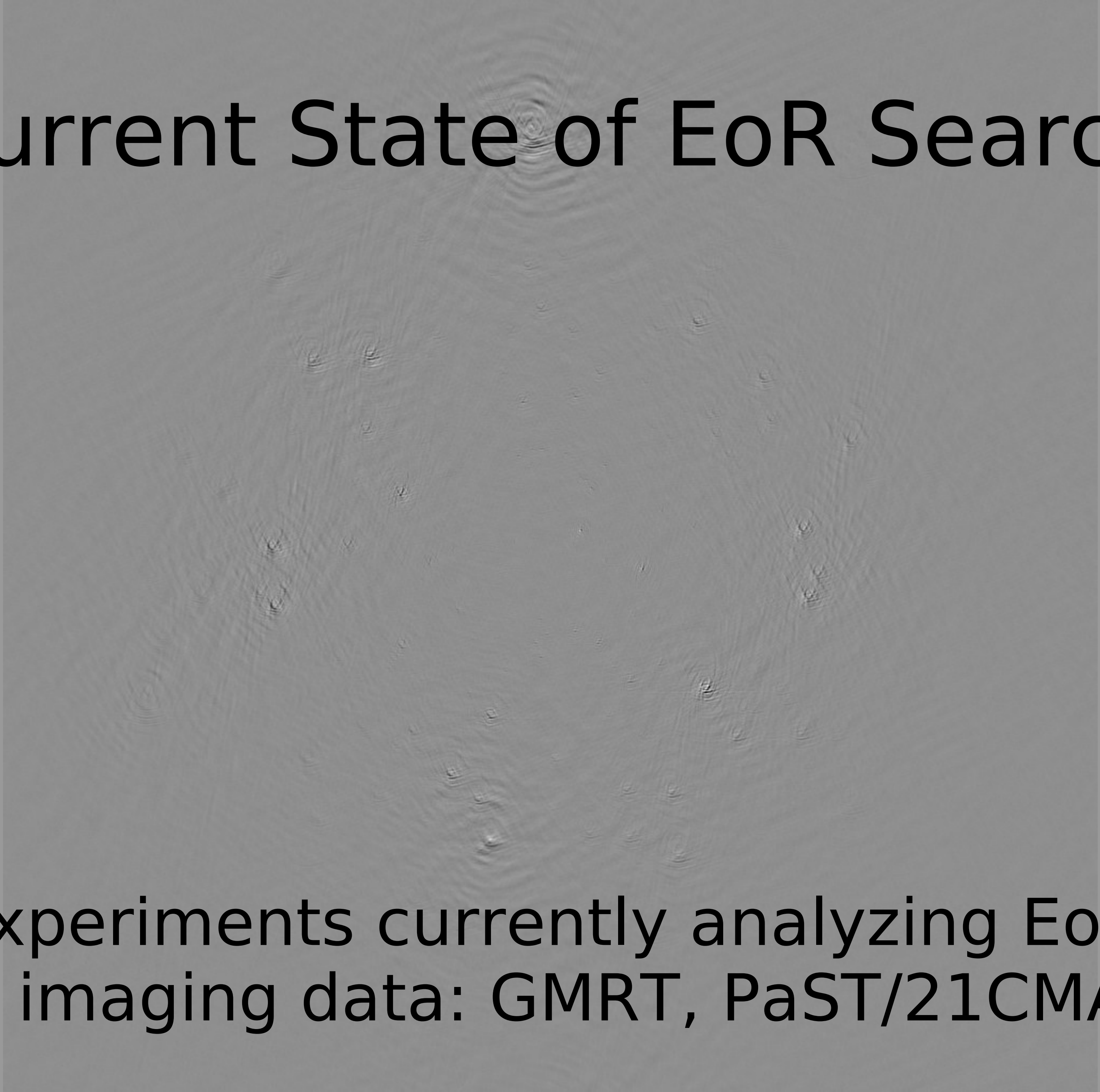
Current State of EoR Search



Experiments currently analyzing EoR imaging data: GMRT, PaST/21CMA

GMRT EoR Project

Collaborators: Y. Gupta (chief scientist), Rajaram Nityananda (director), J. Roy (NCRA), S. Malu, T. Gosht, T Sourandeep (IUCAA), J. Peterson (CMU), C. Hirata (IAS), T. Chang (CITA/IAA), J. Odegova, G. Paciga, J. Sievers, (Toronto), K. Sigurdson (UBC), S. Myers (NRAO)

