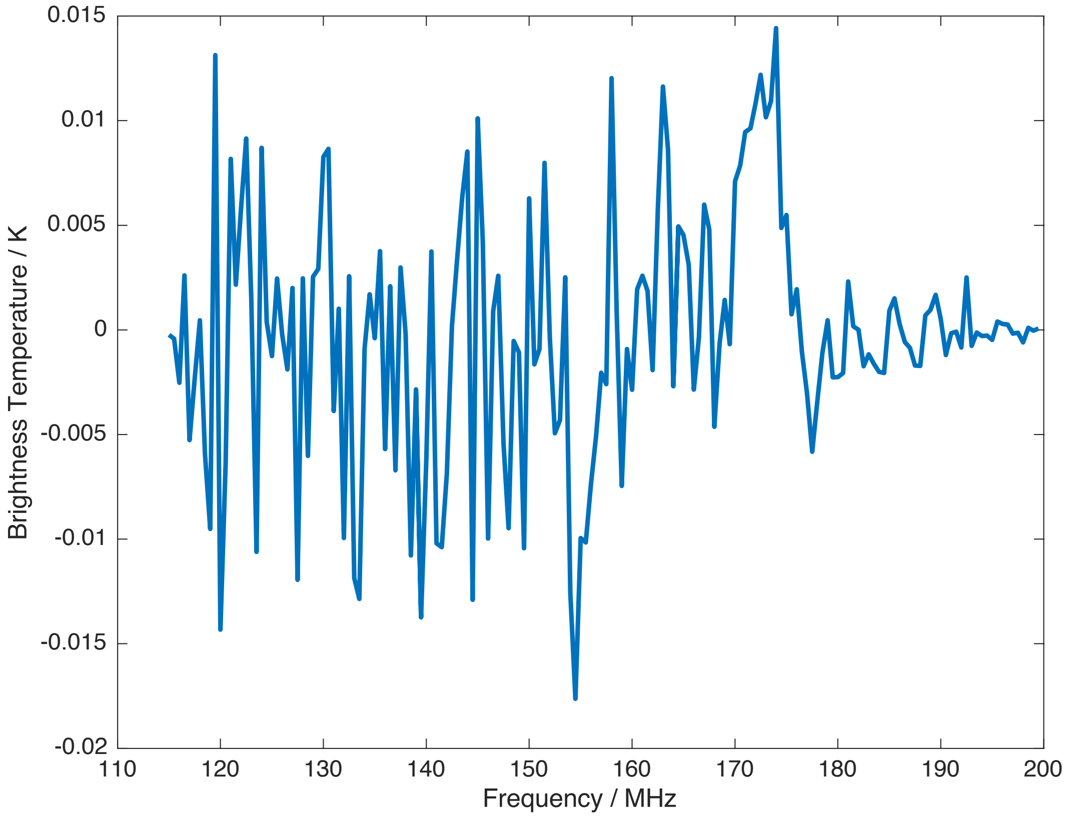

LOFAR
PAPER
GMRT
PAPER
MWA



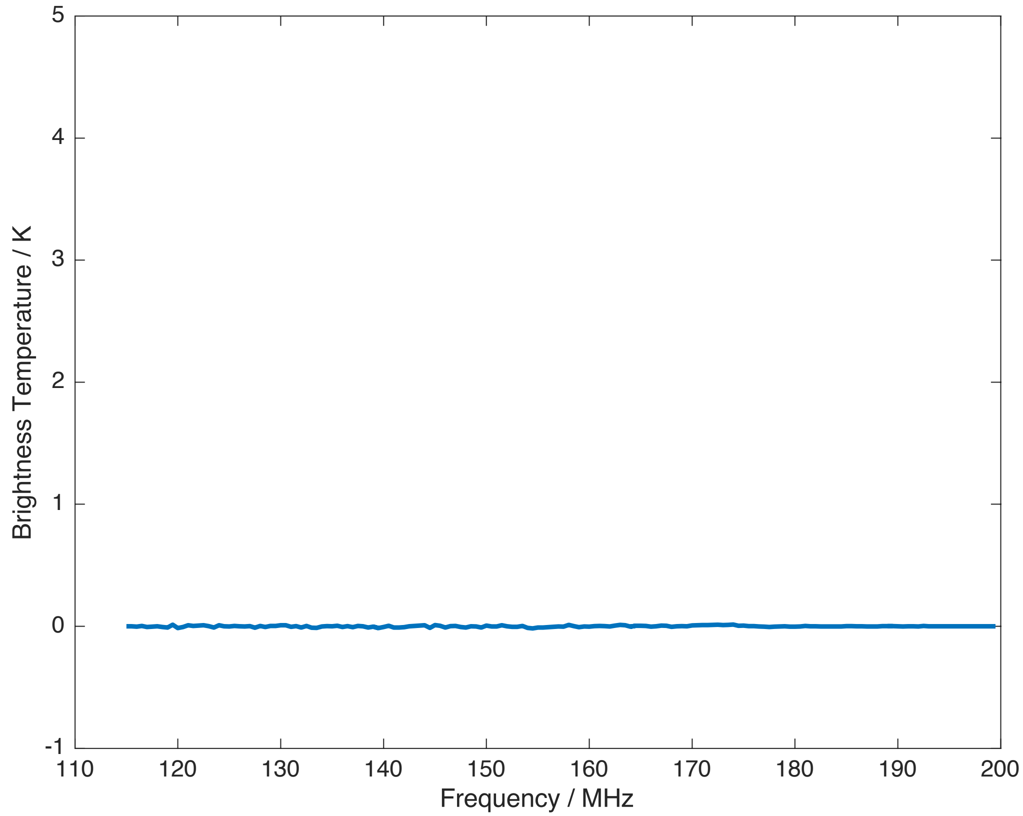


Thomas, . M. et al. 2011, MNRAS, 410, 1377



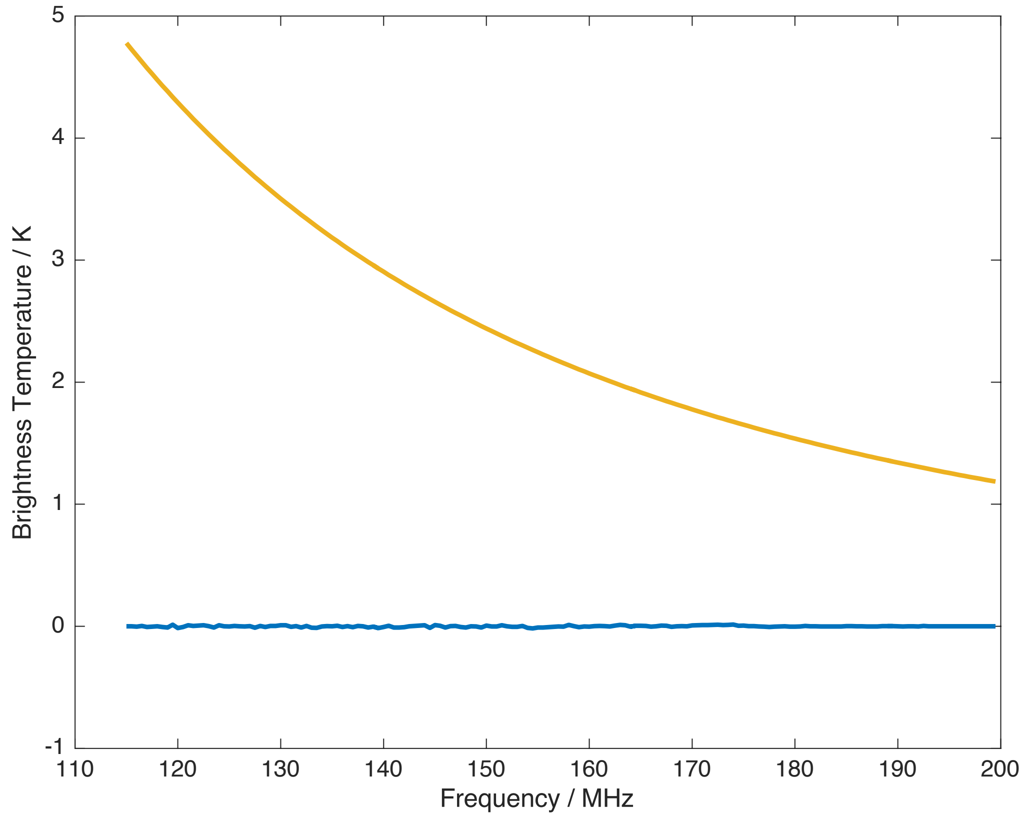


0.015
0.01
0.005
0
-0.005
-0.01
-0.015
-0.02
Brightness Temperature / K
110
120
130
140
150
160
170
180
190
200
Frequency / MHz



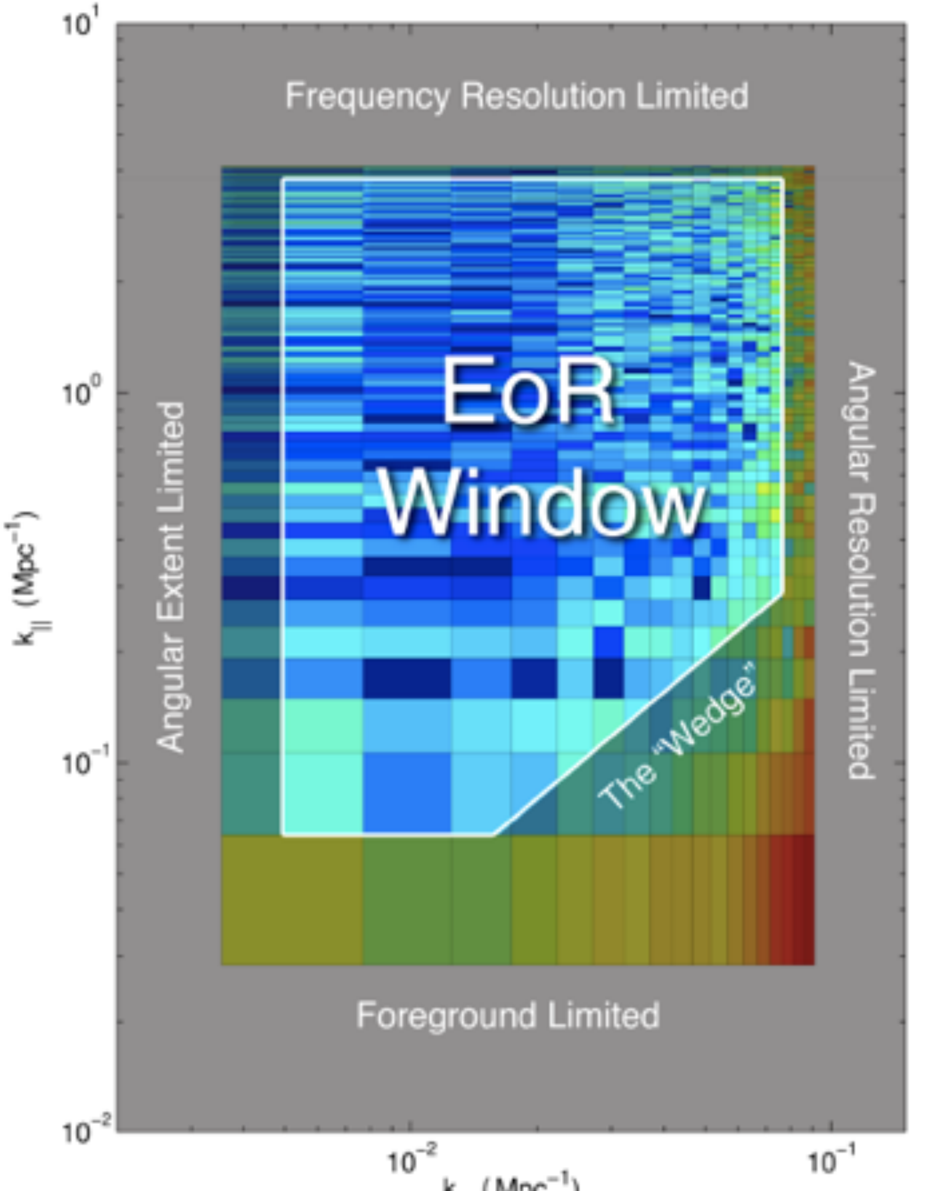
We can model the foregrounds as a polynomial along the line of sight and simply subtract them off.

