MURCHISON WIDEFIELD ARRAY

STEPS TOWARDS OBSERVING THE EPOCH OF RE-IONIZATION

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View from Earth: cosmic radio background from cosmological evolution in gas and galaxies

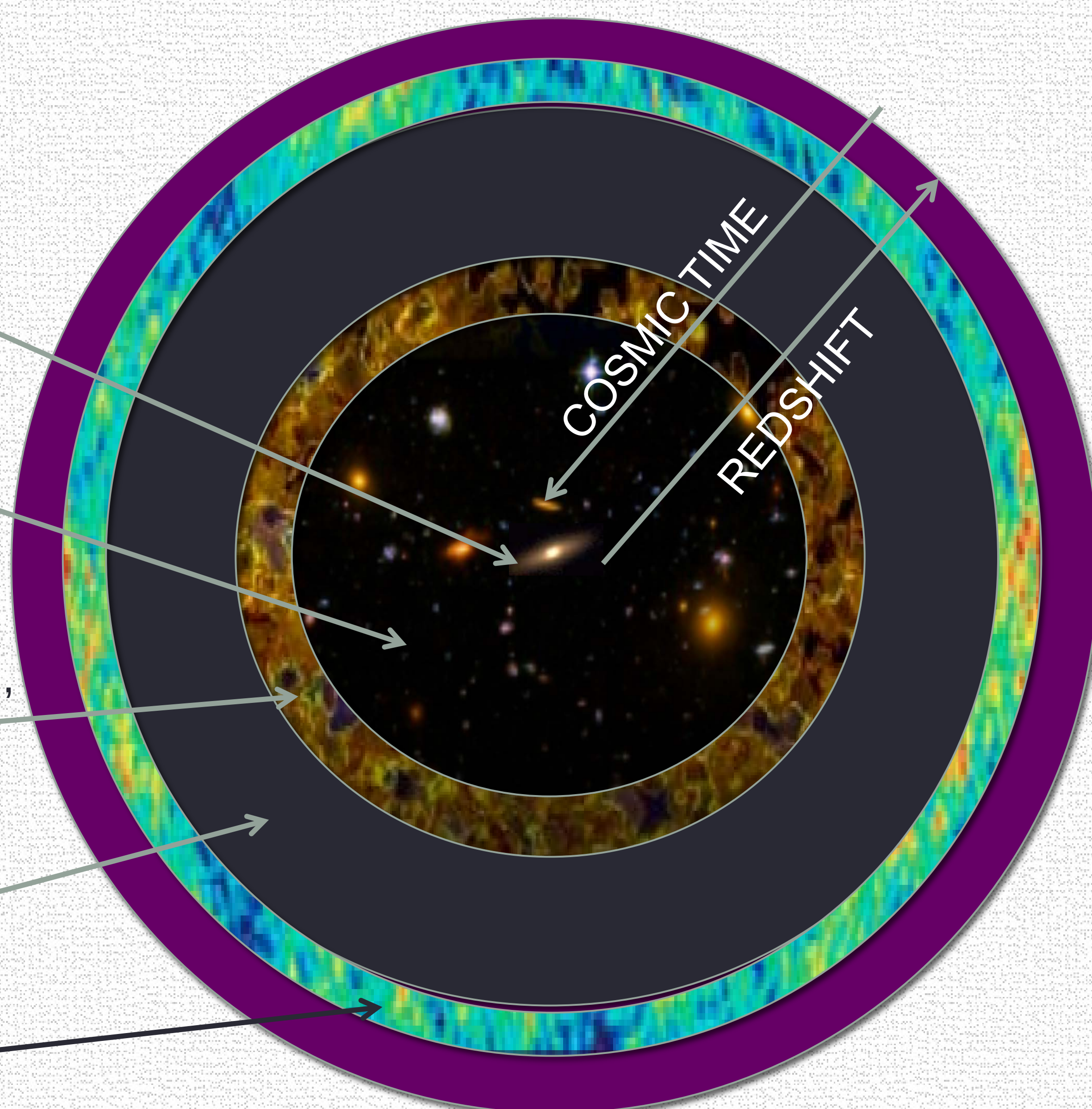
Galactic foreground:
Synchrotron, thermal
(z ~ 0)

Discrete radio sources:
Evolving galaxies, AGNs
(z ~ 0-7)

21-cm from the cosmic dawn, re-ionization
(z ~ 6-15)

21-cm from the dark ages
(z ~ 15-150)

CMB from recombination
(z ~ 1090)

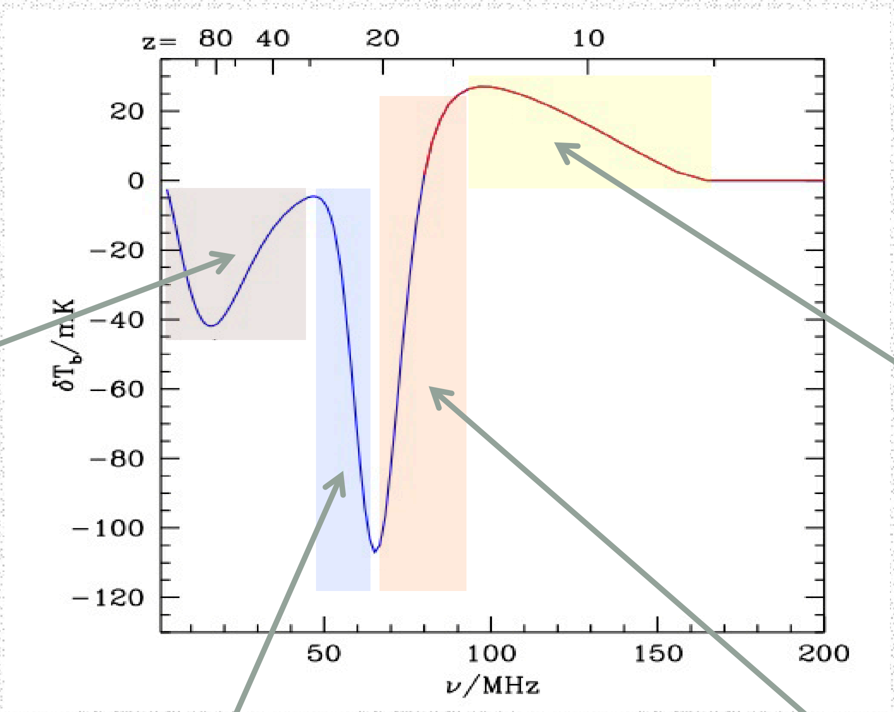


A ‘standard model’ for the history of the gas

Dark ages – cosmic dawn – reionization

Spin temp couples to the low gas kinetic temp when gas densities are high

Subsequently, with cosmological expansion, the spin temp couples to the CMB radiation temp

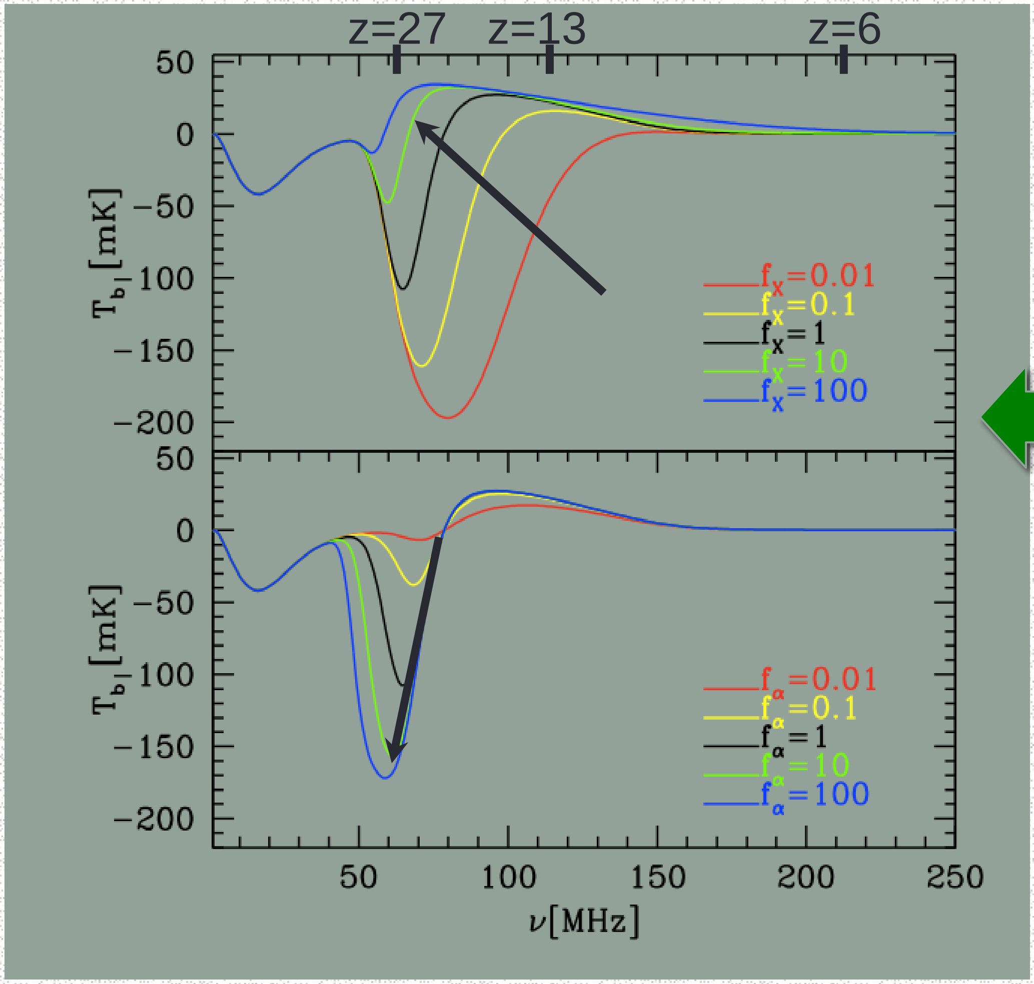


Re-ionization by UV from star formation in the first ultra dwarf galaxies.