GMRT

-- 30 dishes@45m aperture: 14 in central 1km square, rest in Y pattern

-- upgraded T_{sys} < 100K: comparable core sensitivity of Lofar

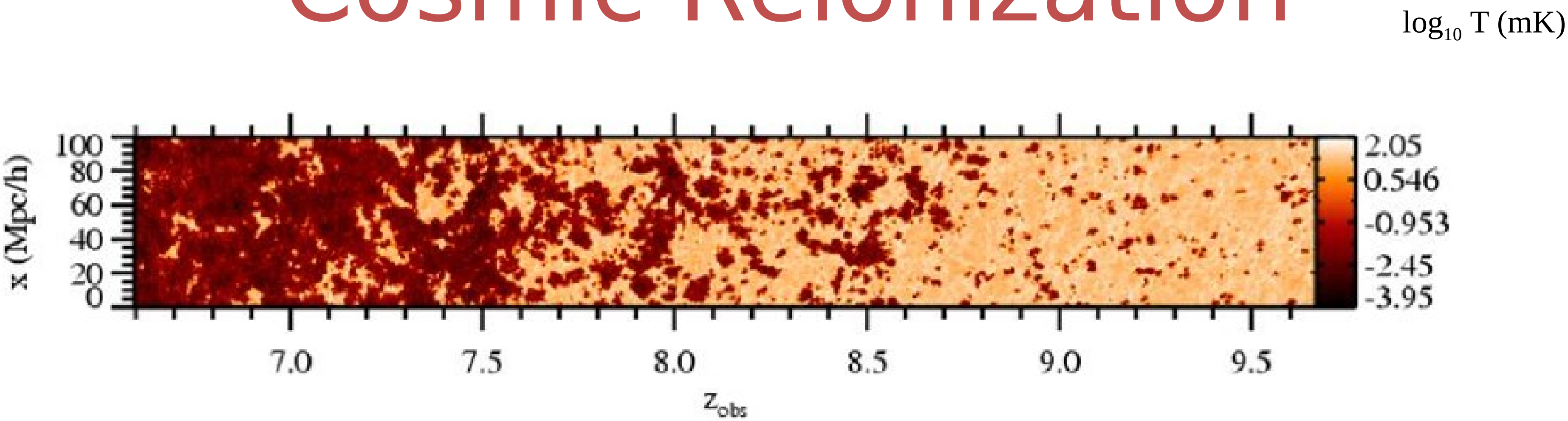
-- rigid dish, no foreshortening: constant, round FoV, polarization, can track targets rise to set, maximal u-v coverage, simple calibration/analysis

-- design frequency: 1.4 GHz. Almost perfect optics at 150 MHz

-- dual polarized signal, 32 MHz, software selectable frequency resolution, up to 4096 channels.

-- $10m inflation adjusted construction cost. 50,000m^2 geometric collecting area.

Cosmic Reionization



(Iliev, Mellema, Pen, Shapiro 2006)

Largest radiative transfer cosmological reionization simulations: 1 degree FOV.

Detection in 21cm hyperfine transition with radio telescopes. Structure on large scales (>20’).