Foreground removal



We can model the foregrounds as a polynomial along the line of sight and simply subtract them off.

Foreground removal



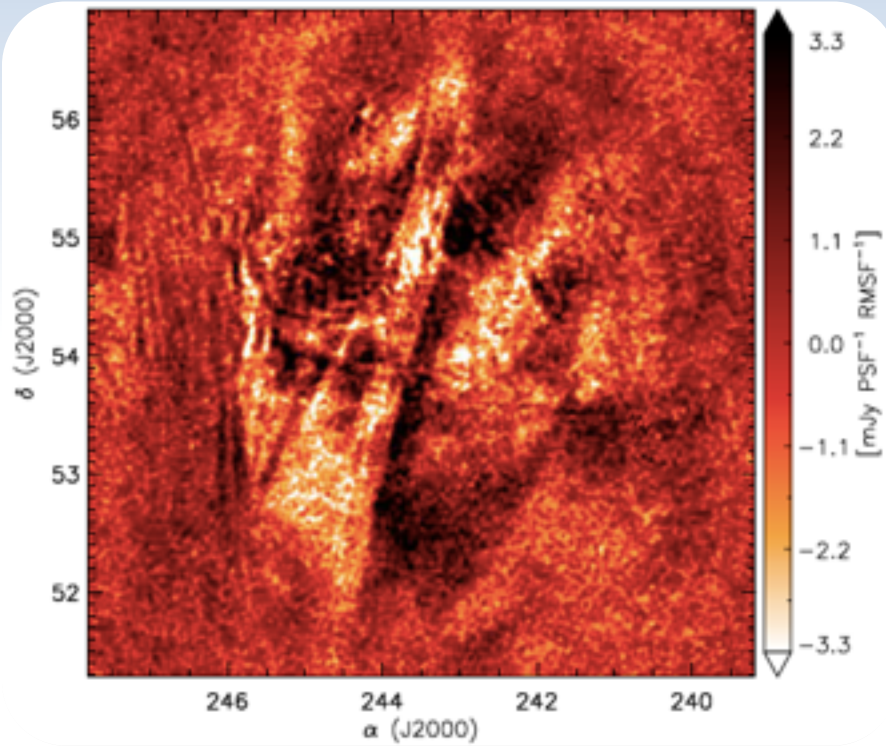
Dillon et al 2013

Foreground **avoidance** only used the EoR window.

Foreground **suppression** downweights scales according to a foreground model.

PAPER: Ali et al., AJ, 809 61, August 2015

MWA: Dillon et al. Phys. Rev. D 91, 123011 (19 June 2015); Trott et al., AJ, 818, Feb 2016



Jelic et al. (inc. EC) 2014

But what if there are foregrounds we do not expect?

Or what if we don't know our instrument as well as we think?

Non-parametric Foreground removal

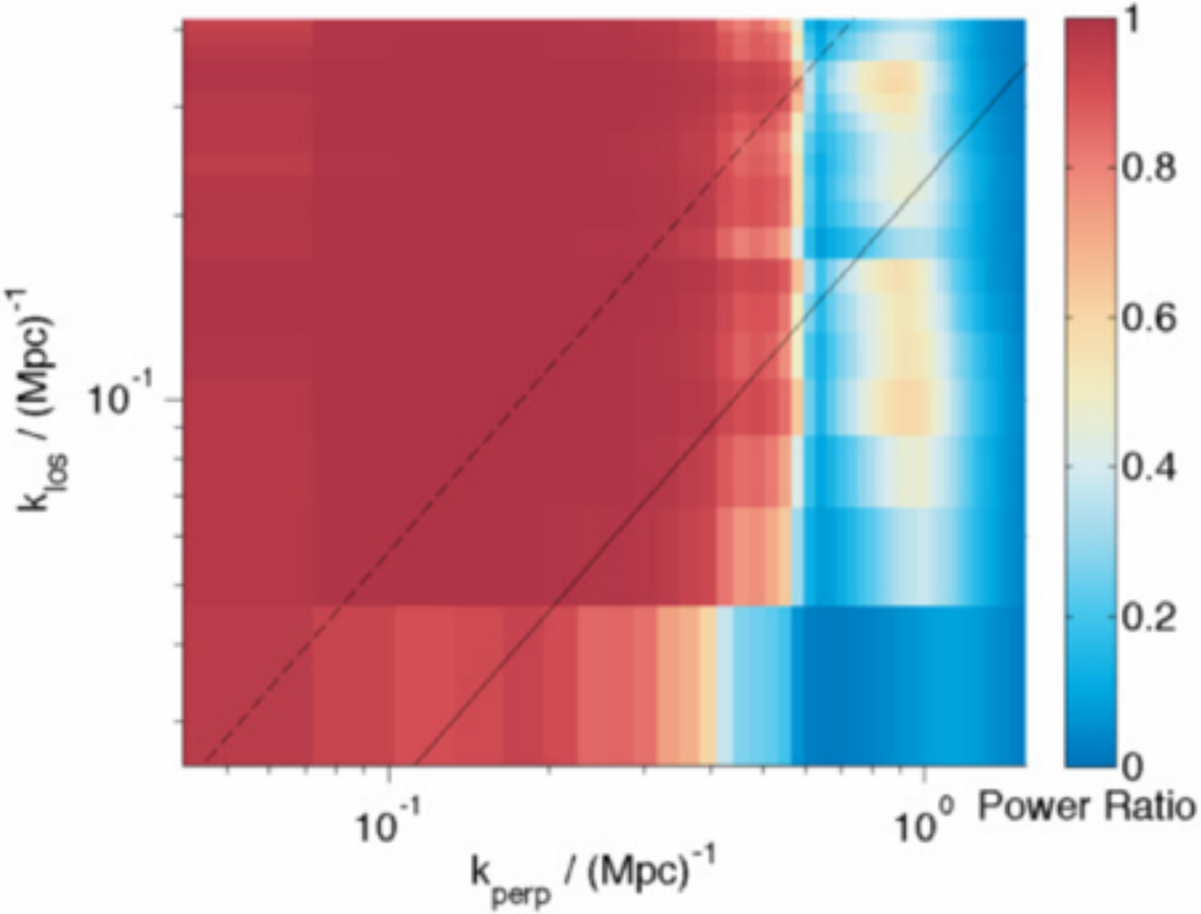
GMRT: Paciga et al. MNRAS (July 21, 2013) 433 (1): 639-647.

LOFAR::

Harker et al.MNRAS 97 (2009) 1138-1152;

Chapman et al. MNRAS, 423, (2012) 2518-2532,,

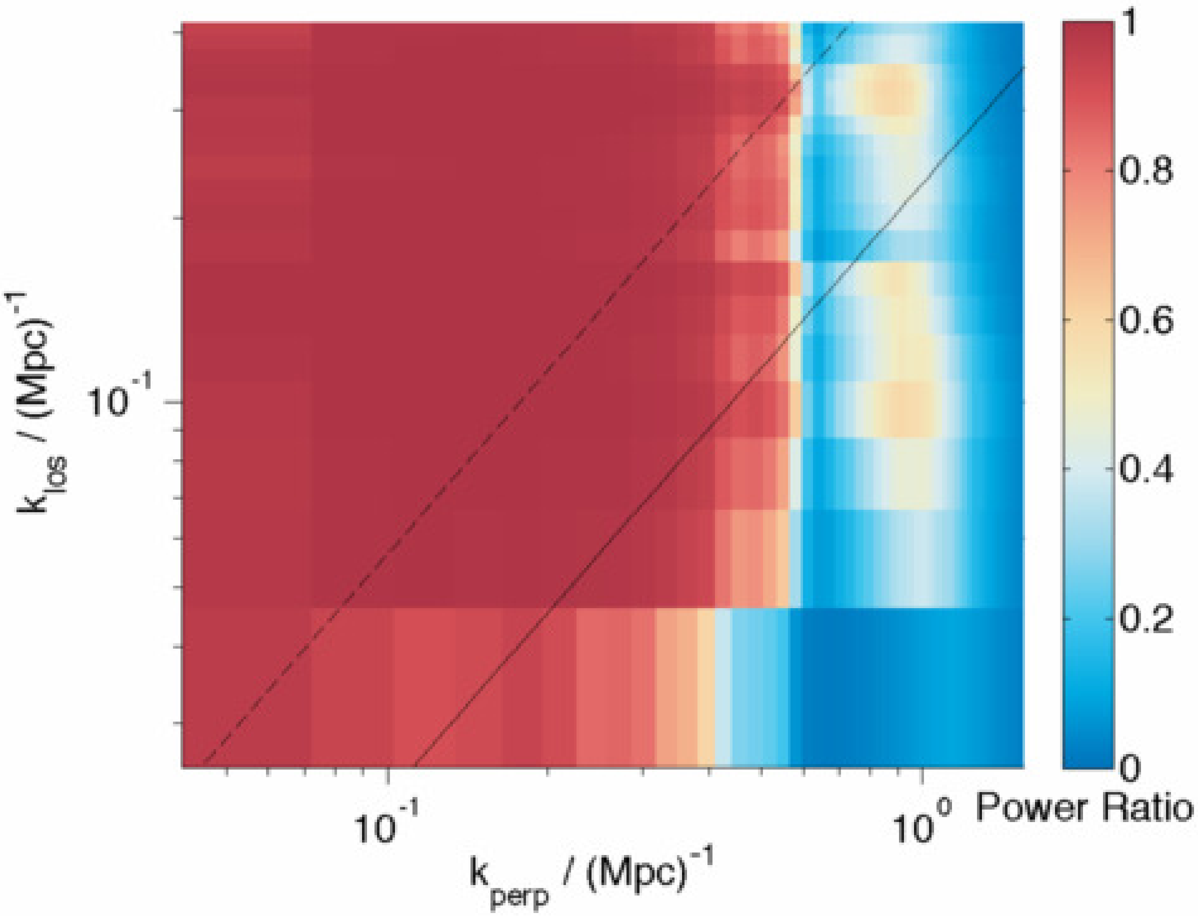
Chapman et al. MNRAS 429, (2013) 165-176