Lyman-α from the first stars scatters off the HI gas coupling spin temp to gas kinetic once again! [Wouthuysen 1952; Field 1959]

UV from first stars/ultra-dwarf galaxies & X-ray heating from accretion onto the first black holes: raise the spin temp and turn the gas from absorption to emission

Detailed spectral structure depends on



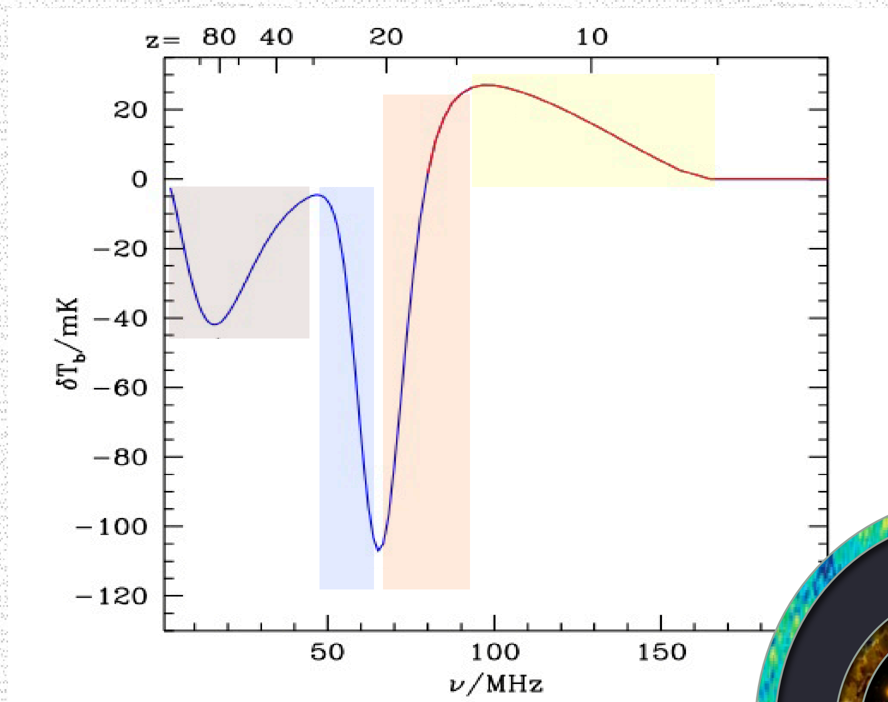
[Pritchard & Loeb 2010]

- Timings
- UV, X-ray spectra of the first ultra-dwarf galaxies, accretion sources
- X-ray and Lyman-α luminosities fx & fα
- Their abundance and distribution

Non-standard models:

- DM decay
- Primordial magnetic fields

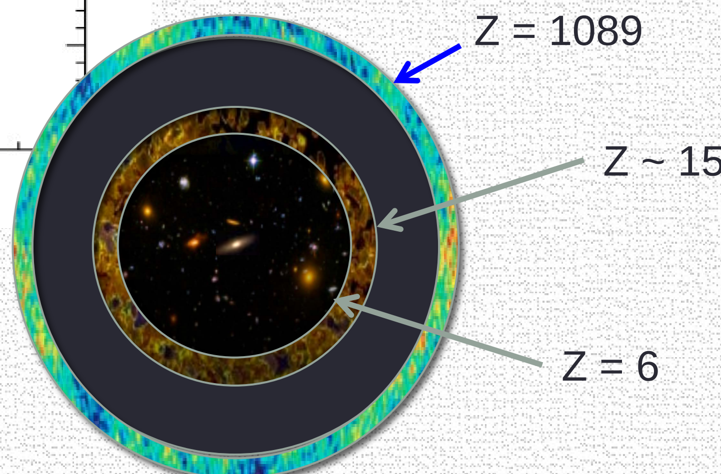
Cosmic dawn – first light – re-ionization
A spectral 'distortion' in the CMB backlight



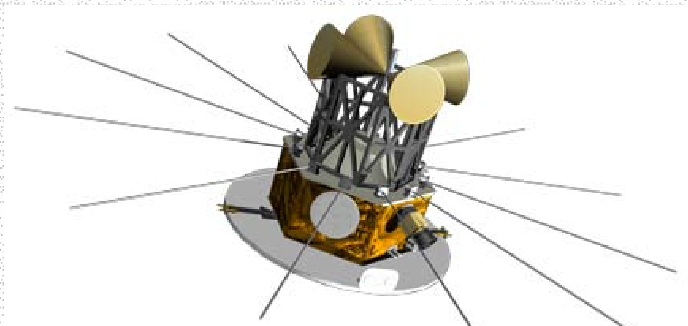
The cosmological history of the gas has its signature in the spectrum of the CRB = cosmic radio background

An 'all-sky' distortion in the CMB backlight

To which is added the foregrounds from discrete and diffuse extragalactic and Galactic radio emission



Detecting the cosmic dawn:
Entering the era of precision cosmology at long wavelengths!



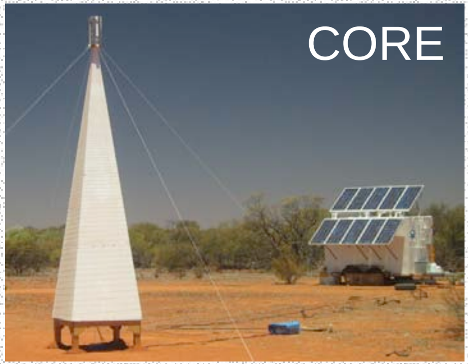
DARE [Burns et al 2011]

10-100 mK features with frequency structure spanning octave bandwidths

Added to 100-1000 K foregrounds that themselves have low-order spectral structure – if only because the wide beams average over power-law spectra

Design of antenna elements and analog and digital receivers with extremely flat spectral response to the CRB

[Chippendale 2009]



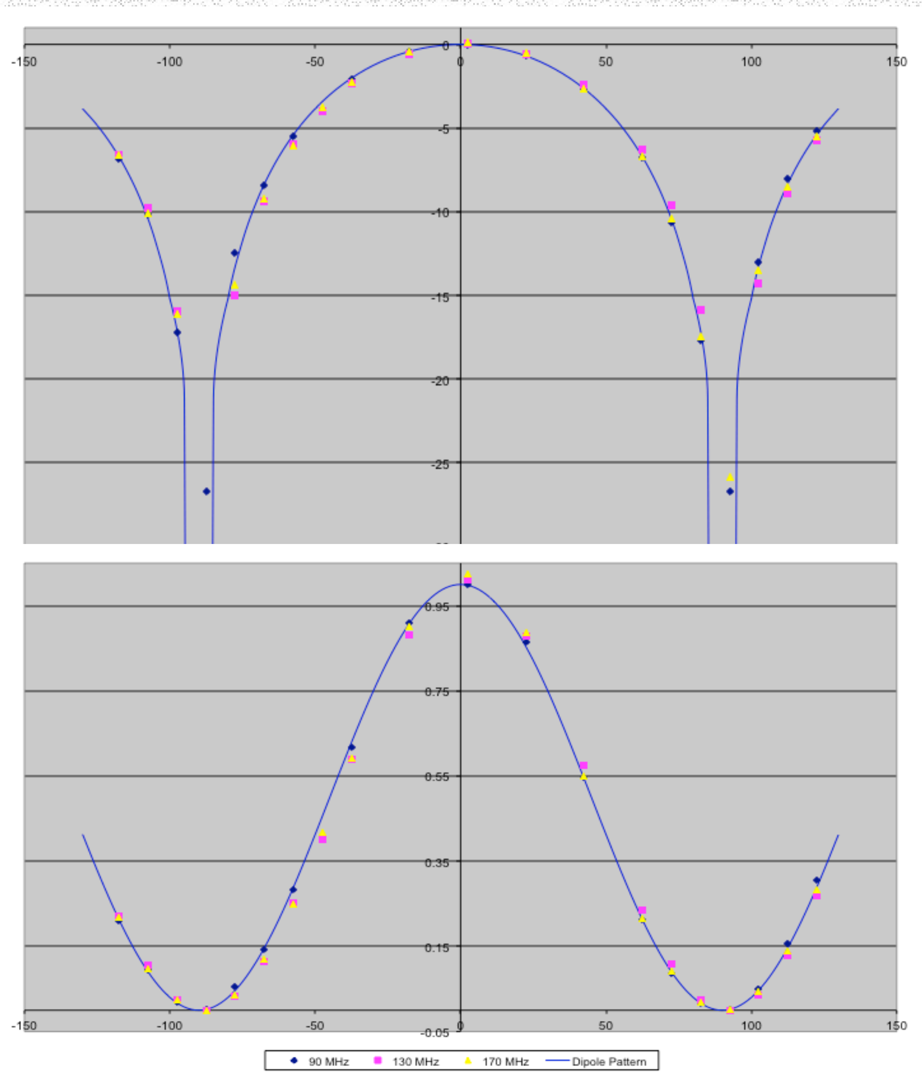
[Bowman & Rogers 2010]

Zero-spacing interferometer!

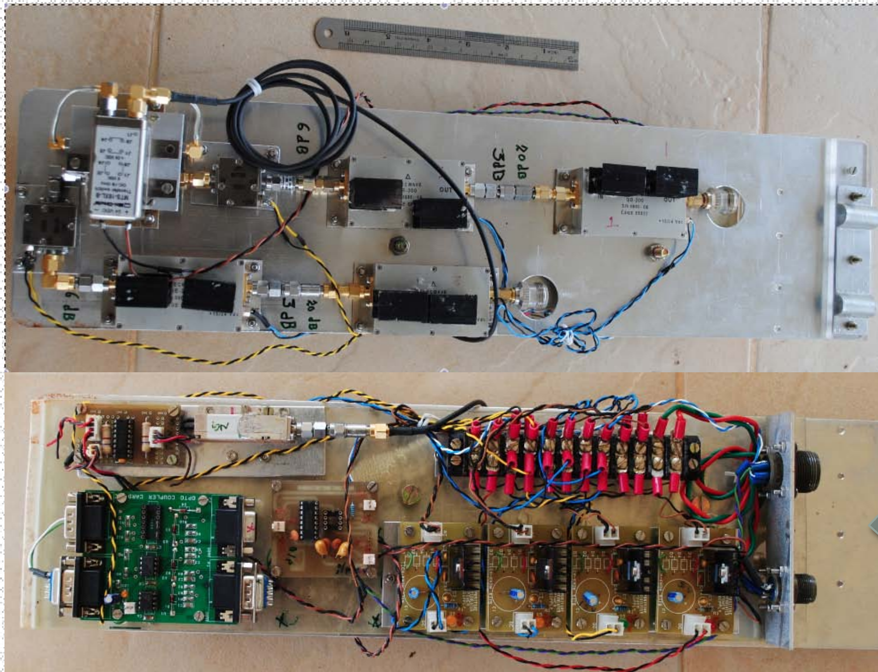
The SARAS experiment
Shaped Antenna measurement of the background RAdio Spectrum

The Antenna

Fat-dipole
$(\text{Sine})^n$ profile
Square cross-section
Made with aluminum sheet metal
1:1 transformer serves as a balun

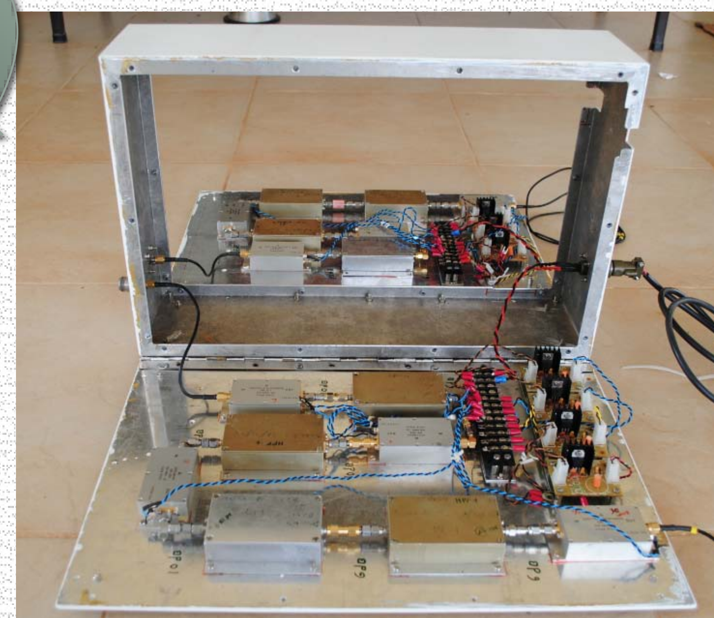


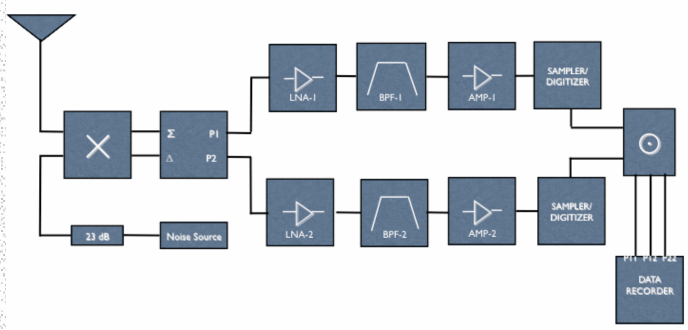
Reconfigurable analog receiver



Effort on understanding propagations paths for noise power from the sky, reference load & receivers.