See also Furlanetto, Oh, Zaldarriaga, Zahn, Morales, Mesinger, Croft, Ciardi, etc

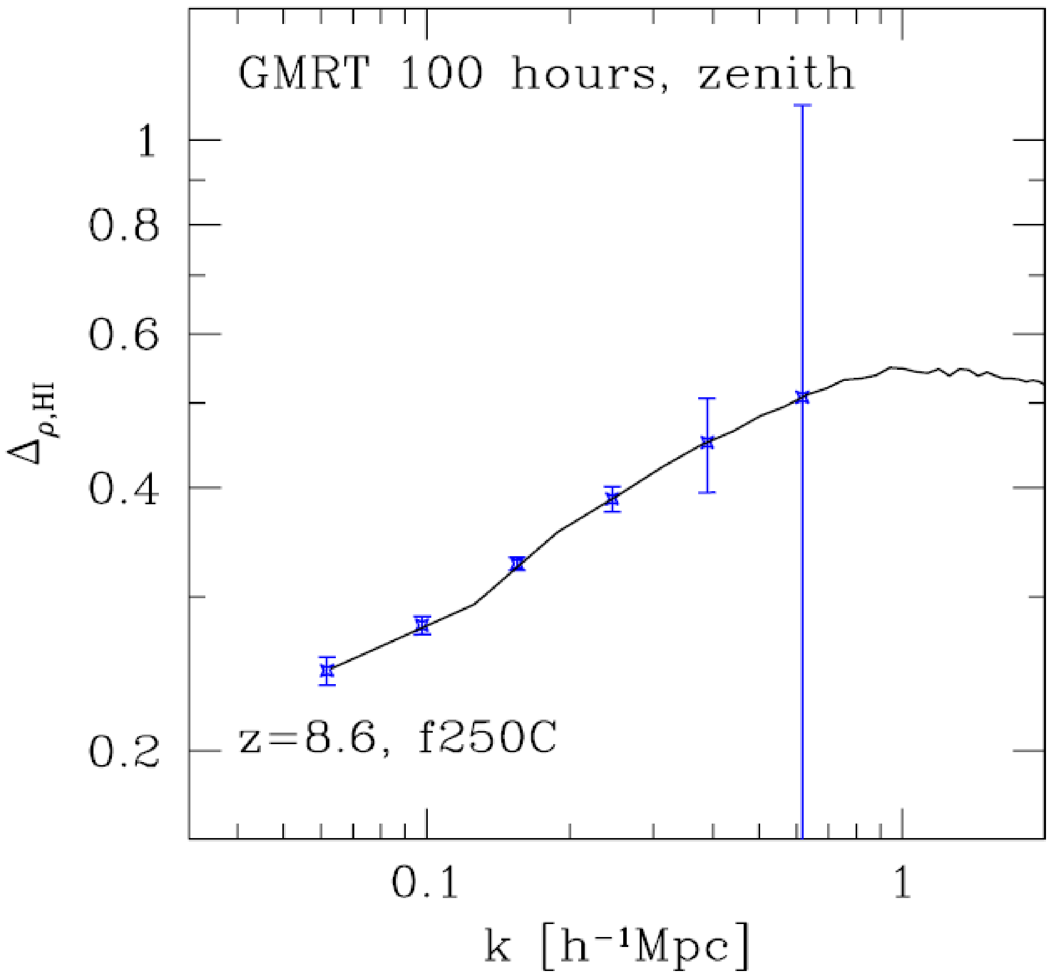


Figure 9. Observability of the 21-cm signal: the 3D power spectrum of the neutral hydrogen density, $\Delta_{\rho,HI}$, at redshift $z = 8.59$ ($\overline{T_b} = 16.3$ mK) with the forecast error bars for 100 hours observation with GMRT vs. wavenumber k. We assumed 15 MHz observing bandwidth (the full instantaneous bandwidth of GMRT), $T_{\rm sys} = 480$ K and assuming $T_S \gg T_{\rm CMB}$. The array configuration is assumed pointed to the zenith, but the sensitivity is only weakly dependent on the pointing.