Ratio = cs / (fitting errors + cs)

cs = cosmological signal

i.e. red is GOOD



1% random wiggle along the line of sight

Ratio = cs / (fitting errors + cs)

cs = cosmological signal

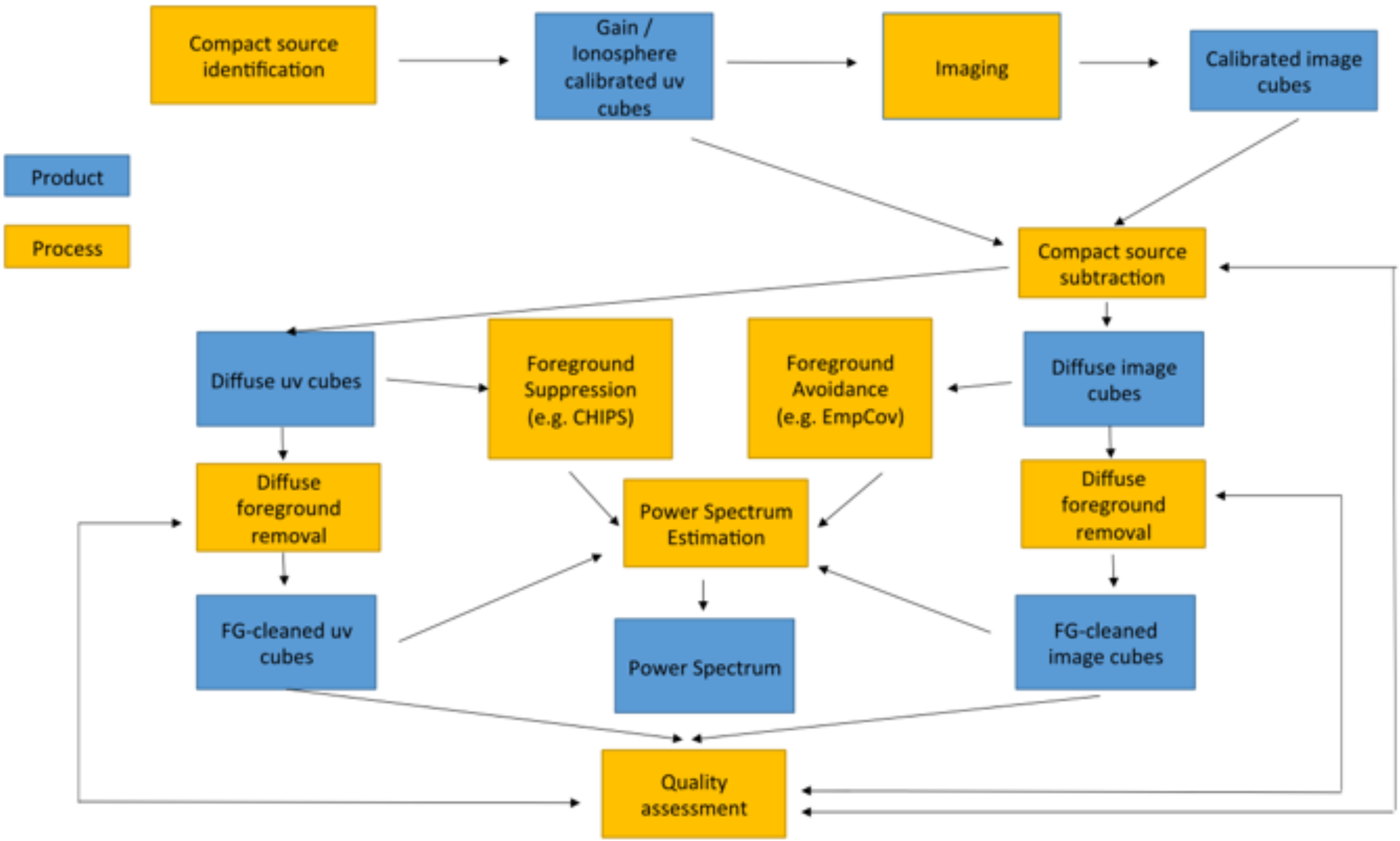
i.e. red is GOOD

Simulating the data pipeline

Simulating the data pipeline

“After the International Space Station and the Large Hadron Collider the world’s next great science project is the Square Kilometre Array,”

David Willetts,
after UK pledged £100m
towards 650m euro cost


Compact source identification
Gain / Ionosphere calibrated uv cubes
Imaging
Calibrated image cubes
Product
Process
Compact source subtraction
Diffuse uv cubes
Foreground Suppression (e.g. CHIPS)
Foreground Avoidance (e.g. EmpCov)
Diffuse image cubes
Diffuse foreground removal
Power Spectrum Estimation
Diffuse foreground removal
FG-cleaned uv cubes
Power Spectrum
FG-cleaned image cubes
Quality assessment

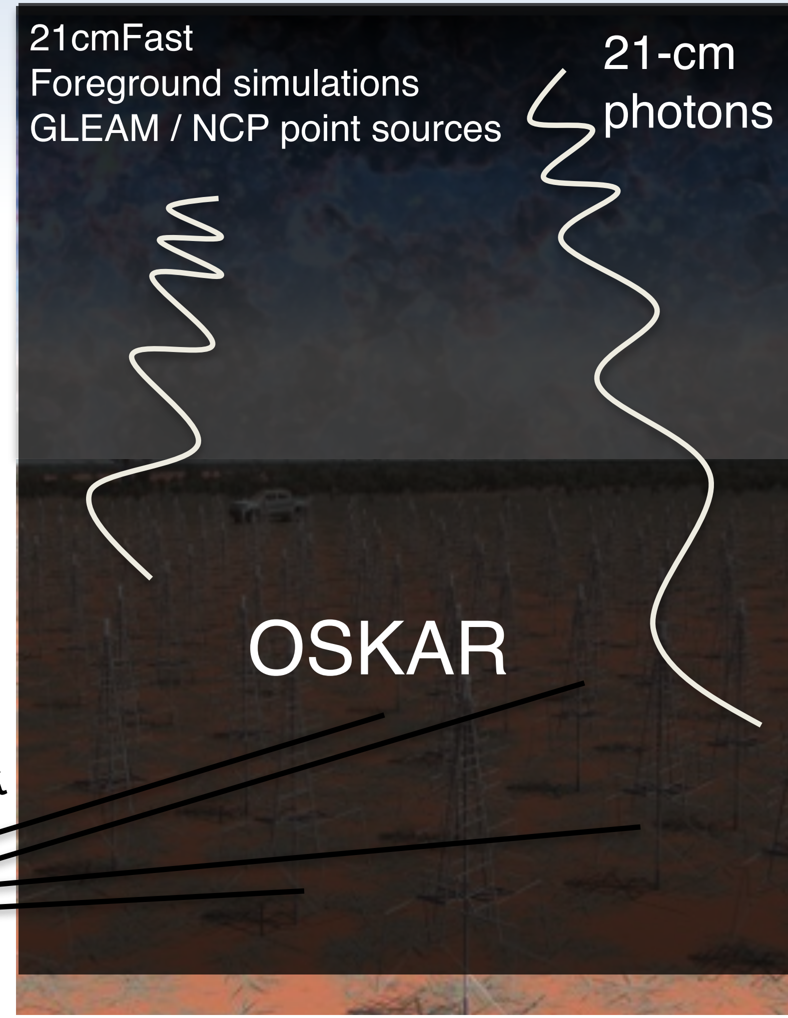
Before we receive real data we will need to simulate the sky and the telescope.

OSKAR is a radio interferometry simulator which simulates the effect of the antennas and produces “fake” data to test the pipeline.