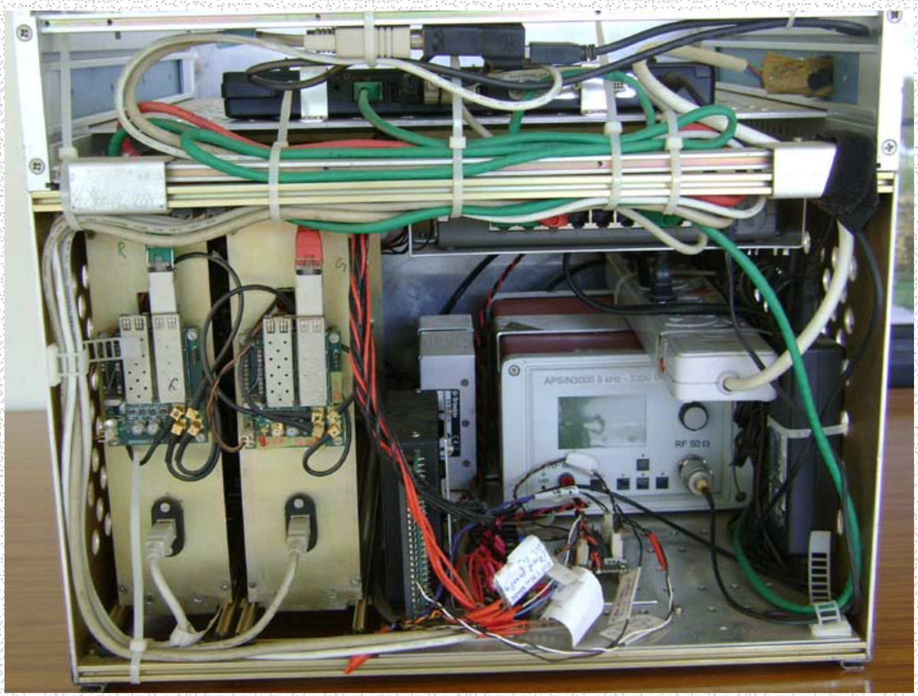
Multi-path propagation with mutiple reflections that results in a spectrum of pass-band ripples.



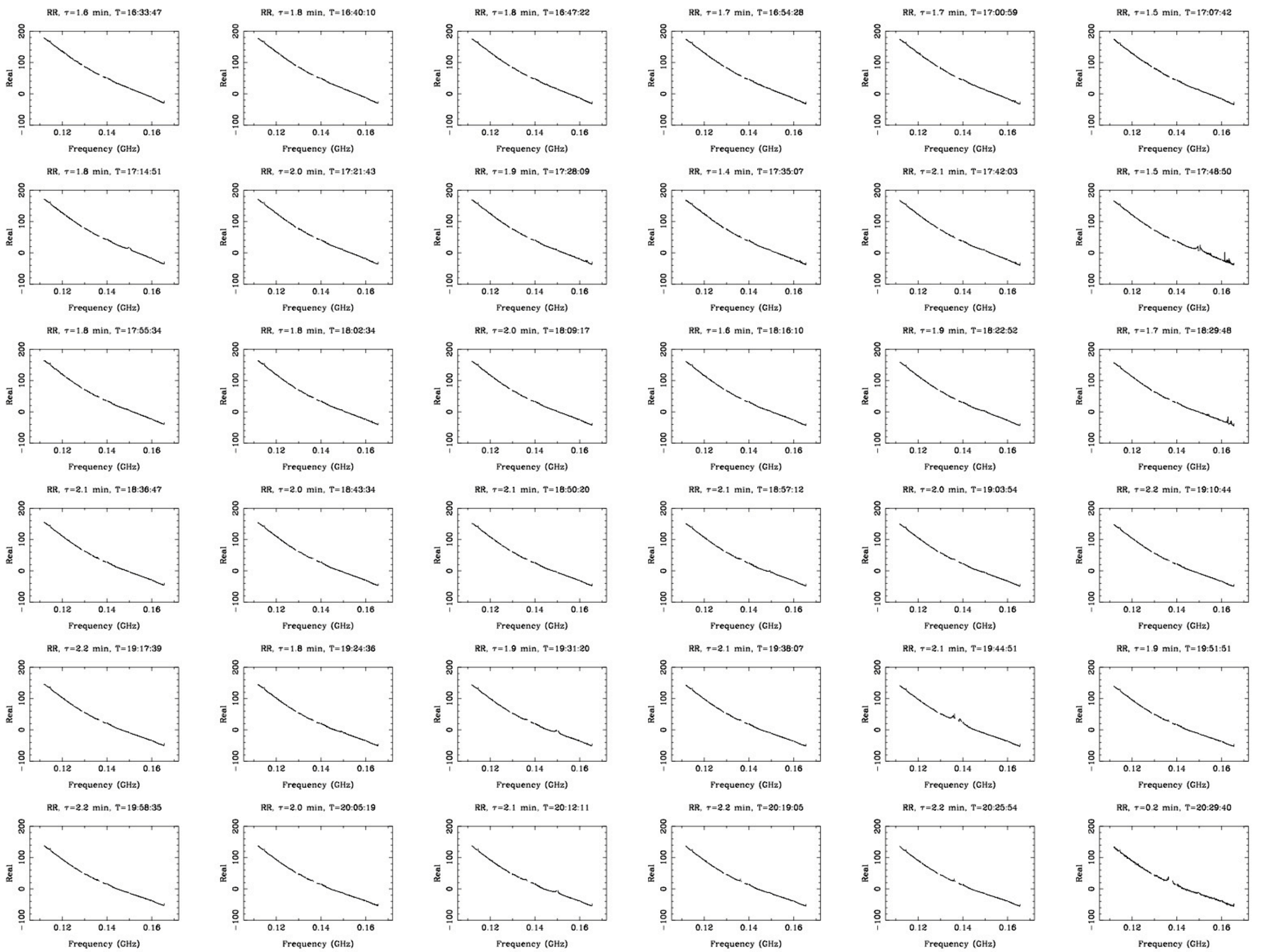


Digital receiver

- Virtex-5 FPGA based cross-correlation spectrometers
- Synthesizer for digital clock, locked to a
- GPS disciplined oscillator
- Digital i/o for switching waveforms
- Laptop with solid state drive on a docking station
- Heat exchangers

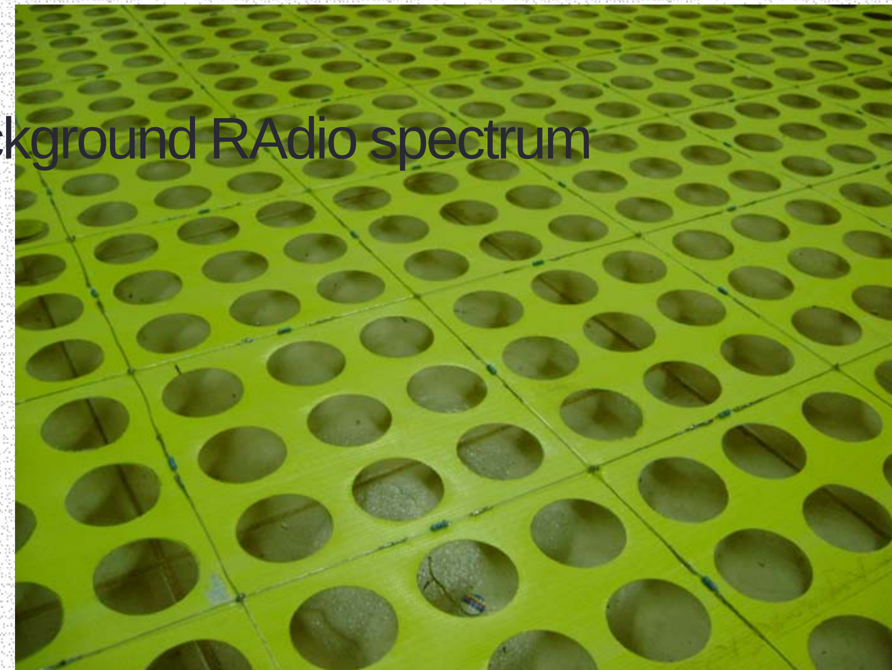


Spectra of the Cosmic Radio Background



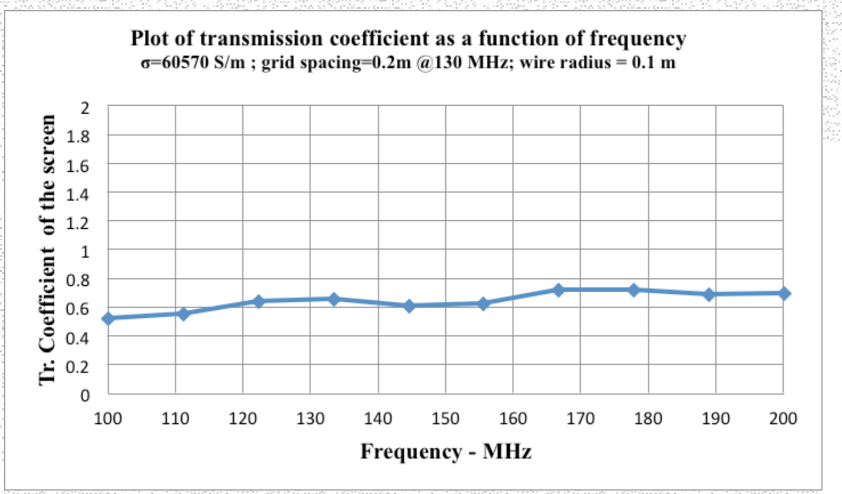
The ZEBRA experiment

ZEro-spacing measurement of the Background RAdio spectrum

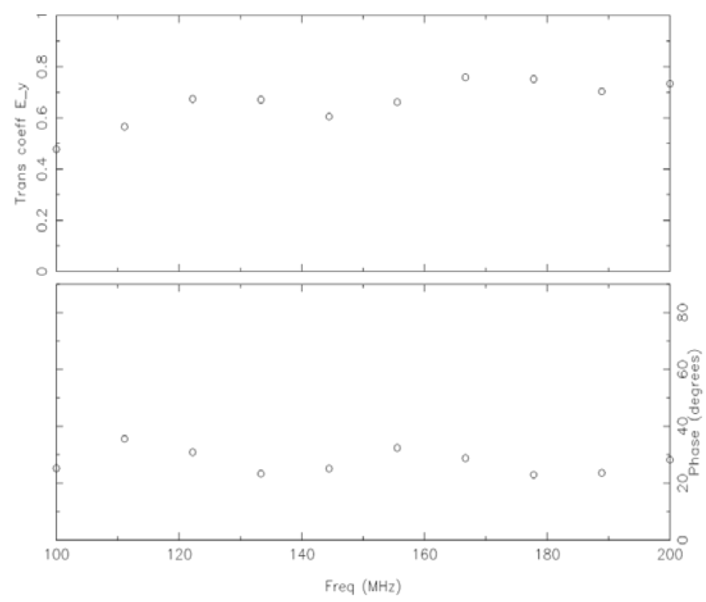


Transmission amplitude and phase for finite screen

Predictions based on WIPL-D model vs



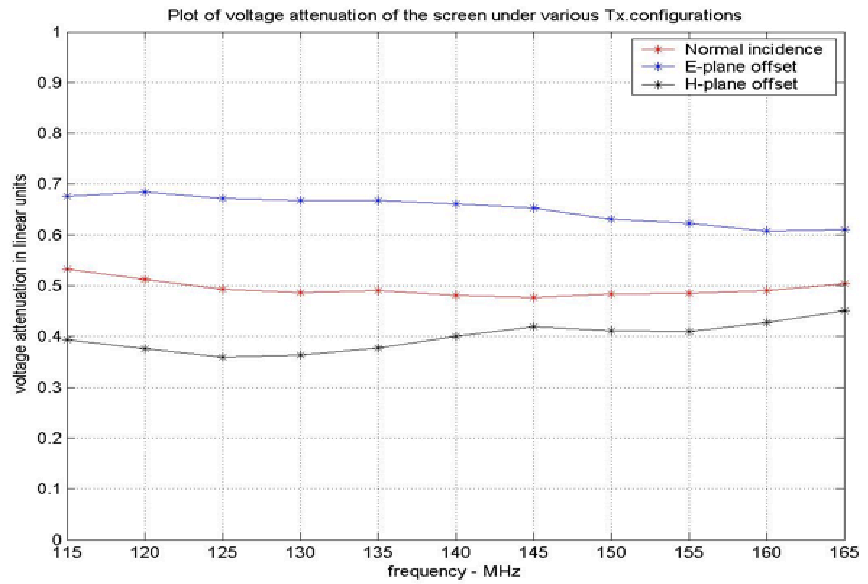
Predictions from analytic formulation of transmission thro’ a mesh plus physical optics