Iliev et al 2008

GMRT EoR Project

- Effort started 2004, science data since 2007
- 500 hours of data, allocation of 150h/semester, biggest science project at GMRT
- Simplest of EoR experiments: rigid, tracking dishes, low polarization leakage, small FoV.
- Resulted in several instrument upgrades: new receivers, software correlator, new filters, RFI localization, removal.

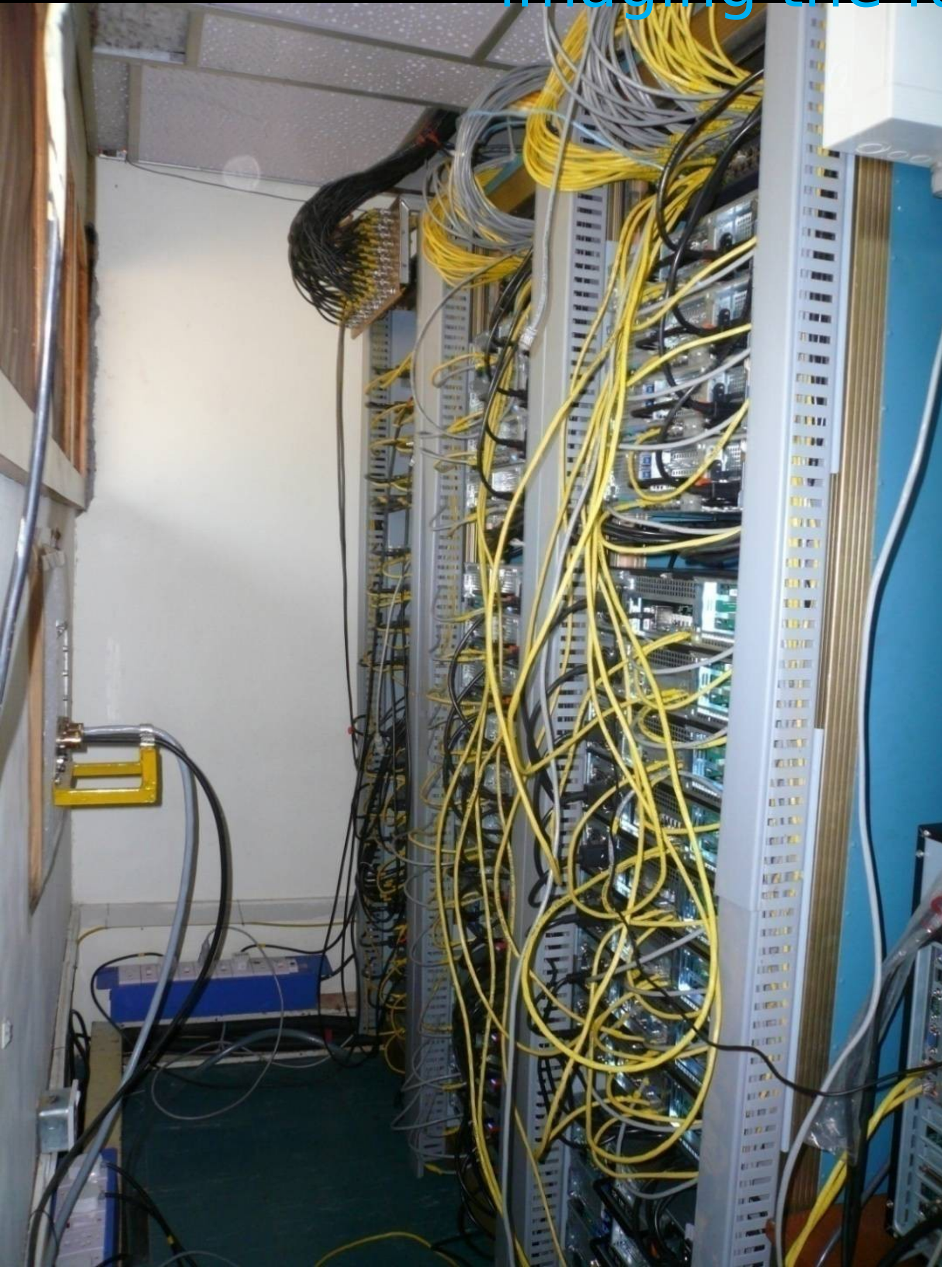
Main Issues

- Calibration: pulsar based gated calibration. Perfect on-axis phase and amplitude solution, including polarization. Pulsar is brighter than the sum of all other fluxes in the field (sufficient, but not necessary condition).