Movie of the First Stars

Calibration Pipeline

2 Pb/night



OSKAR:
http://www.oerc.ox.ac.uk/~ska/oskar2/

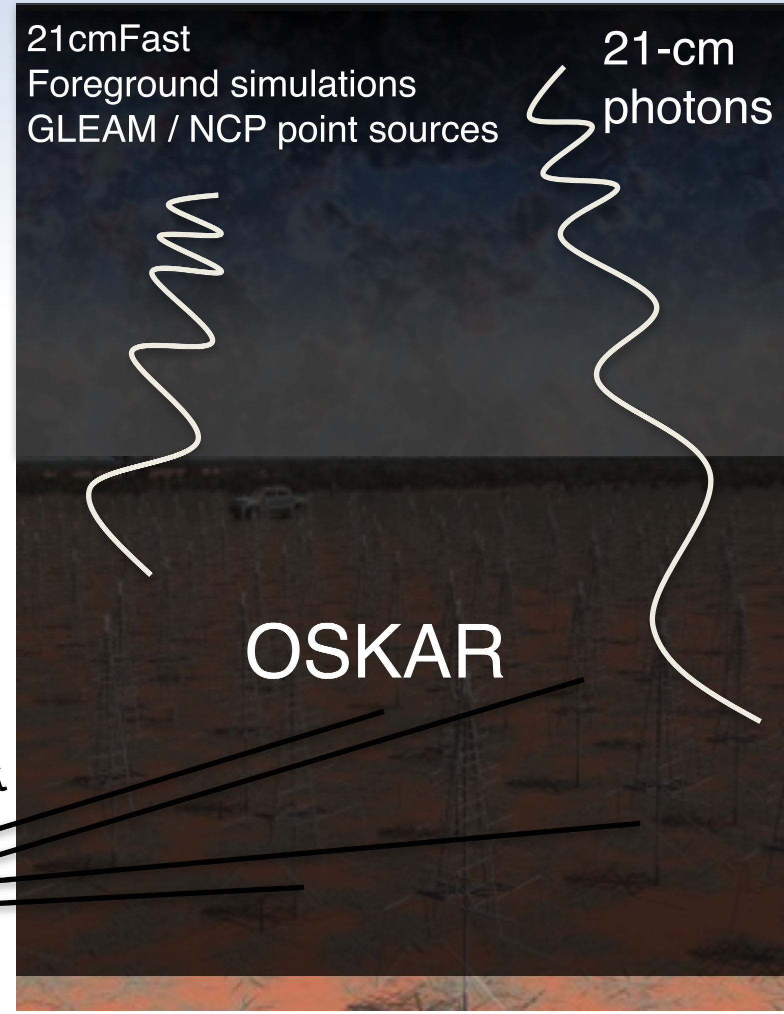
Dr Ben Mort

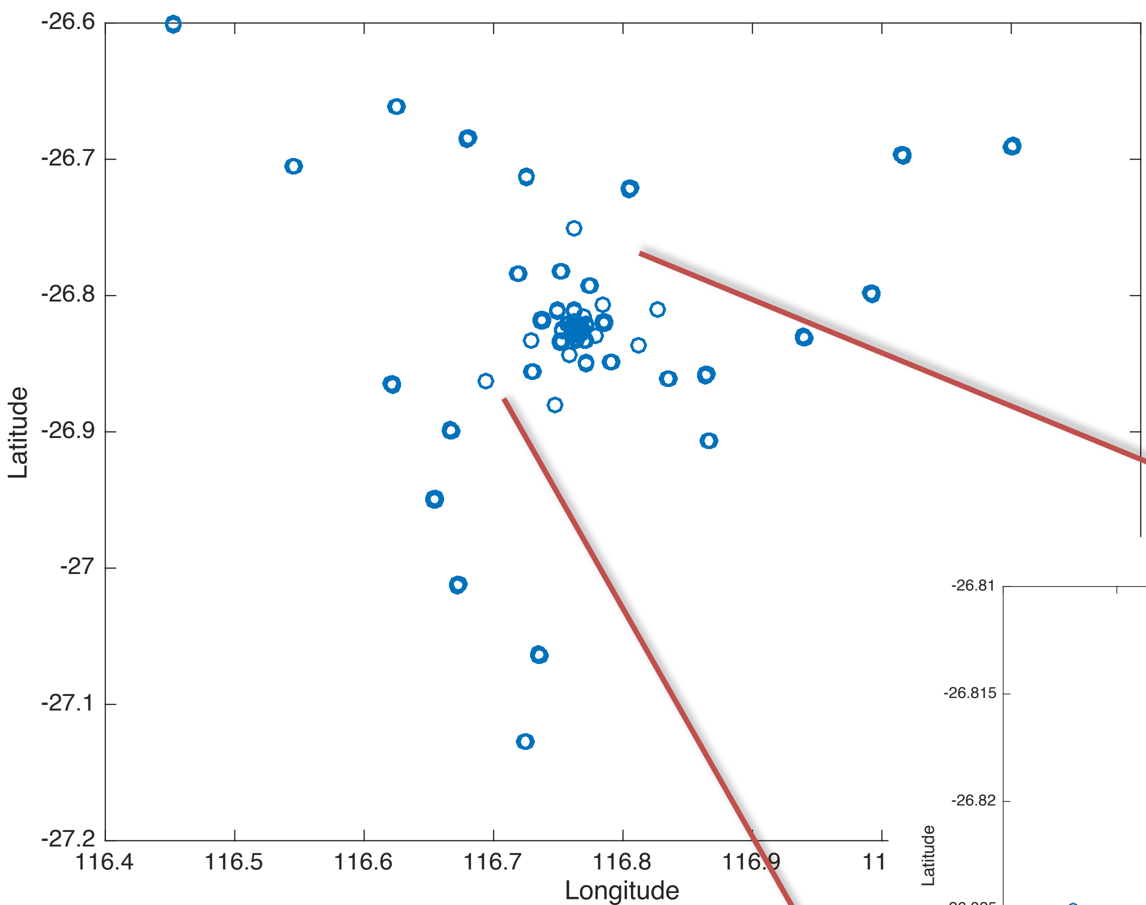
Dr Fred Dulwich

Movie of the First Stars

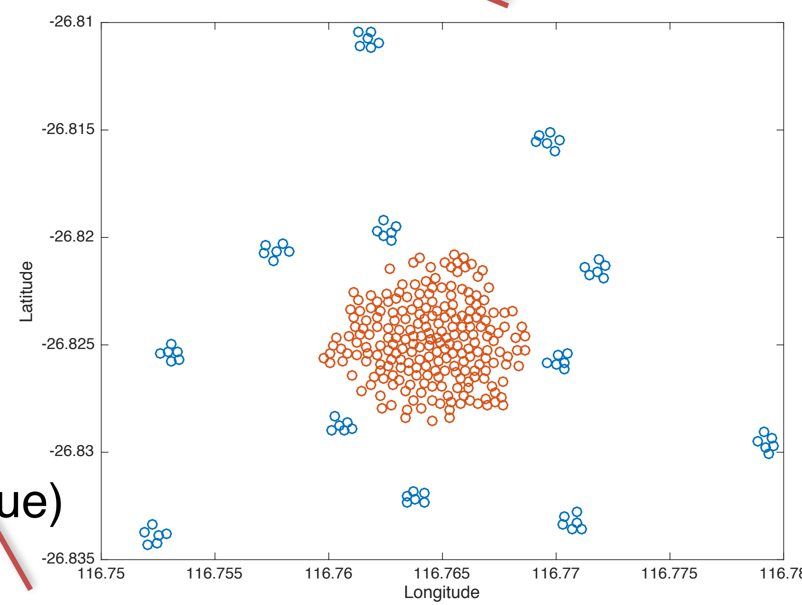
Calibration Pipeline

2 Pb/night

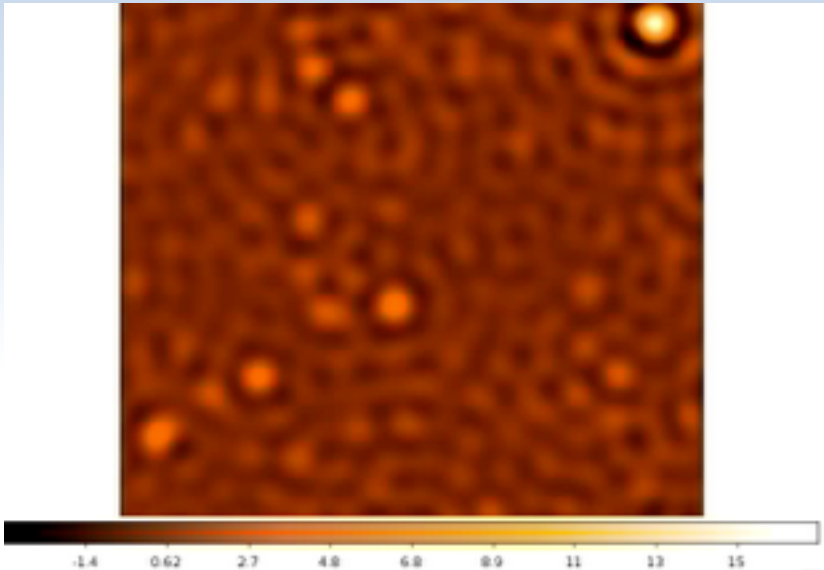




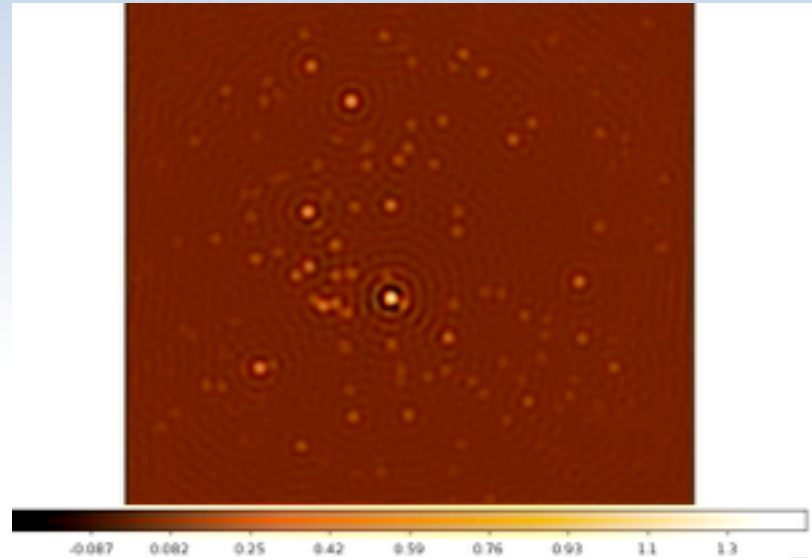
SKA - Full Array



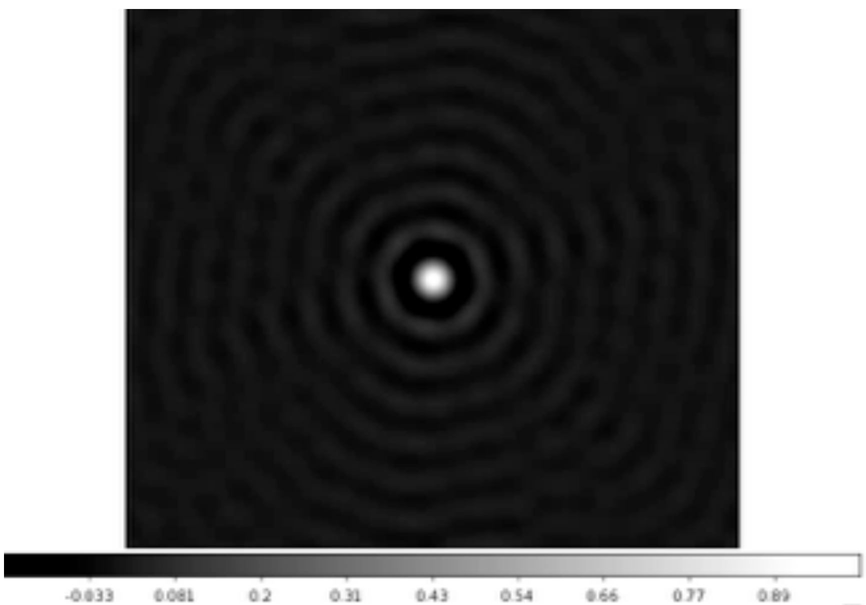
SKA Central Area (core in blue)