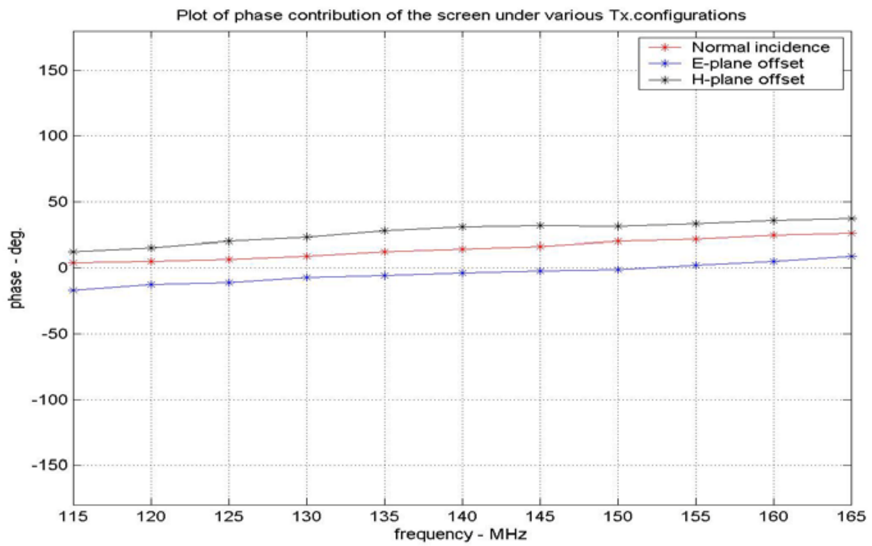


Measurements of propagation
Amplitude & phase through
the resistive mesh

For normal and oblique incidence

Measurements of
E and H plane fields





Murchison wide-field array (MWA)

MWA is an SKA-Low precursor array located at the Australian SKA site.

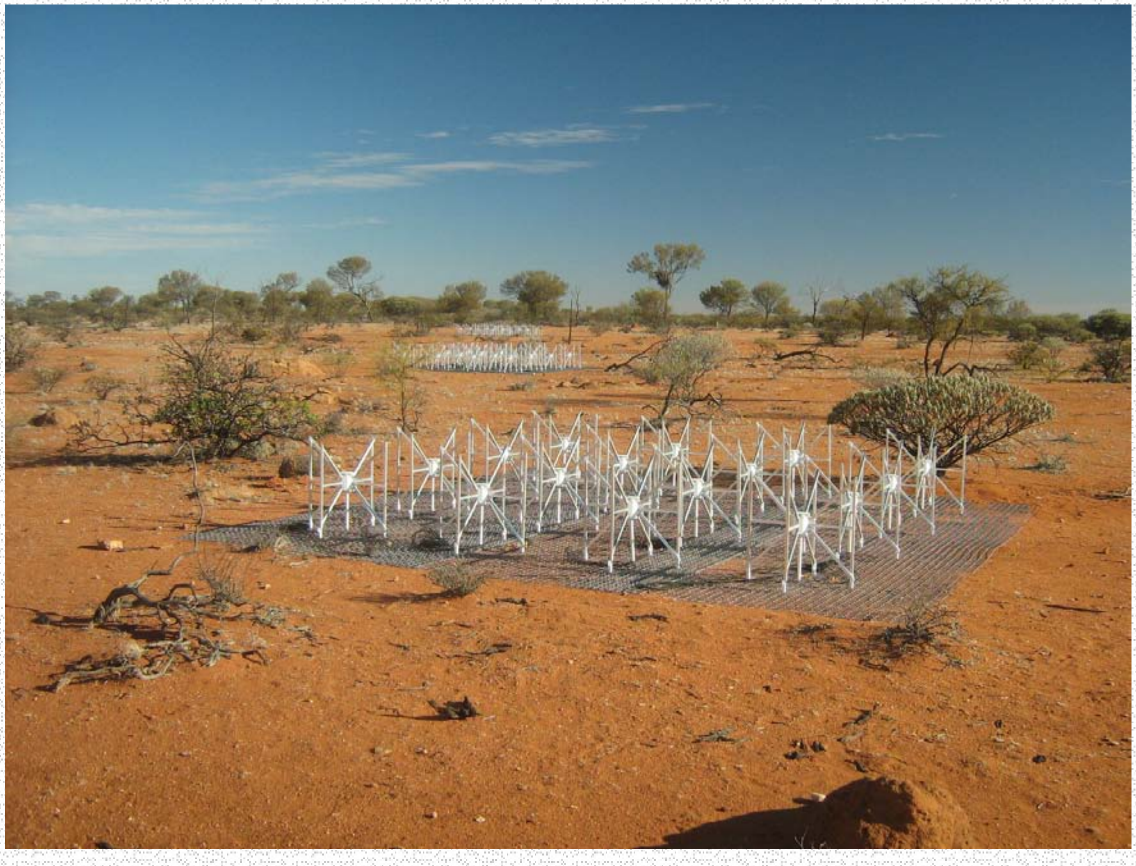
MWA is an international partnership between the US, Australia, New Zealand and the Raman Research Institute, India.

MIT Haystack observatory
MIT Kavli Institute
Harvard University - CfA
University of Washington

CSIRO-CASS
Australian National University
Curtin University
University Western Australia
University of Melbourne

Victoria University

Raman Research Institute

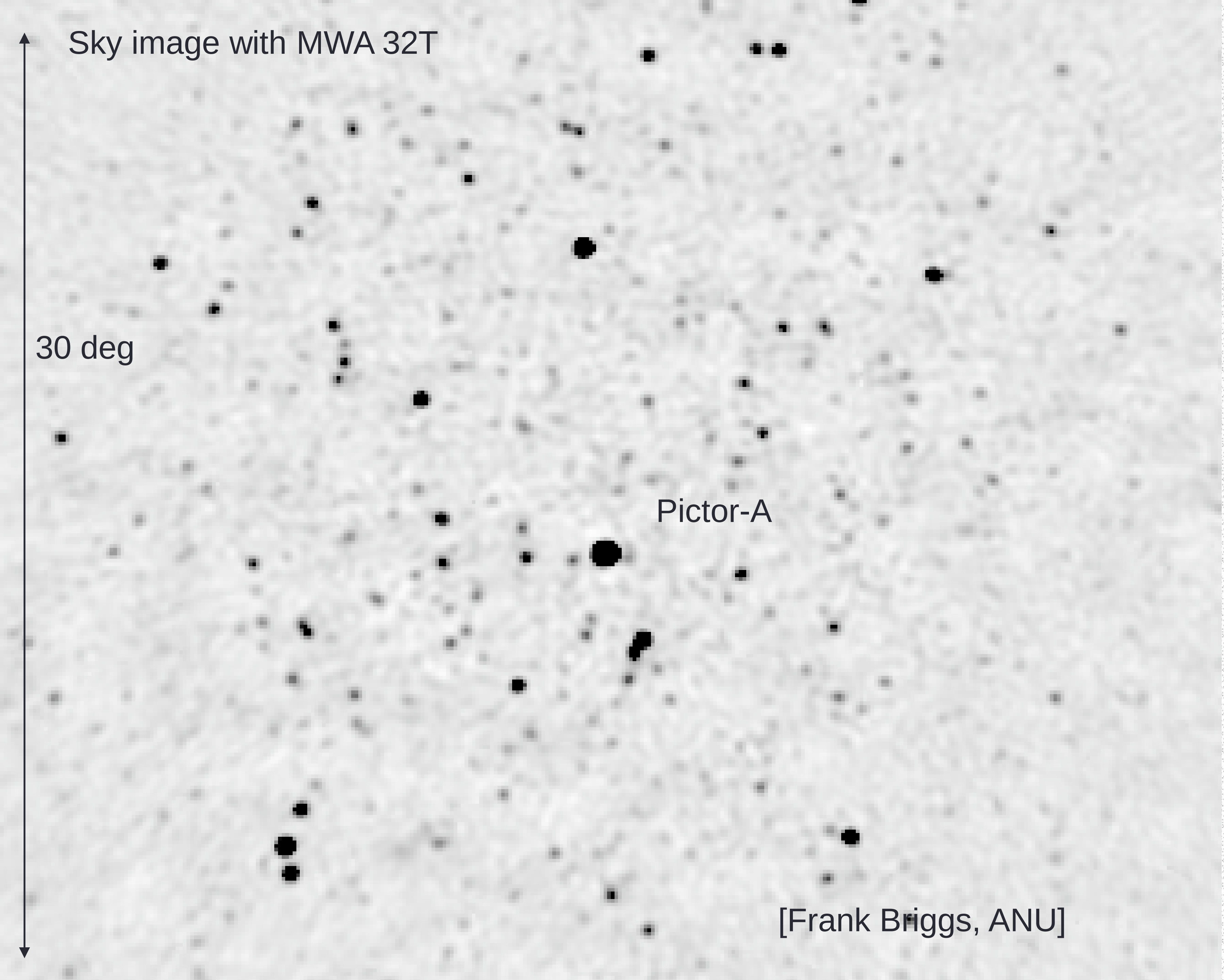


The System

- 128 'tiles' – each tile is a 4x4 array of wide-band bow-tie antennas
- Spread in a 2D array configuration over 1.5 km diameter area
- 32 MHz instantaneous band selectable in the 80-330 MHz range
- Each tile is followed by an analog beam-former
- 8 beam-formers feed 16 coax into a 16-input digital receiver
- Fibers from digital receiver to central GPU based correlator

Yesterday: 32-tiles on the ground

Operating as a 32T interferometer array for early science and systems and software development


Sky image with MWA 32T
30 deg
Pictor-A
[Frank Briggs, ANU]