- Foregrounds, RFI
- Side lobe source. Tapered illuminated dishes have clean beams, but bright sources (e.g. Cass A) do leak through. Problem on short baselines: non-parametric modelling.

RFI localization

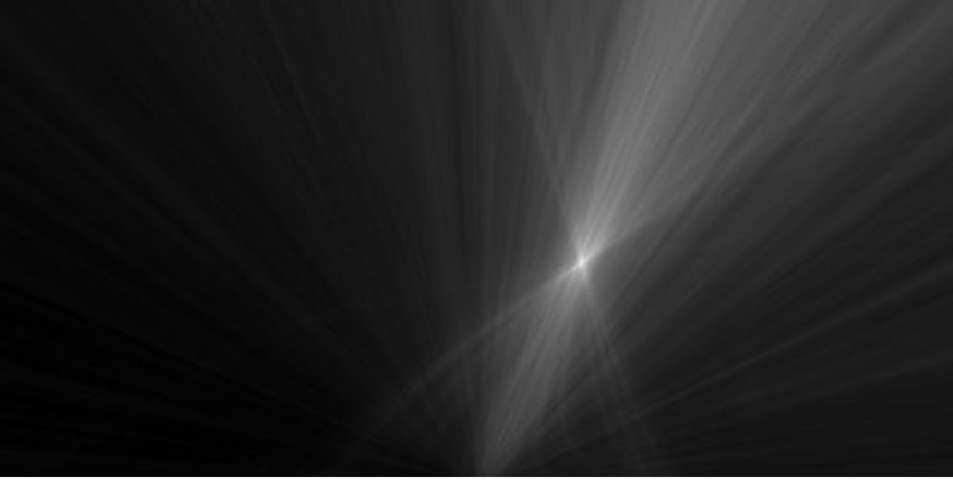
- Interferometer intrinsically measures positions
- Requires different imaging and calibration strategies in the near field
- GSB and EoR project developed identification strategies.
- Uses SVD based strategy (see rajaram’s talk last year). Runs on GSB, at CITA, and working on porting to HP cluster.

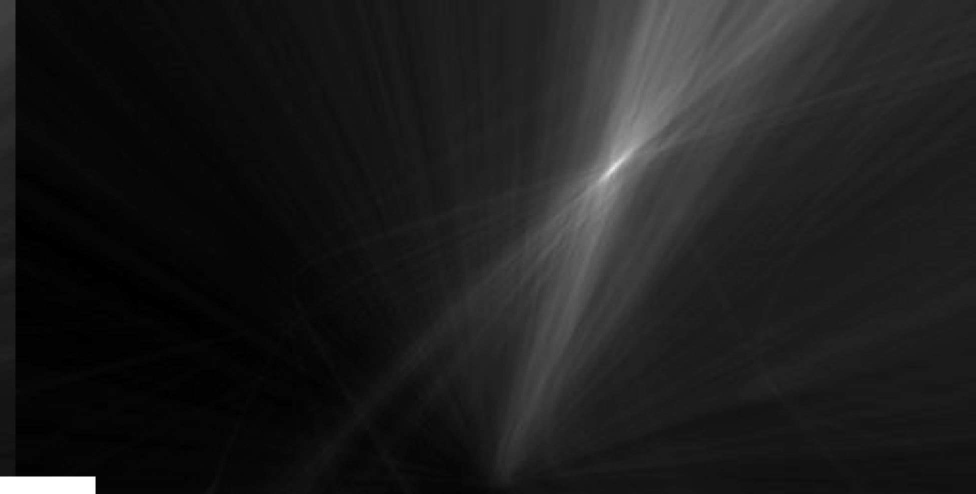
new software correlator:
imaging the full sky+horizon