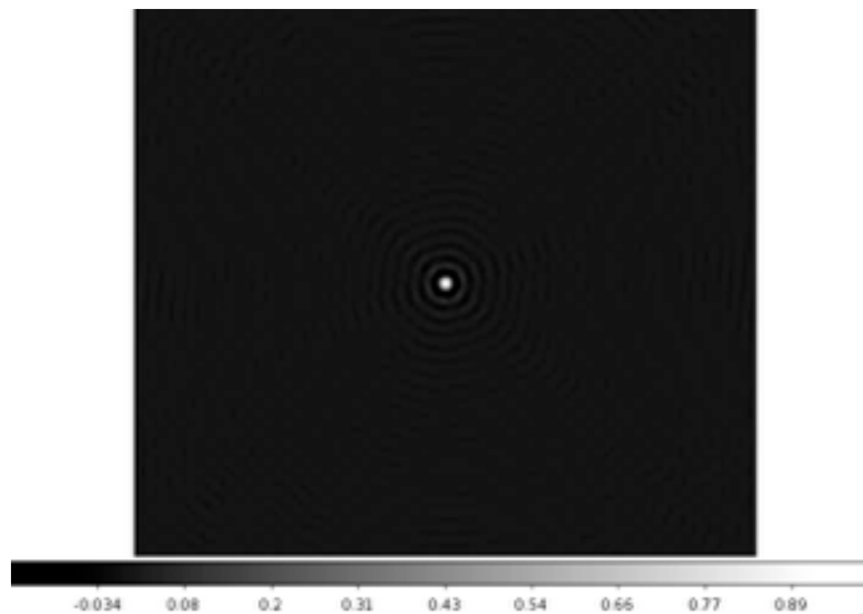


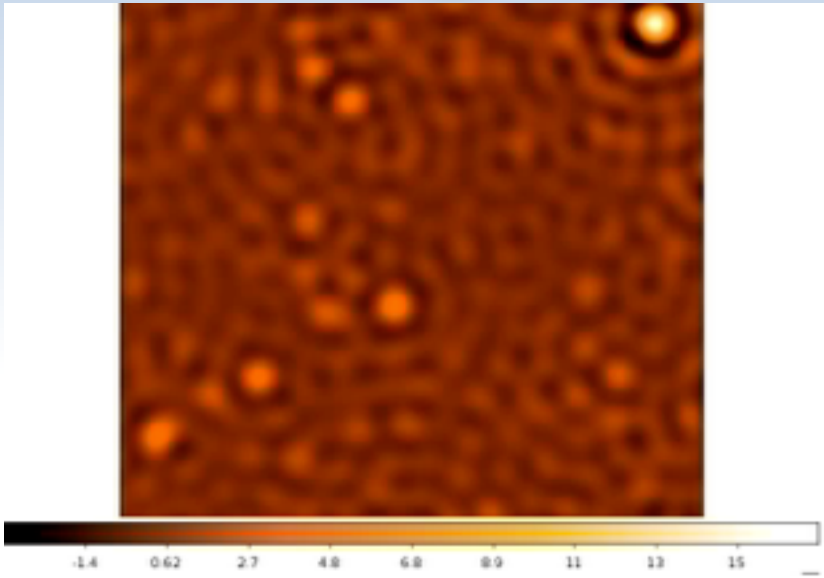
65-75 MHz

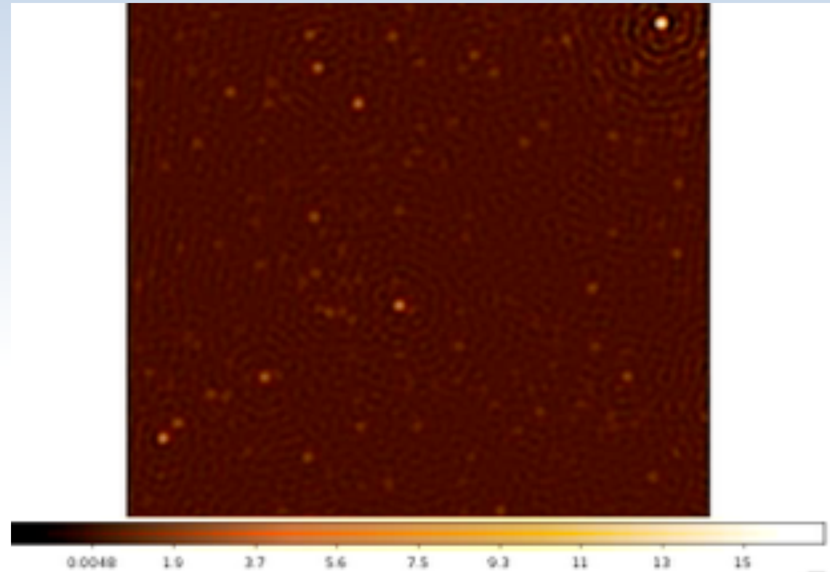


185-195 MHz



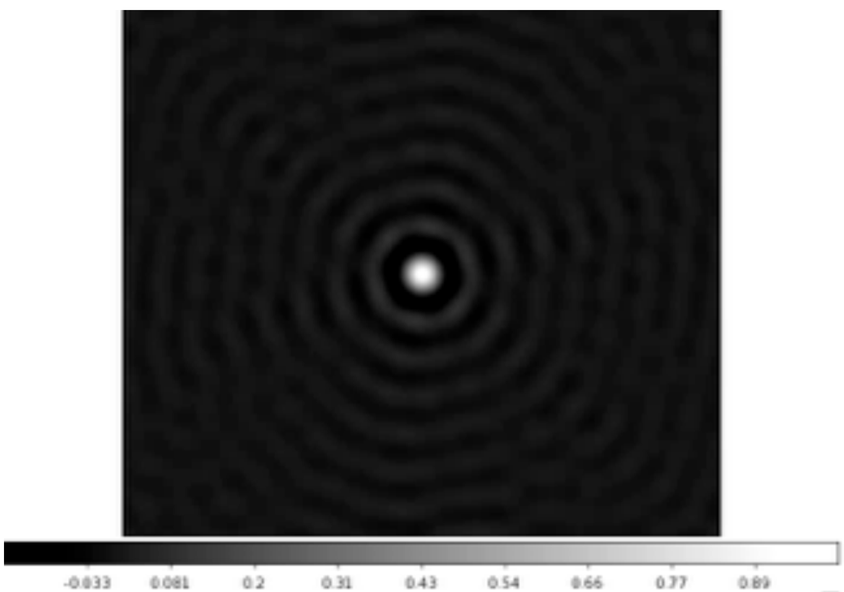


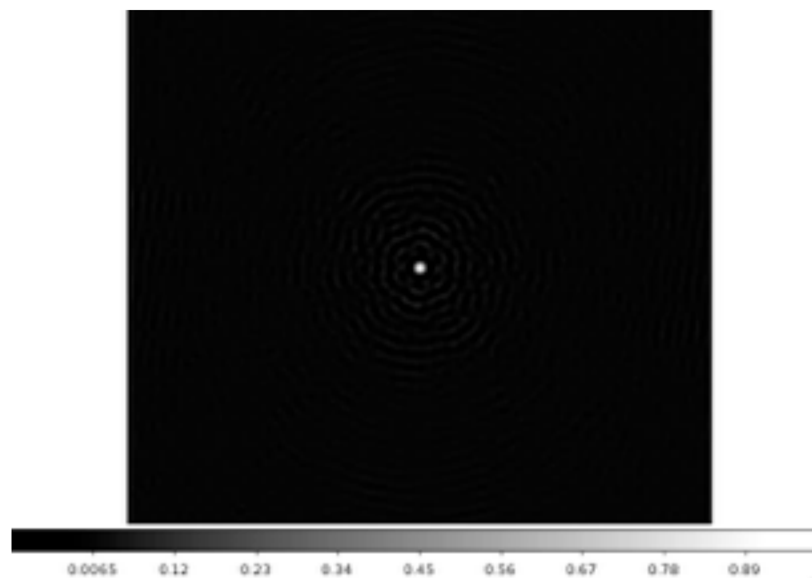




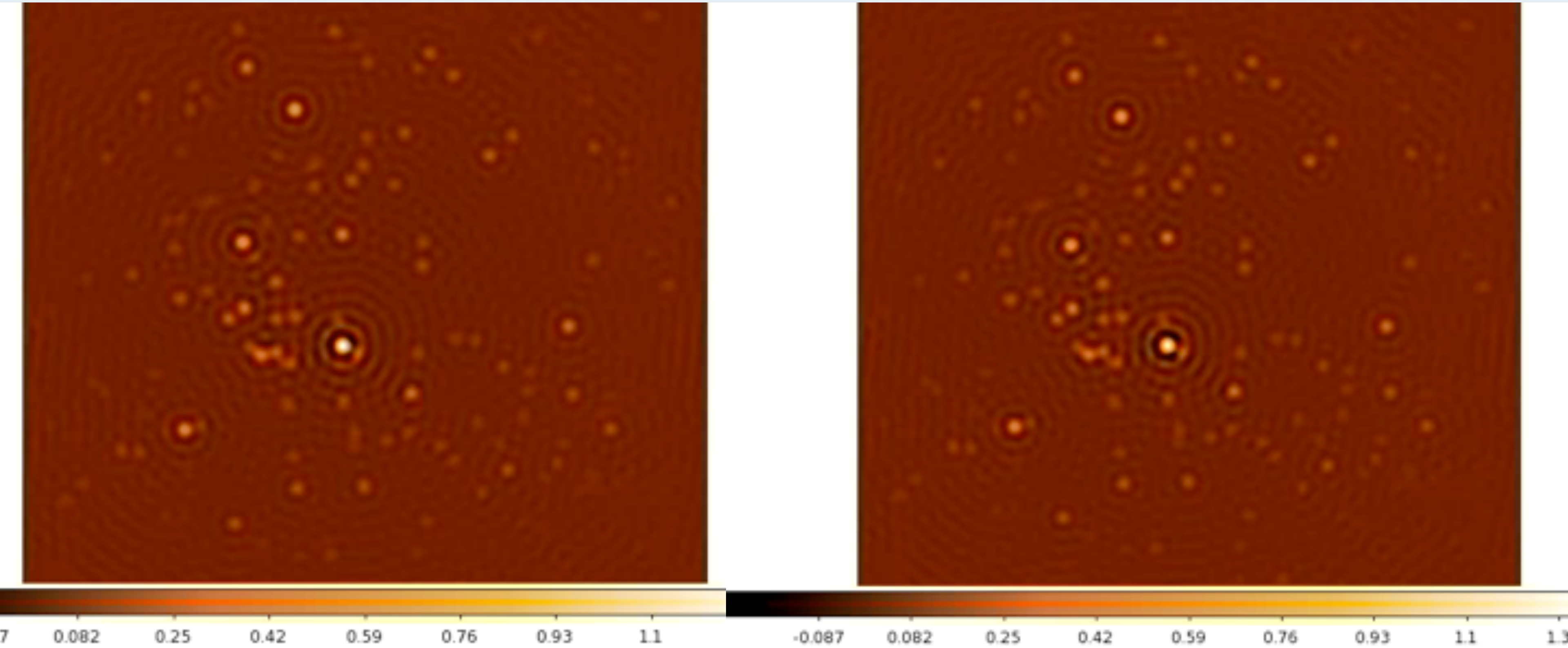
core

central area





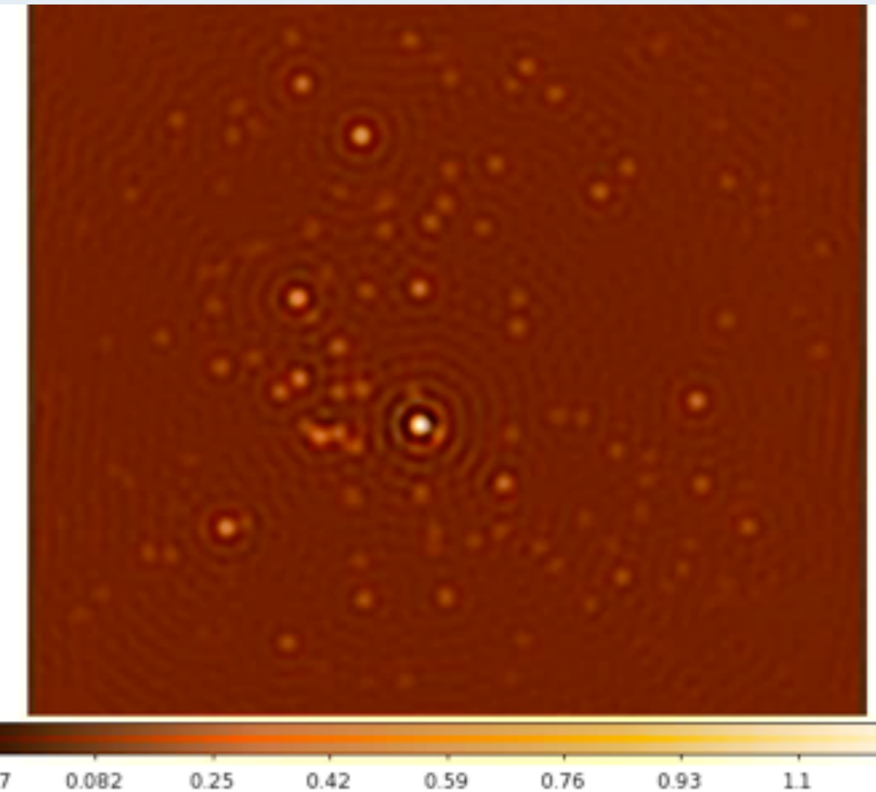
Introducing Calibration Errors

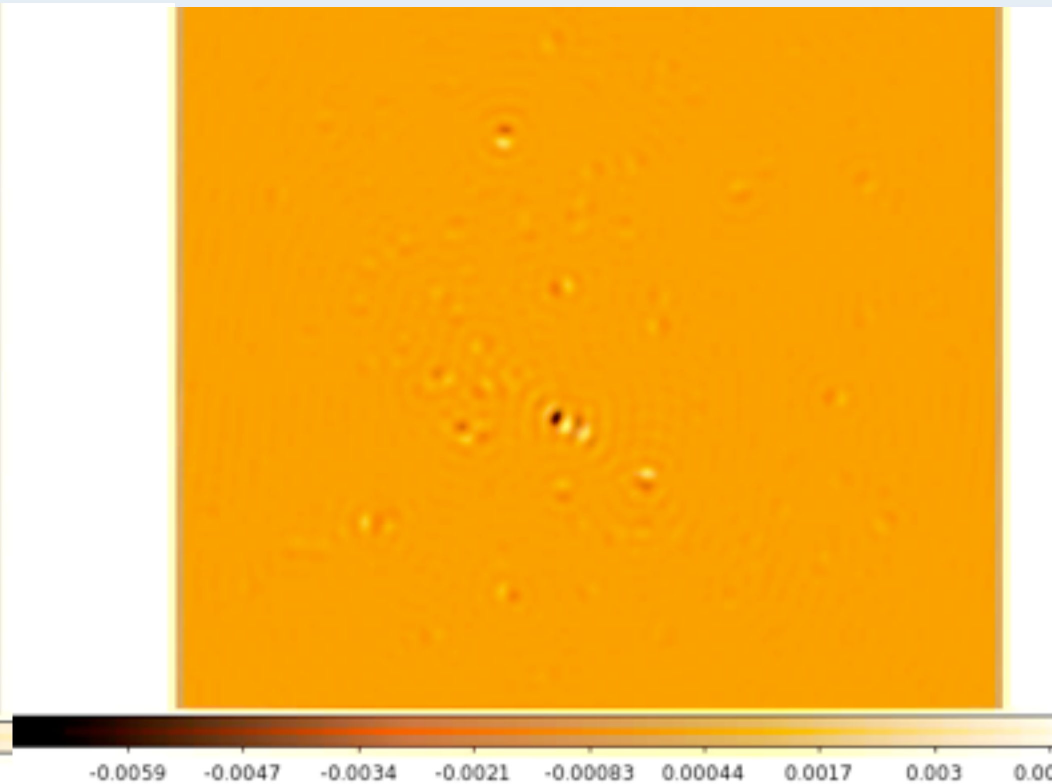