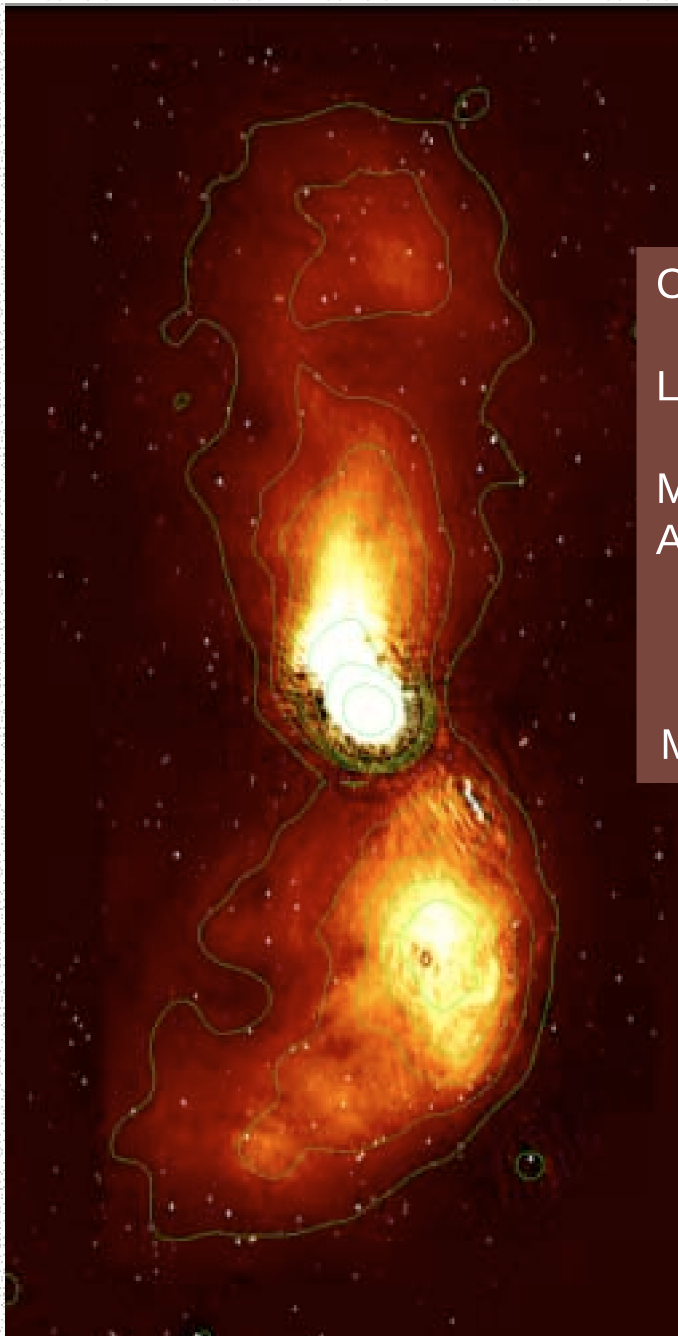
Centaurus-A

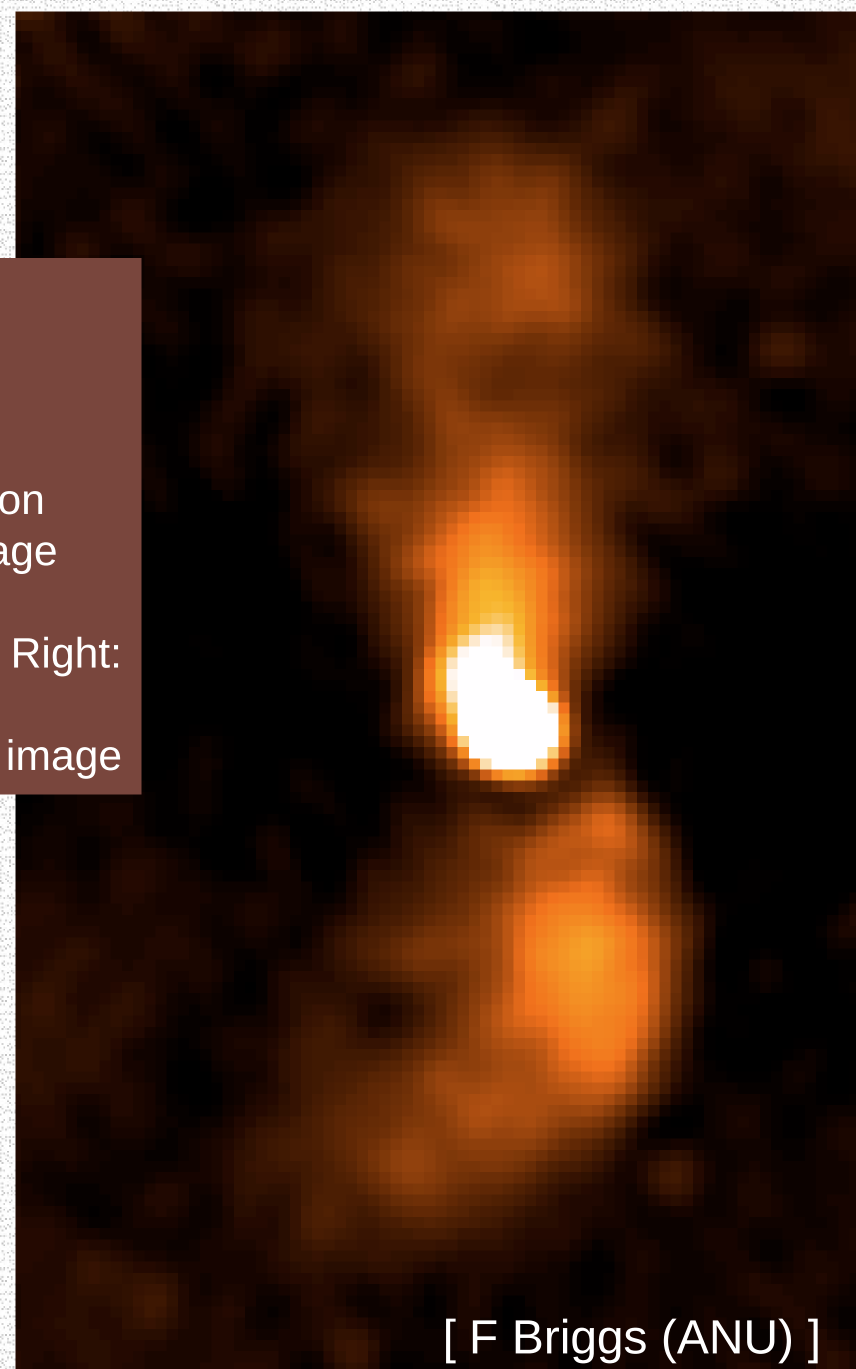
Left:

MWA contours on ATCA+PKS image

Right:

MWA 115 MHz image



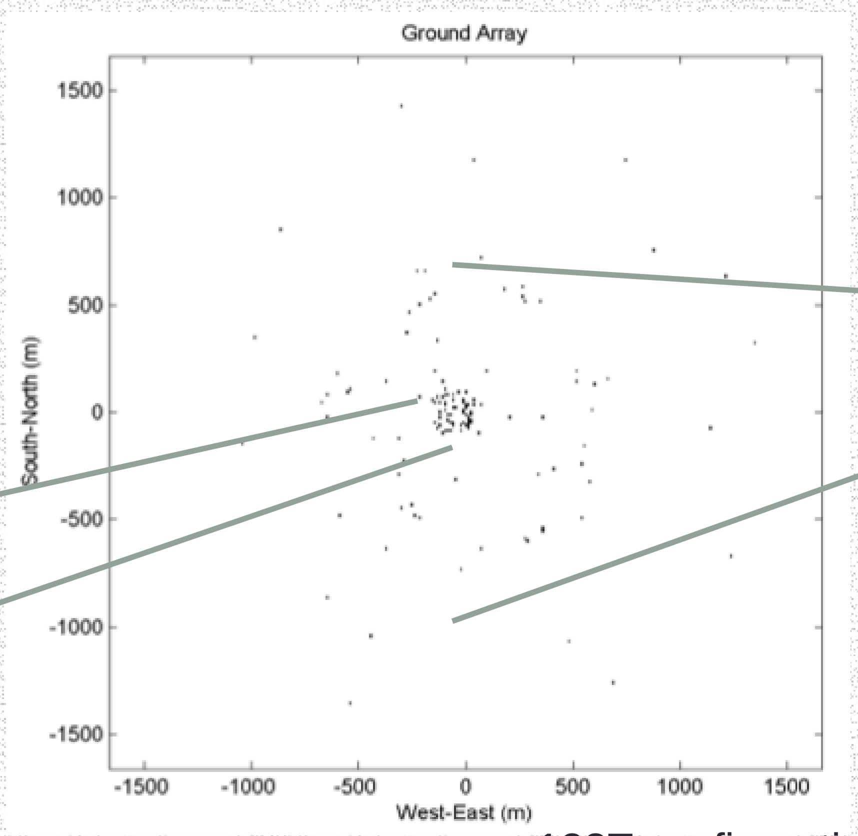


[F Briggs (ANU)]

Tomorrow: 128T – compact array plus outliers

Completion of installation and start of commissioning in late 2012

Observing for EoR in 2013



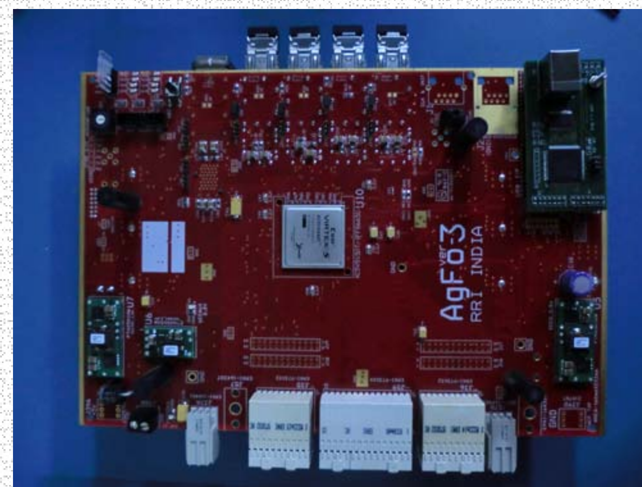
50 tiles in a core with baselines out to 100 m