Aim: To introduce sky models which have errors, either in terms or gains, source positions or flux completeness and see how this affects diffuse foreground removal.

Chapman, Dulwich and Mort 2017, in prep

Introducing Calibration Errors

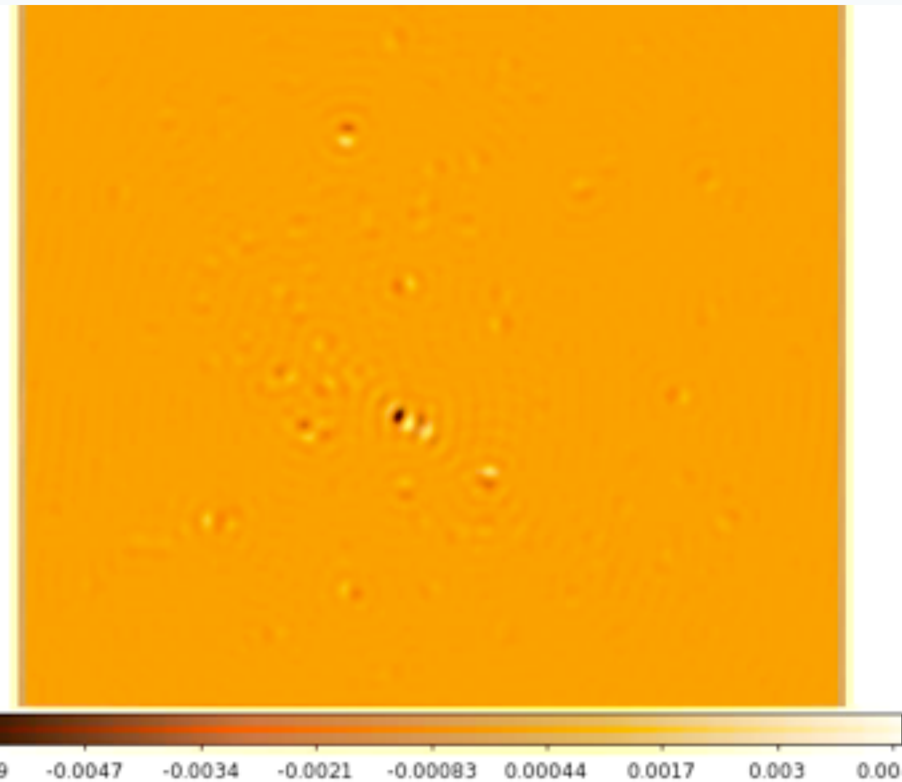


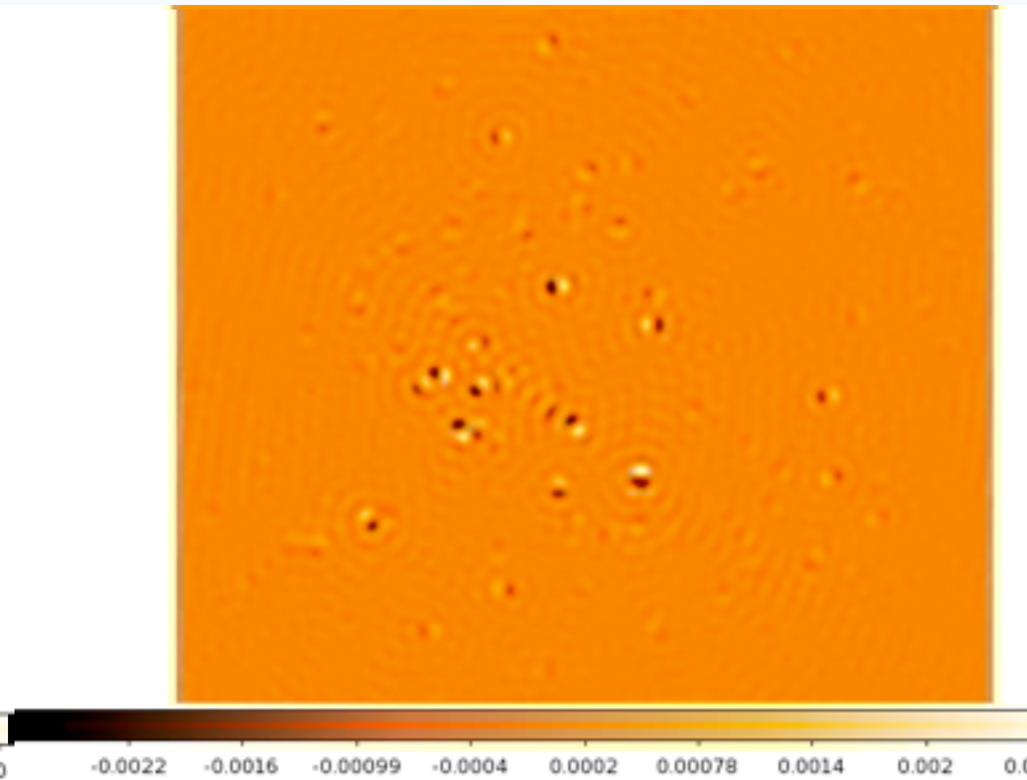


Aim: To introduce sky models which have errors, either in terms or gains, source positions or flux completeness and see how this affects diffuse foreground removal.