50 + 60 tiles with baselines out to 750 m

Plus 16 outlier tiles

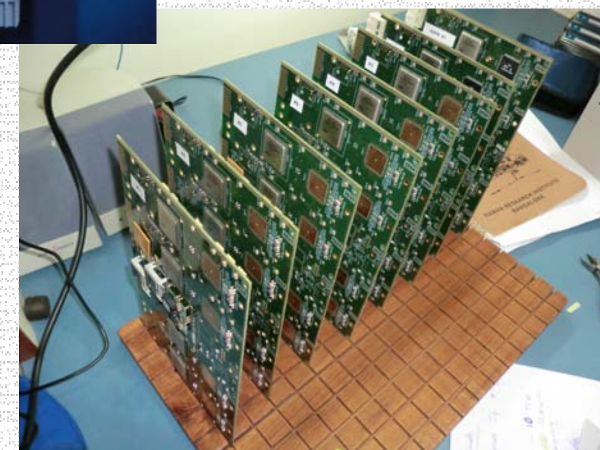
128T configuration study: A. Beardsley

MWA Digital receivers
made in the
Radio Astronomy Lab, RRI, India

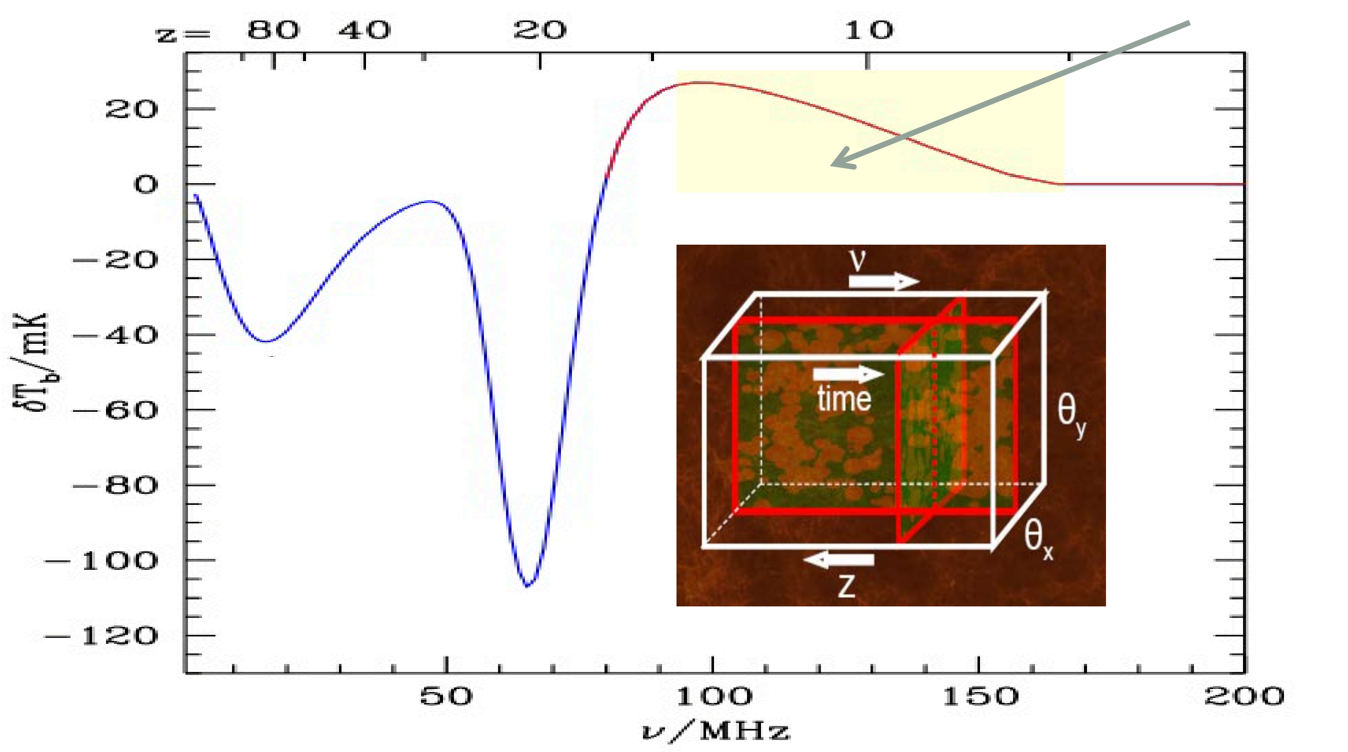


Operates on 80-330 MHz analog
signals from 8T beamformers

Based on Virtex-5 FPGAs



Key science: imaging the epoch of re-ionization



Sky images stacked in frequency:

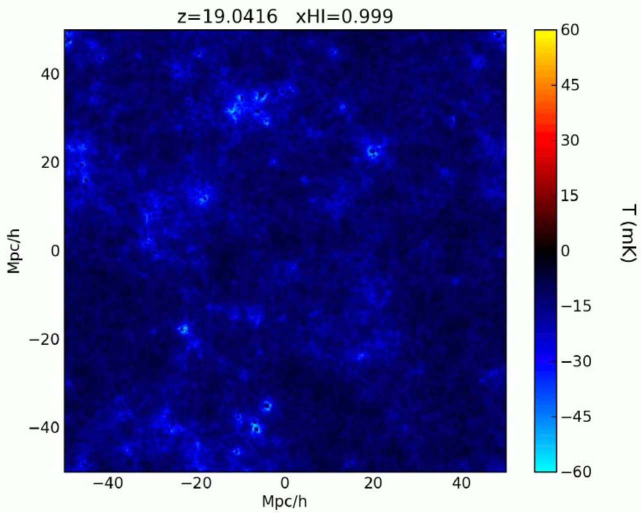
Represents the HI distribution in spatial & cosmic time/redshift space.

ΔT_b depends on

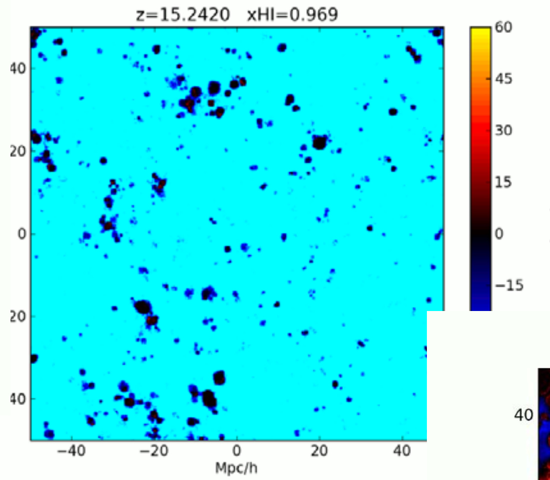
- x_{HI} neutral fraction
- δ_b over-density in gas

The observable is the differential red-shifted 21-cm intensity

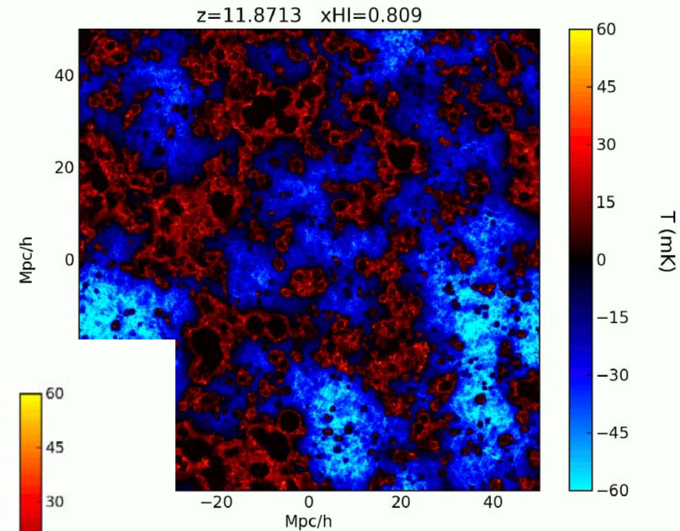
$$T_b = 27 x_{\rm HI} \left(\frac{T_S - T_\gamma}{T_S}\right)\left(\frac{1+z}{10}\right)^{1/2} \times (1+\delta_b)\left[\frac{\partial_r v_r}{(1+z)H(z)}\right]^{-1} \text{mK}$$