Chapman, Dulwich and Mort 2017, in prep

Applying non-parametric foreground removal to the source position errors (left)
A lot of the main sources of error are picked up but lots still left in residual signal - on to
of the cosmological signal





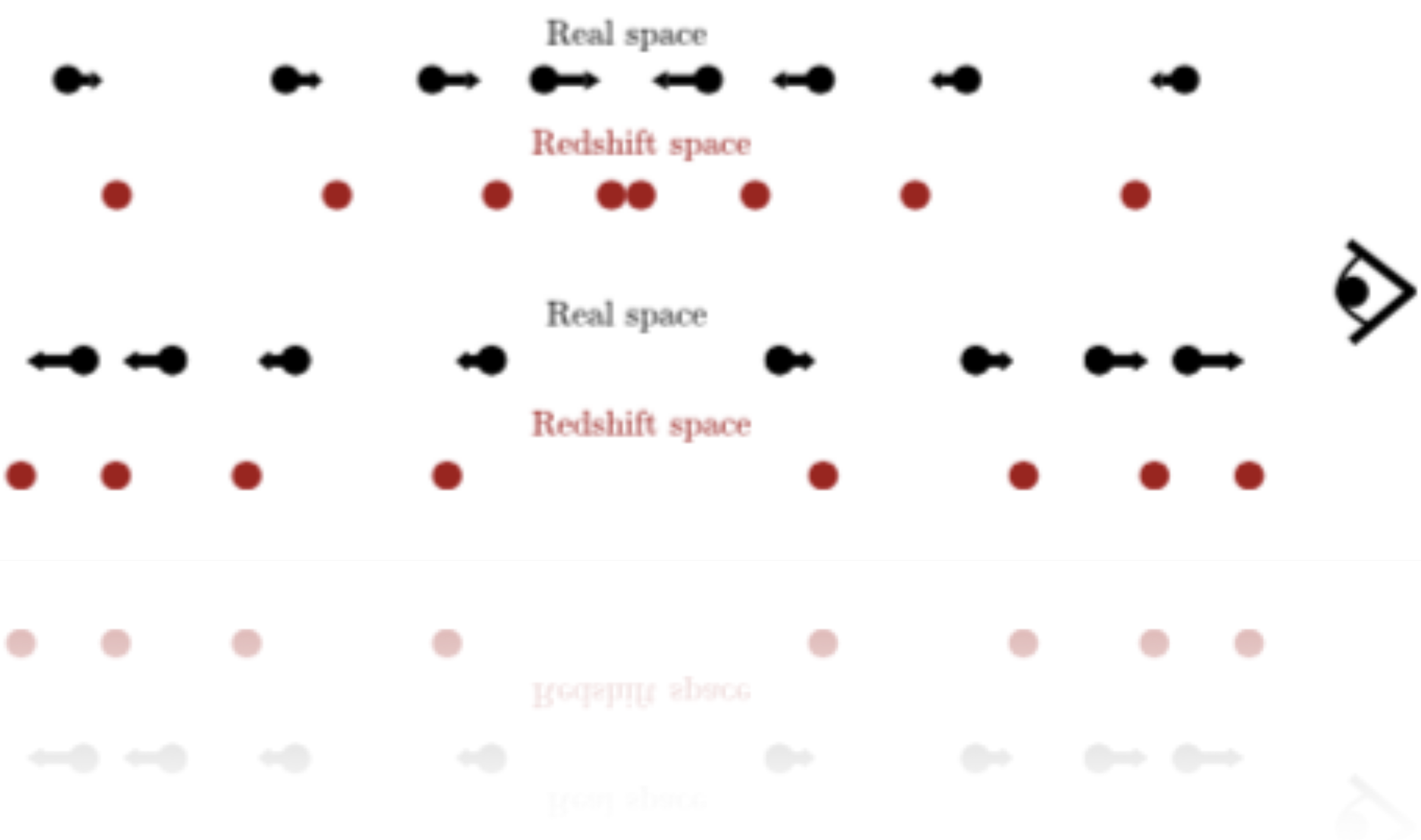
Predicting the Science

Predicting the Science

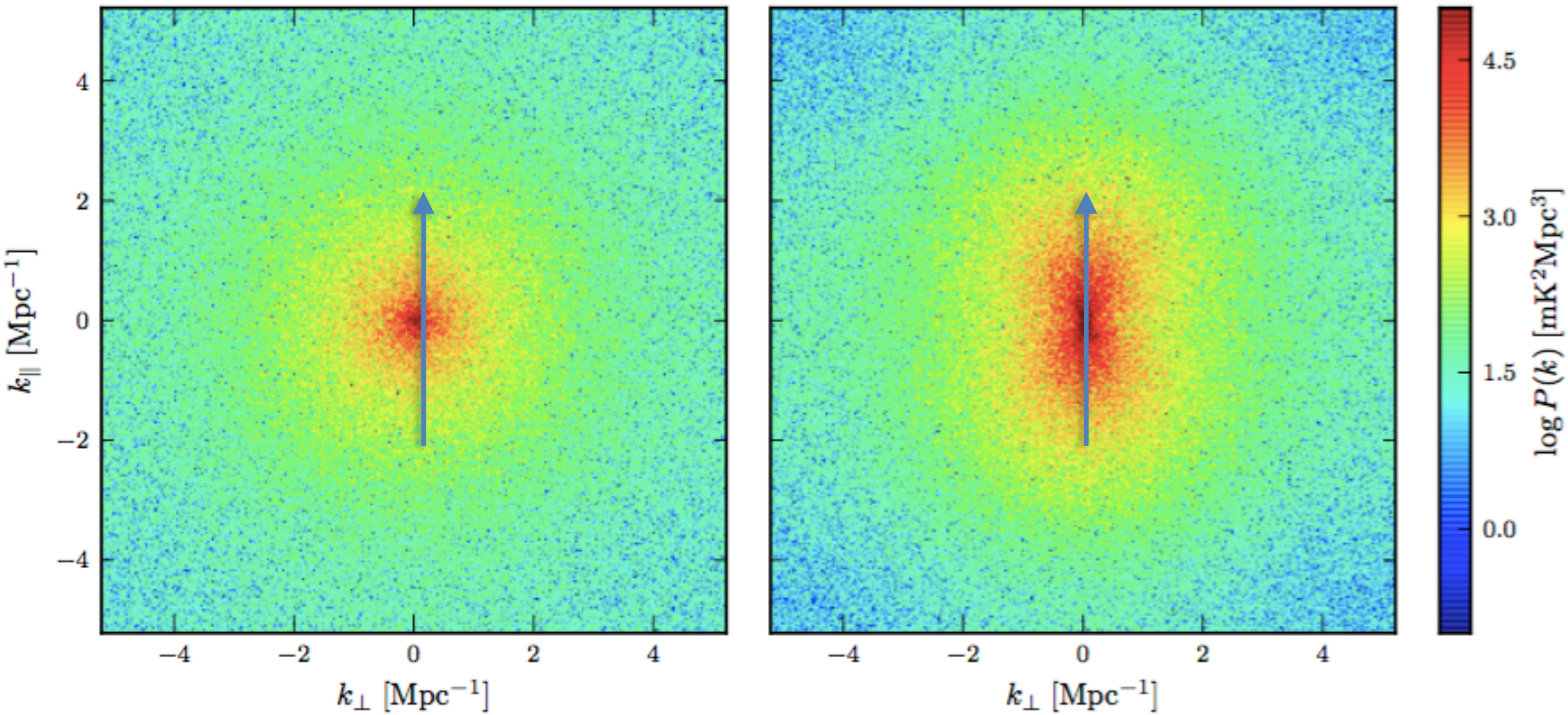
A METHOD FOR SEPARATING THE PHYSICS FROM THE ASTROPHYSICS OF HIGH-REDSHIFT 21CM FLUCTUATIONS

RENNAN BARKANA[1] & ABRAHAM LOEB[2]

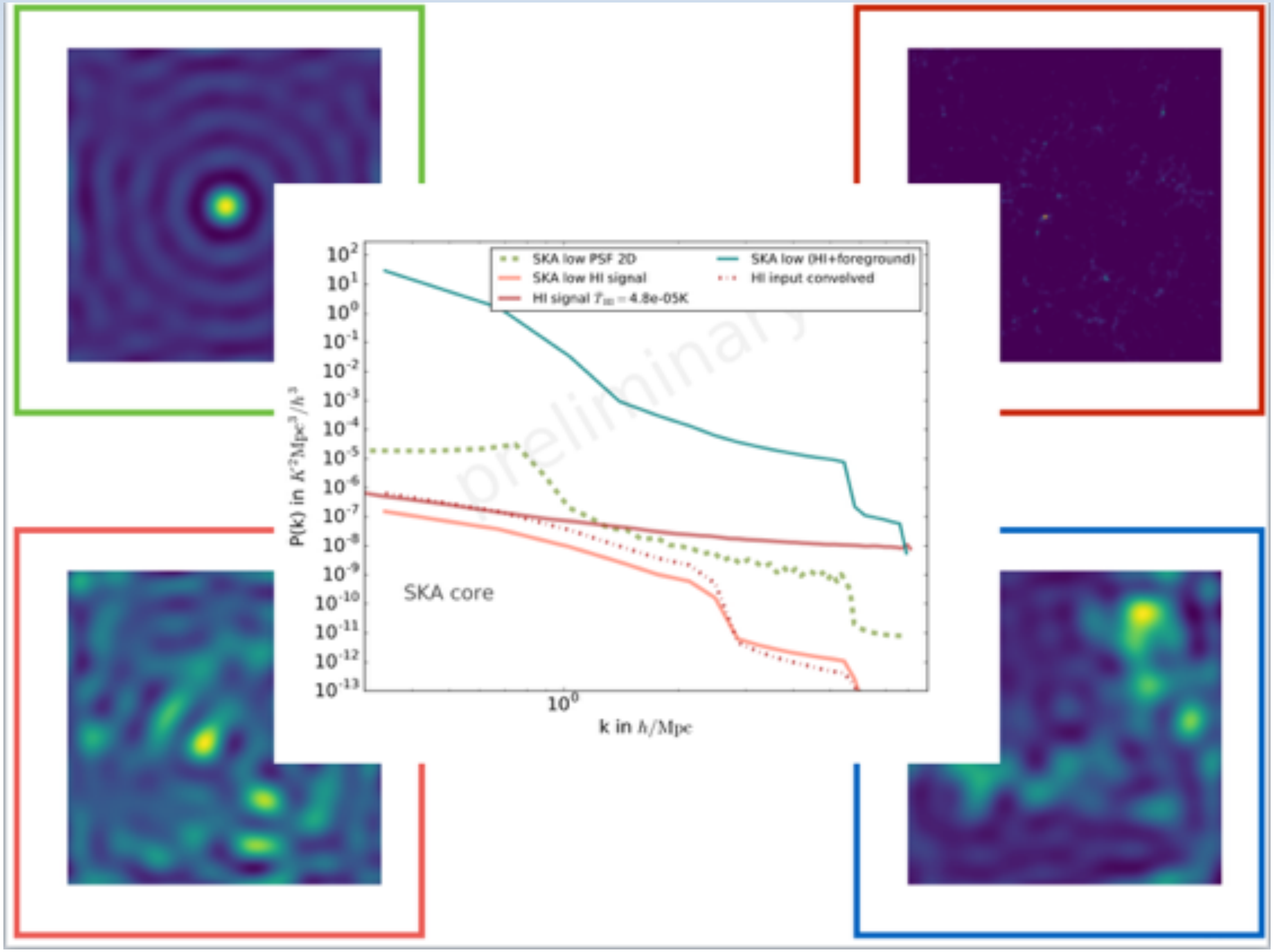
Draft version February 2, 2008



Jensen et al. inc. Chapman 2014



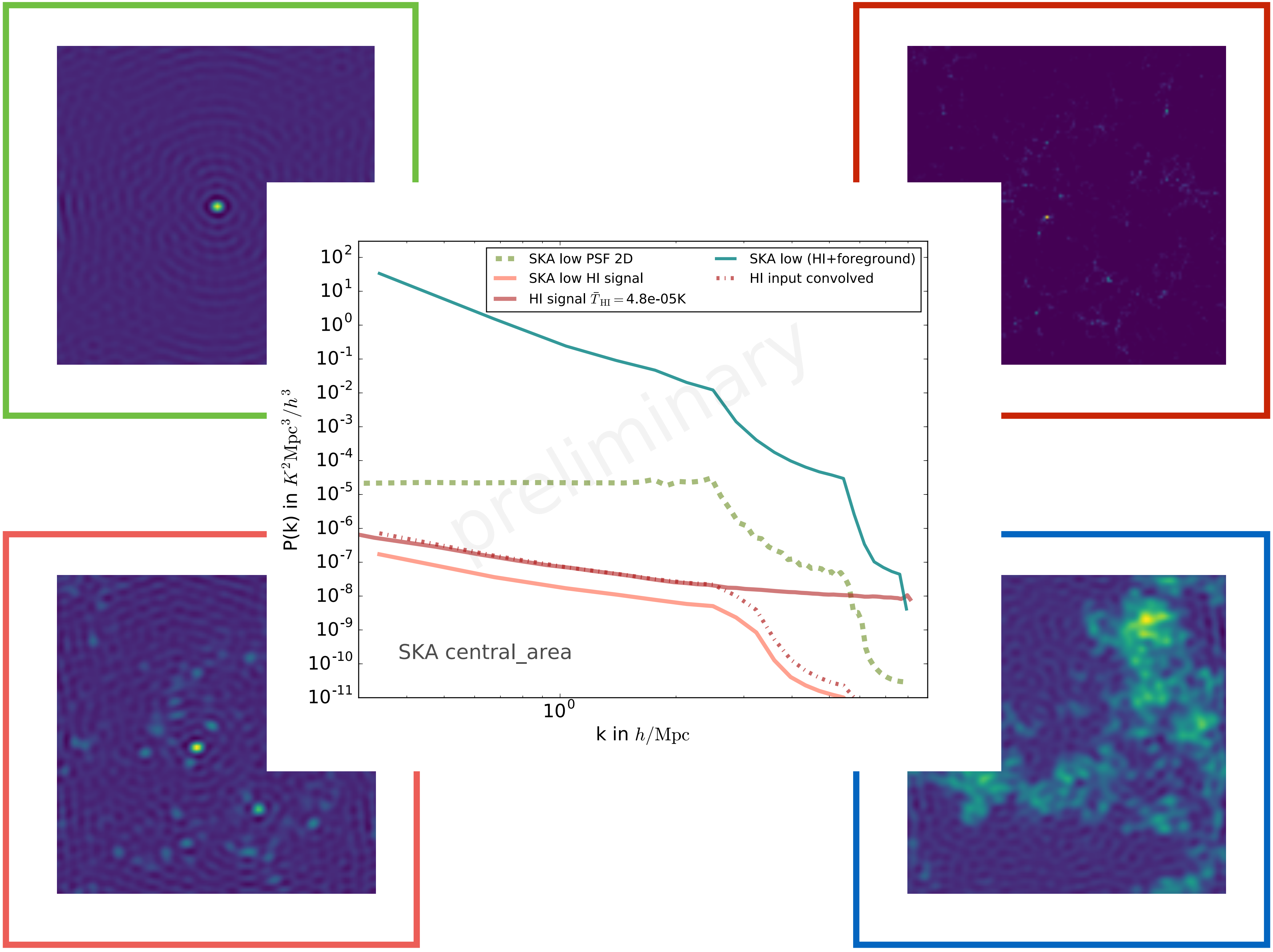
$$P^{s}(k,\mu) = \overline{\delta T_b}^{2}(z)\,[P_{\rho_{\mathrm{HI}},\rho_{\mathrm{HI}}}(k) + \\ +2\mu^2 P_{\rho_{\mathrm{HI}},\rho_{\mathrm{M}}}(k) + \mu^4 P_{\rho_{\mathrm{M}},\rho_{\mathrm{M}}}(k)]\,, \qquad (3)$$

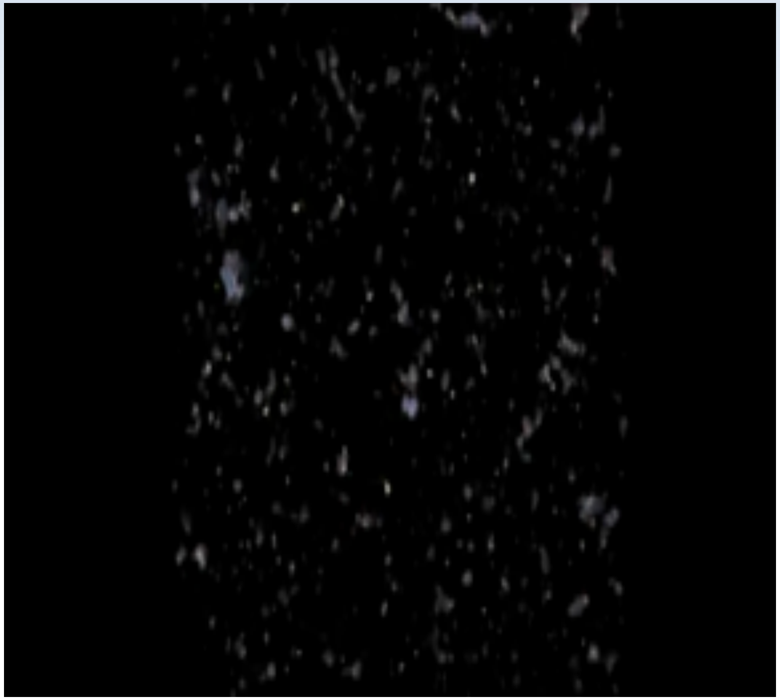


Top Left: PSF of SKA_LOW core
Top Right: Meraxes slice
Bottom left: OSKAR output
Bottom right: OSKAR output with foregrounds

Intensity Mapping of HI at redshift 5

Dr Laura Wolz
Dr Jonathan Pritchard
Dr Alkistis Pourtsidou

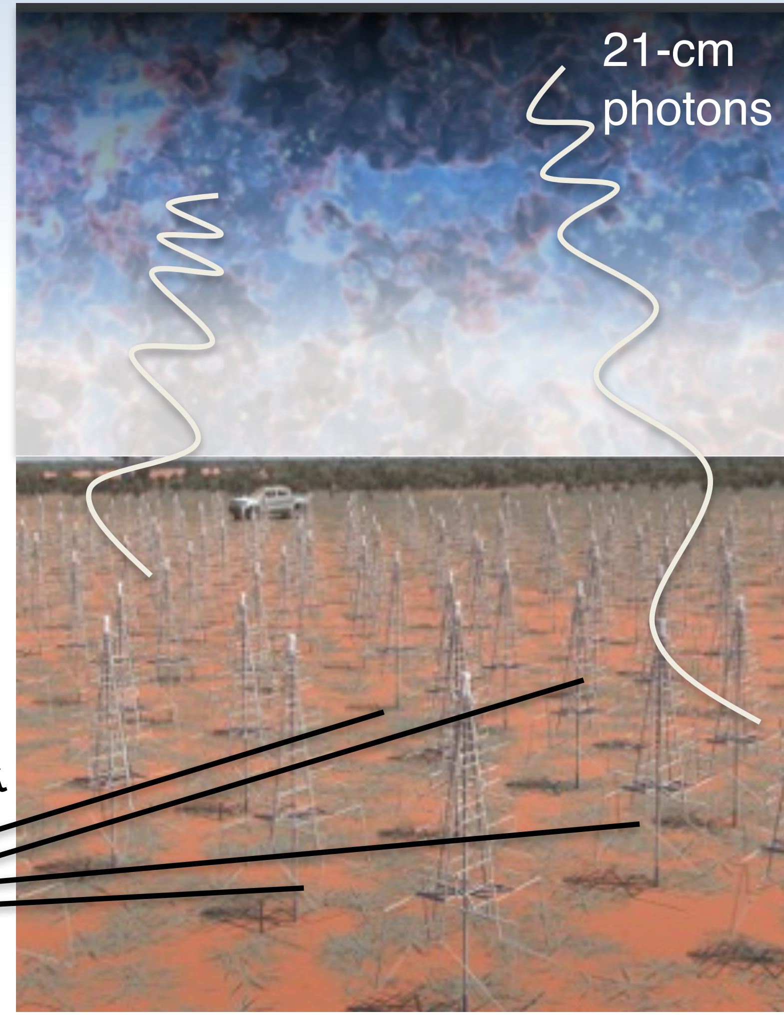

SKA low PSF 2D
SKA low HI signal
HI signal $\bar{T}_{\mathrm{HI}} = 4.8\mathrm{e}{-05}\mathrm{K}$
SKA low (HI+foreground)
HI input convolved
SKA central_area
preliminary
P(k) in $K^2\mathrm{Mpc}^3/h^3$
k in h/Mpc
10^{2}
10^{1}
10^{0}
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{-8}
10^{-9}
10^{-10}
10^{-11}
10^{0}



Movie of the First Stars

Calibration Pipeline

2 Pb/night



Foreground Removal in the Epoch of Reionisation

Dr Emma Chapman

@DrEOChapman
e.chapman@imperial.ac.uk
dremmachapman.wordpress.com

Thank you

Imperial College London

Royal Astronomical Society

LOFAR

SKA
SQUARE KILOMETRE ARRAY