Z=15



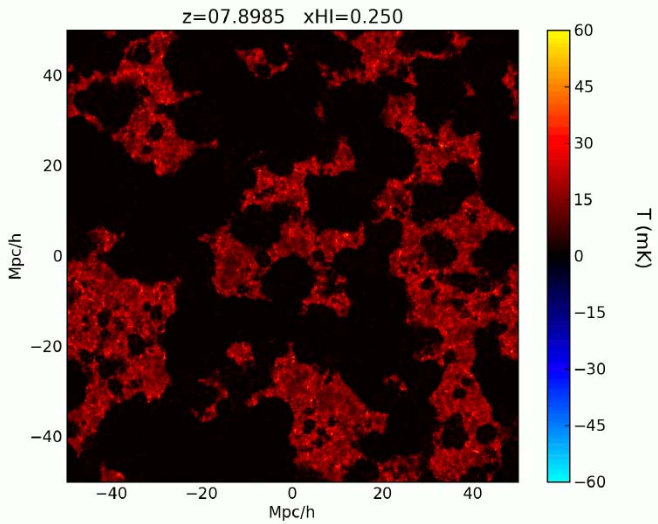
Z=12

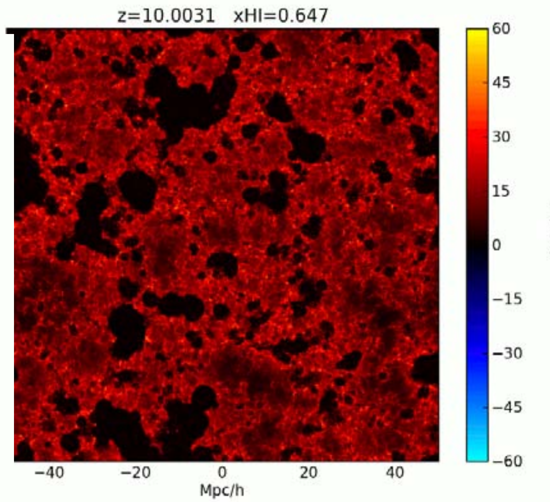


Z=19

Evolution in the sky brightness fluctuations with observing frequency = redshift

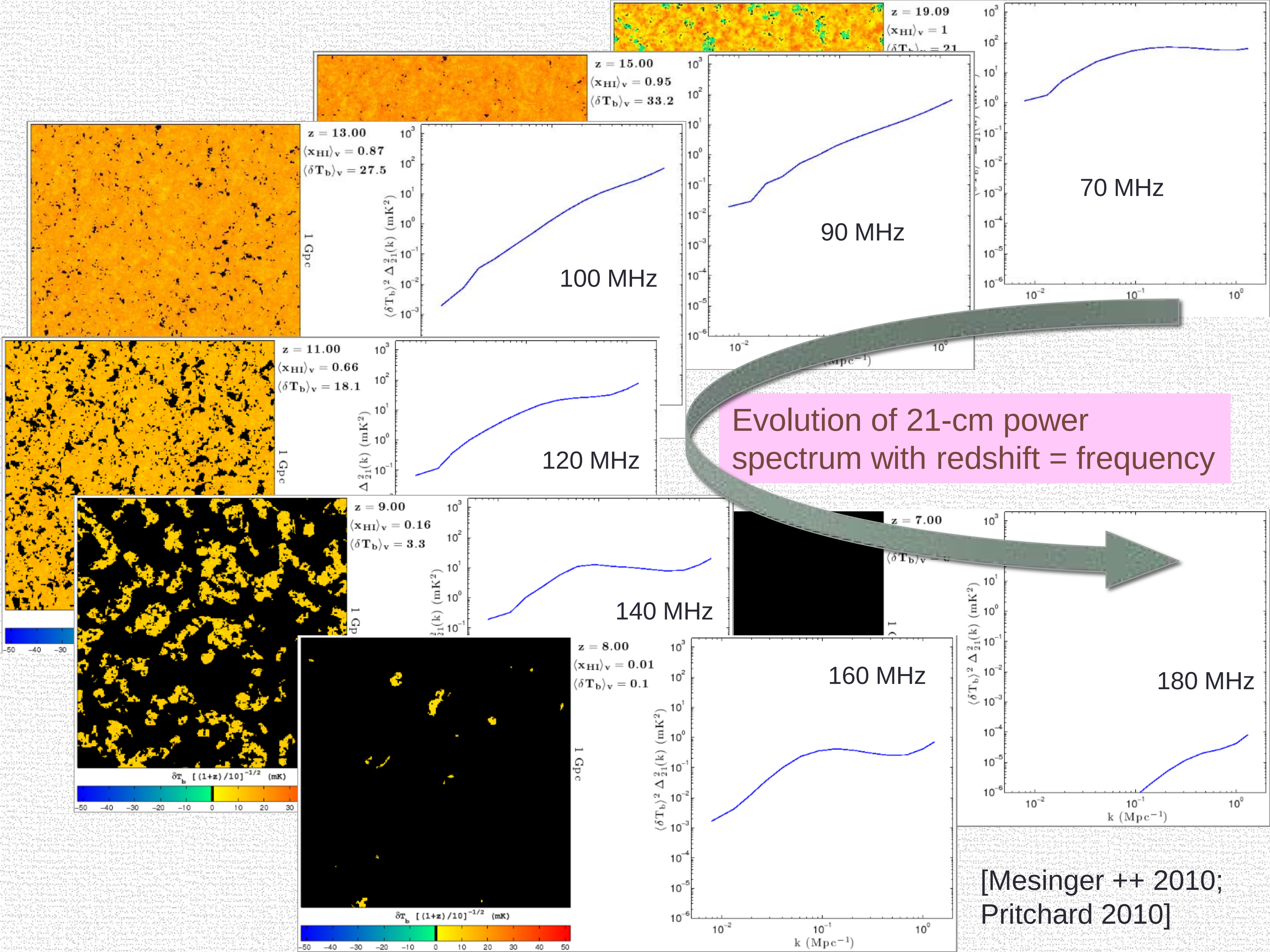
Z=8





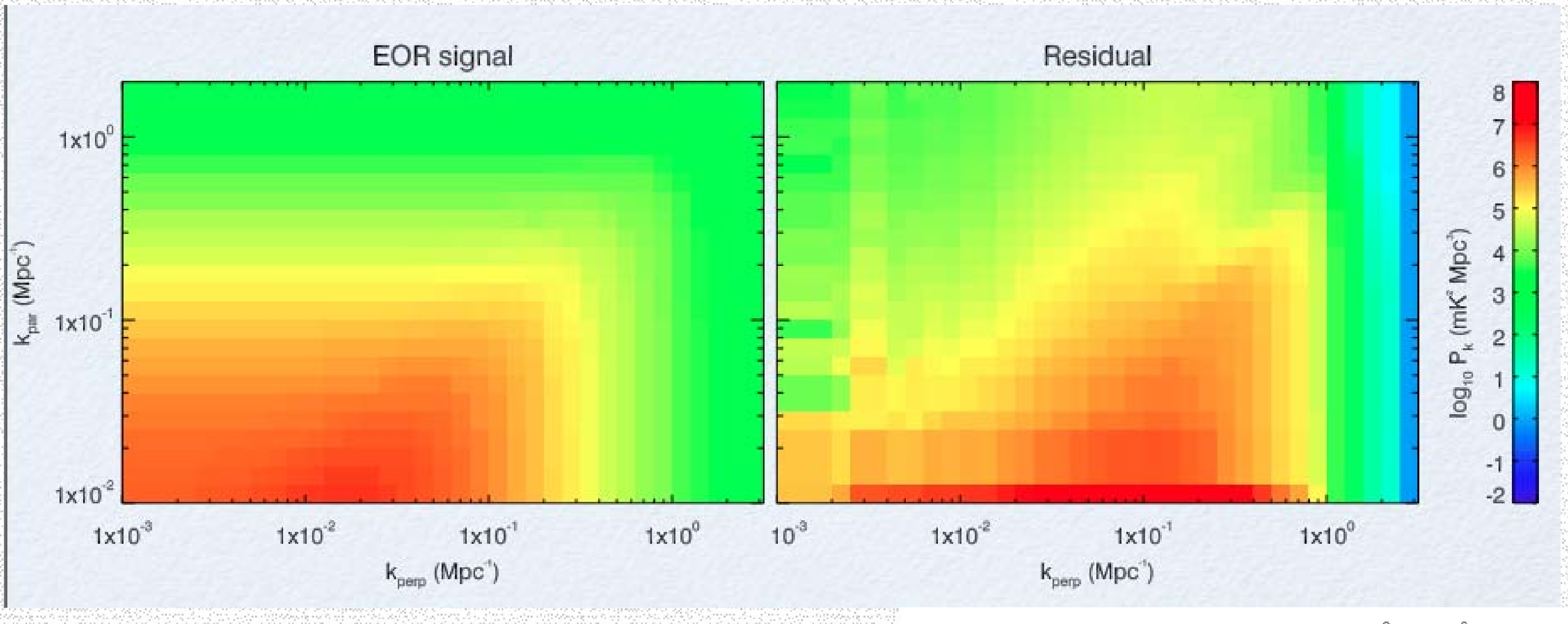
Z=10

[Pritchard 2010]



[Mesinger ++ 2010;
Pritchard 2010]

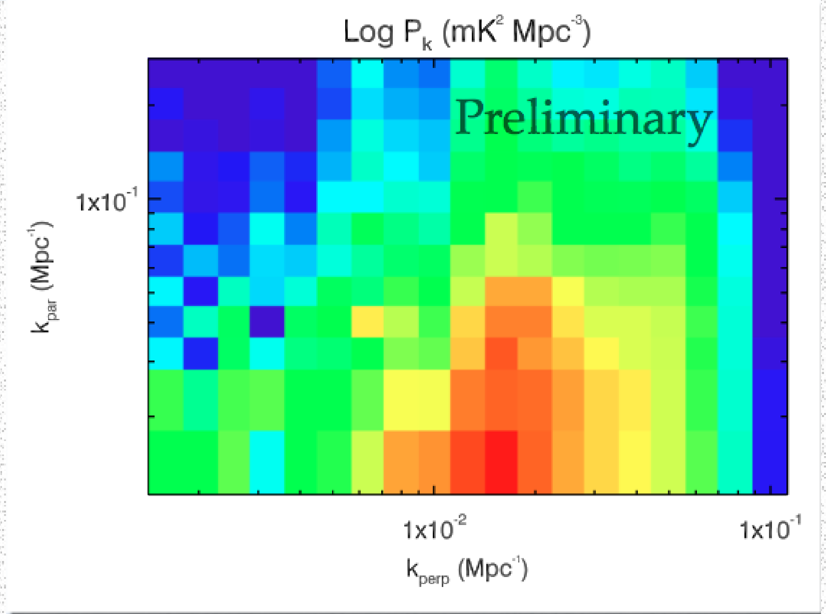
EoR power spectrum: distribution in k-space



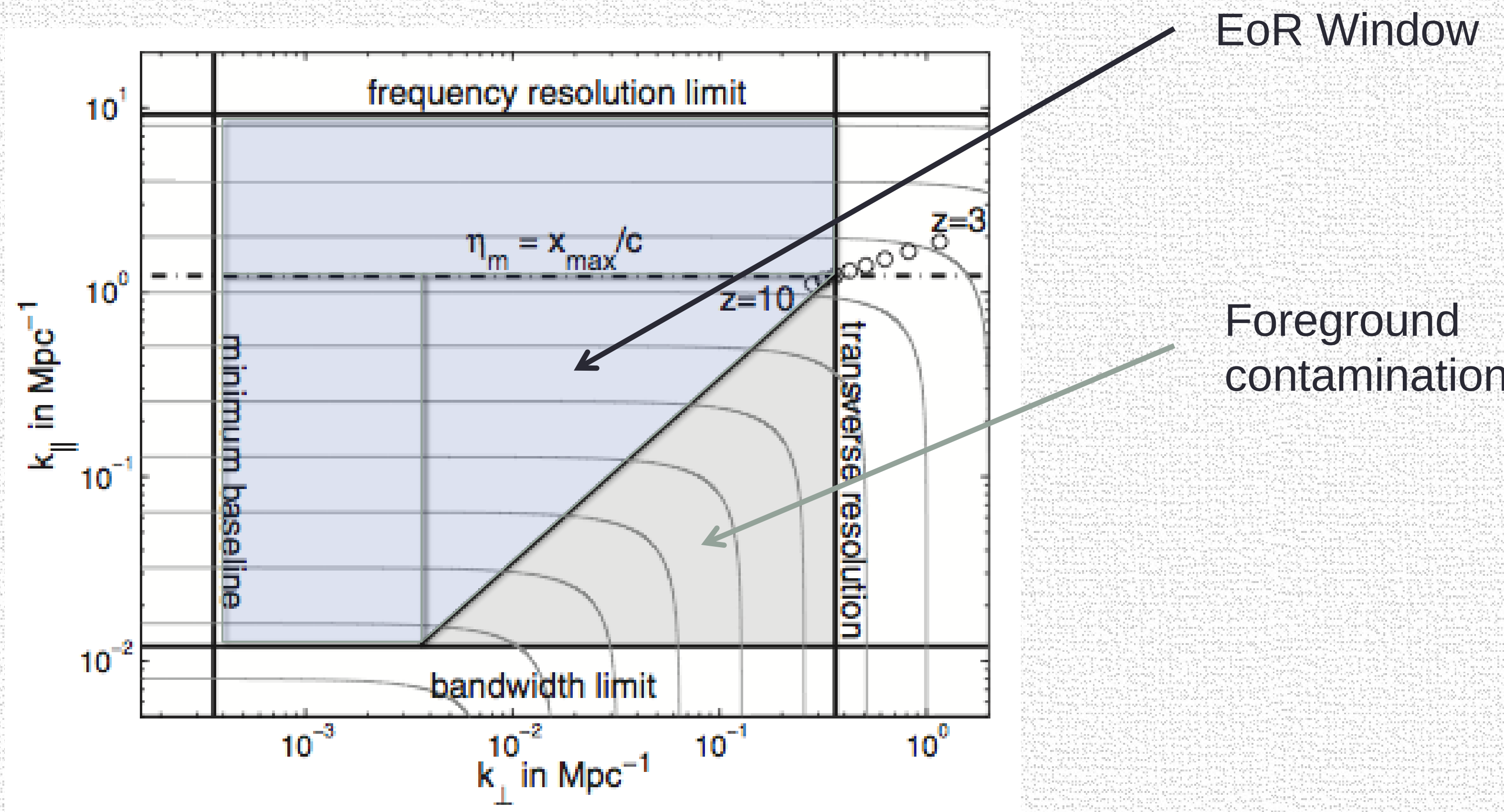
Expectations for the distribution of EoR power in k-space; along with expectations for residual continuum confusion

MWA EoR field: first look at the distribution of continuum confusion

[Morales ++ 2012]



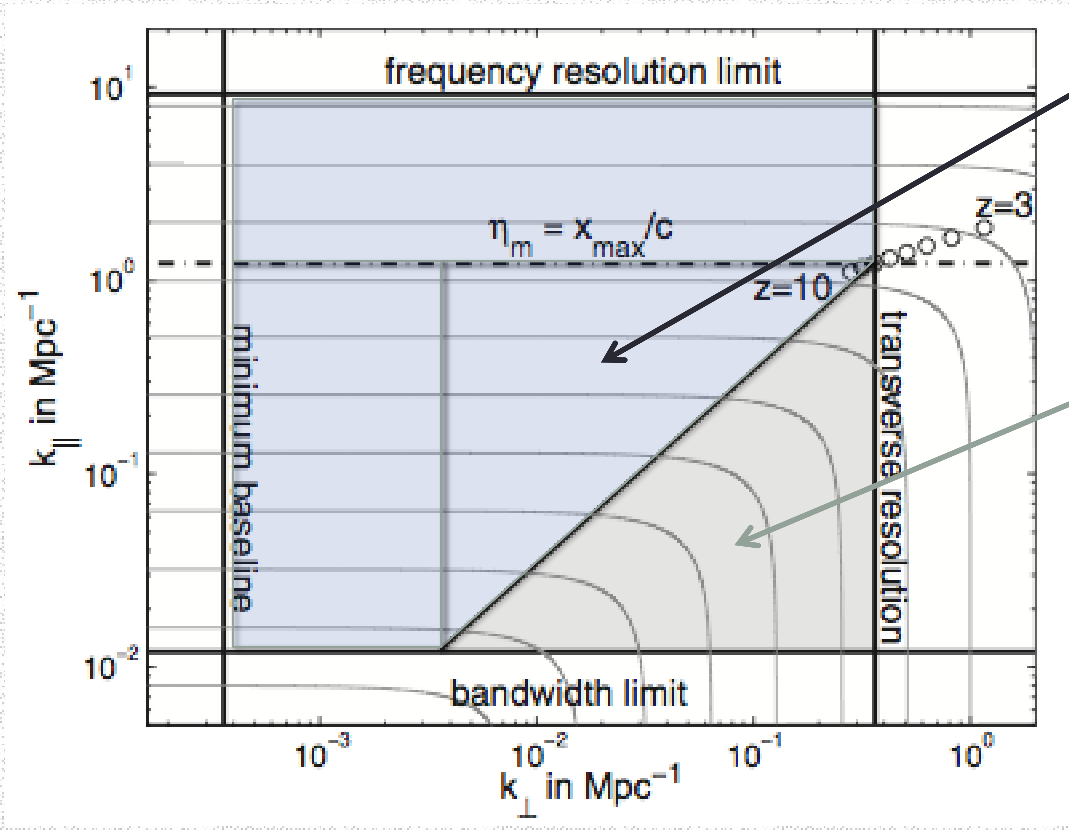
‘EoR window’ in k-space



Reduce foreground contamination

- By shaping the tile beam pattern
- By having close to complete u,v coverage
- By shaping the synthetic beam pattern
- By subtracting sources – particularly those far from boresight

‘EoR window’ in k-space



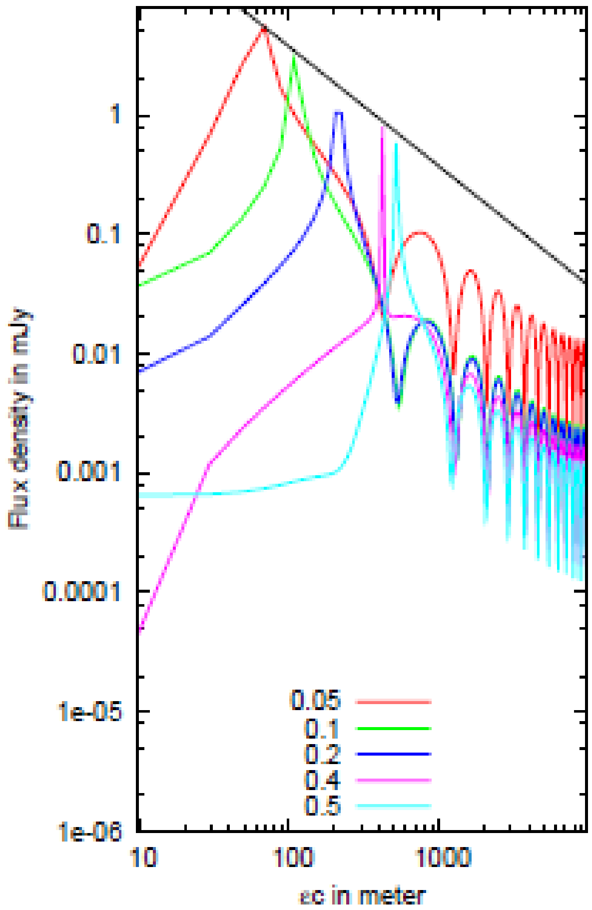
EoR Window

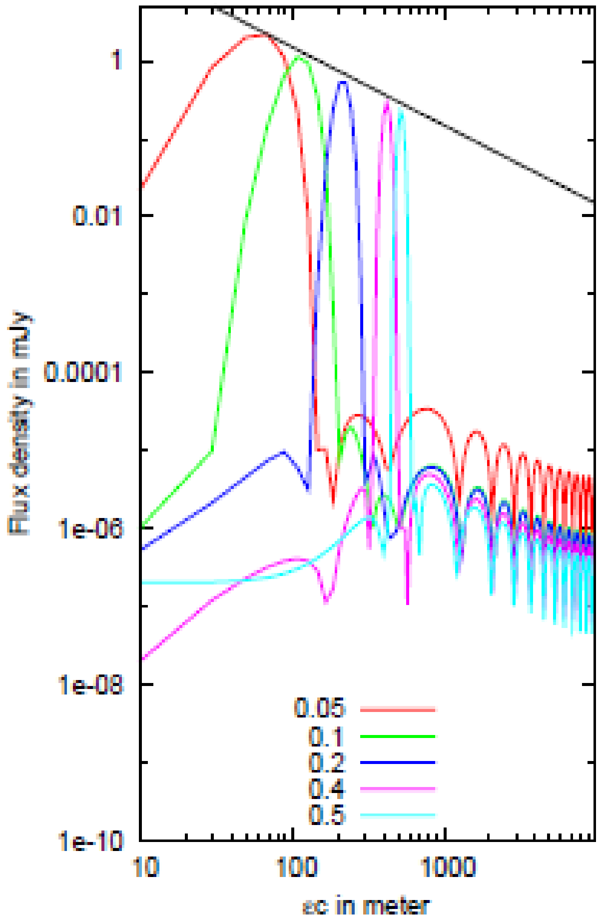
Foreground contamination

Reduce spill over into the EoR window

- By choice of good frequency window
- If imaging is inevitable – grid in meters and use CZT

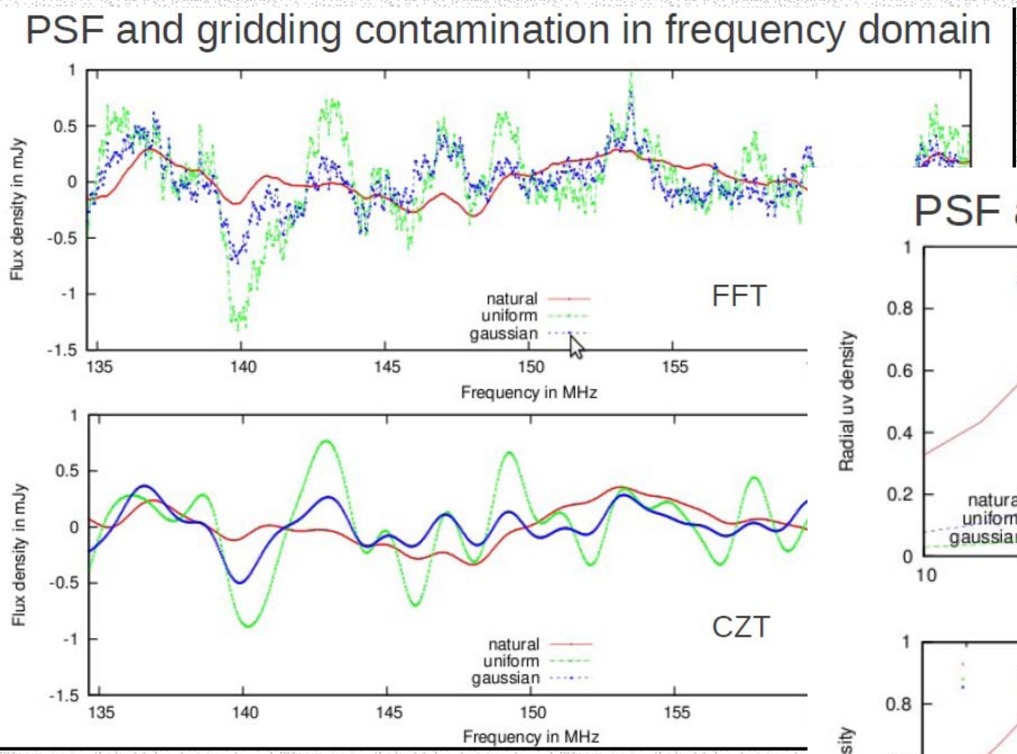
Blackman-Nuttall window to suppress spillover of foreground contamination into the EoR window

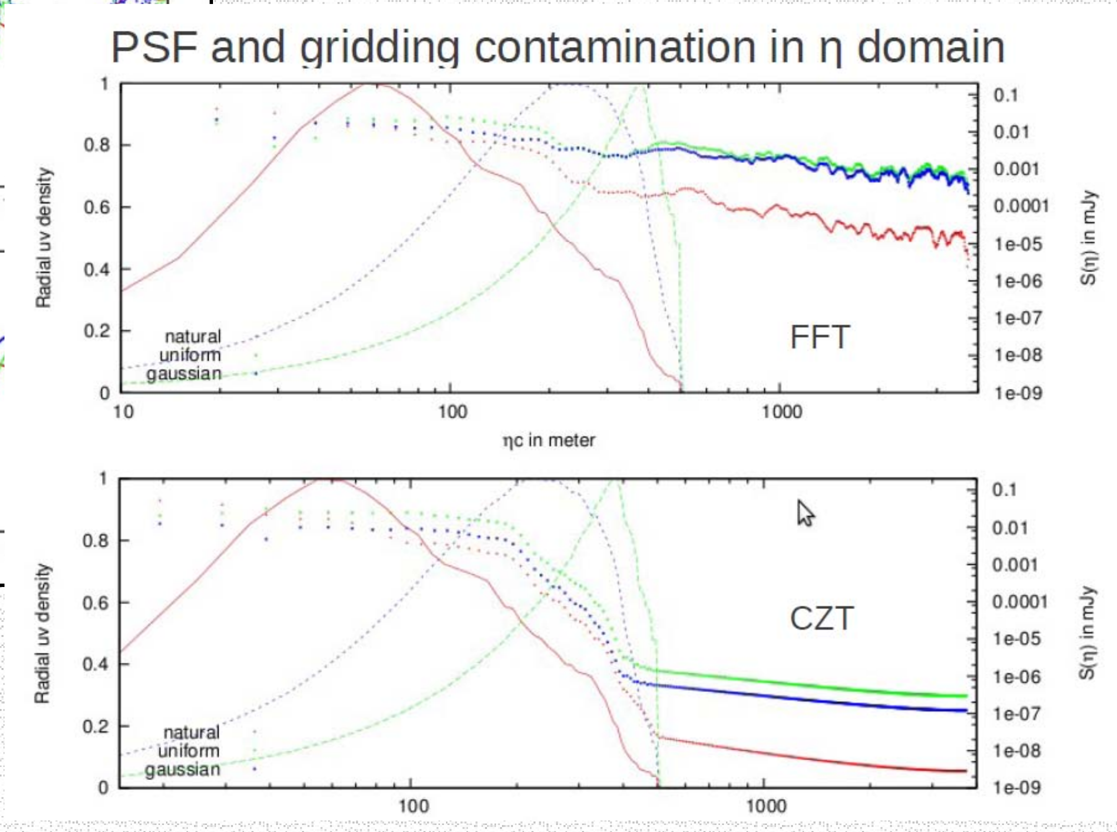




[Vedantham, Udayashankar & RS 2011]

Gridding in u,v + FFT → Gridding in meters + CZT





[Vedantham, Udayashankar & RS 2011]

Summary

- Detecting re-ionization signatures predicted by reasonable models is challenging.
- Foregrounds, RFI & low level RFI, can be show stoppers: need to pay attention to details of foreground models, system design, good site, RFI excision algorithms
- There are many experiments exploring the global signature & the spatial structure in red-shifted 21-cm. They are teaching us a lot about
- MWA can make the first detection of EoR in the next 2-5 years