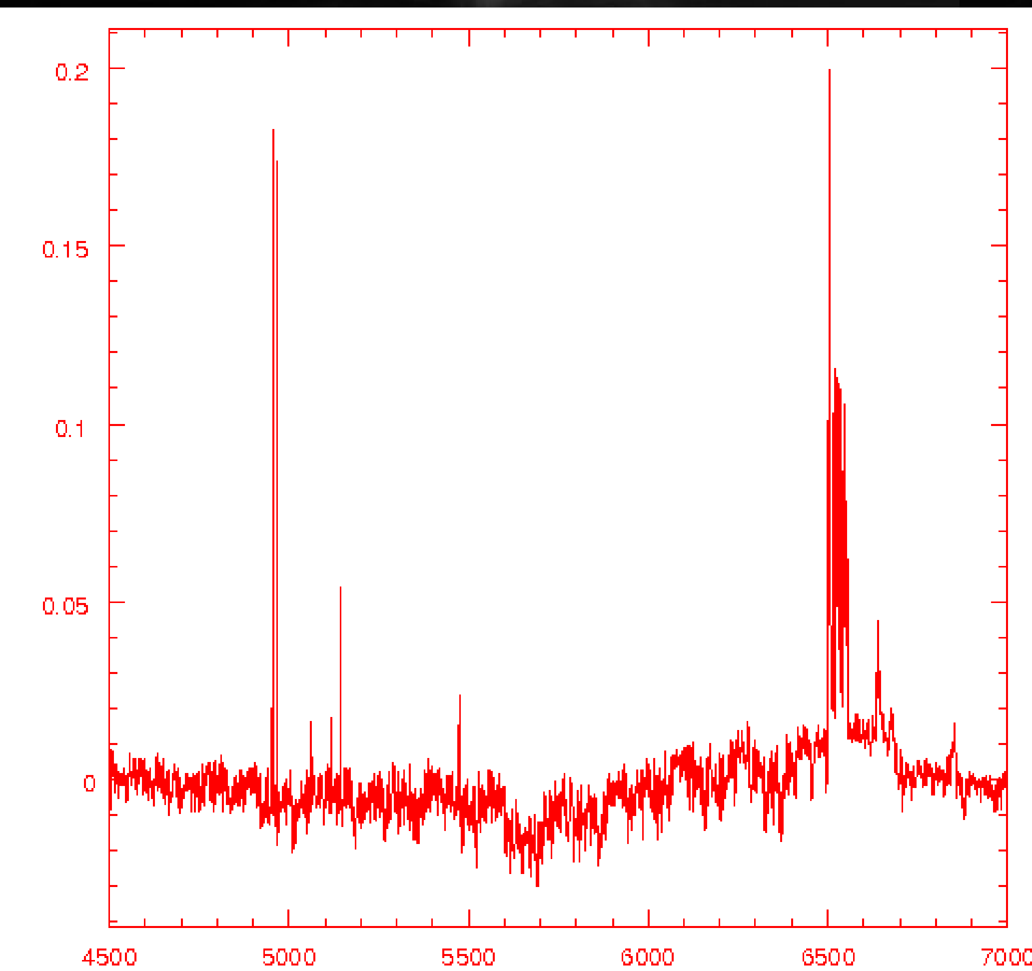


Data Acquisition

- RFI locations are produced as a by-product of EoR observations, or by specific calibrated obervations with feeds pointed to the control building.
- Requires operation of software correlator to obtain sufficient lags: avoid bandwidth smearing for horizon-to-horizon imaging.



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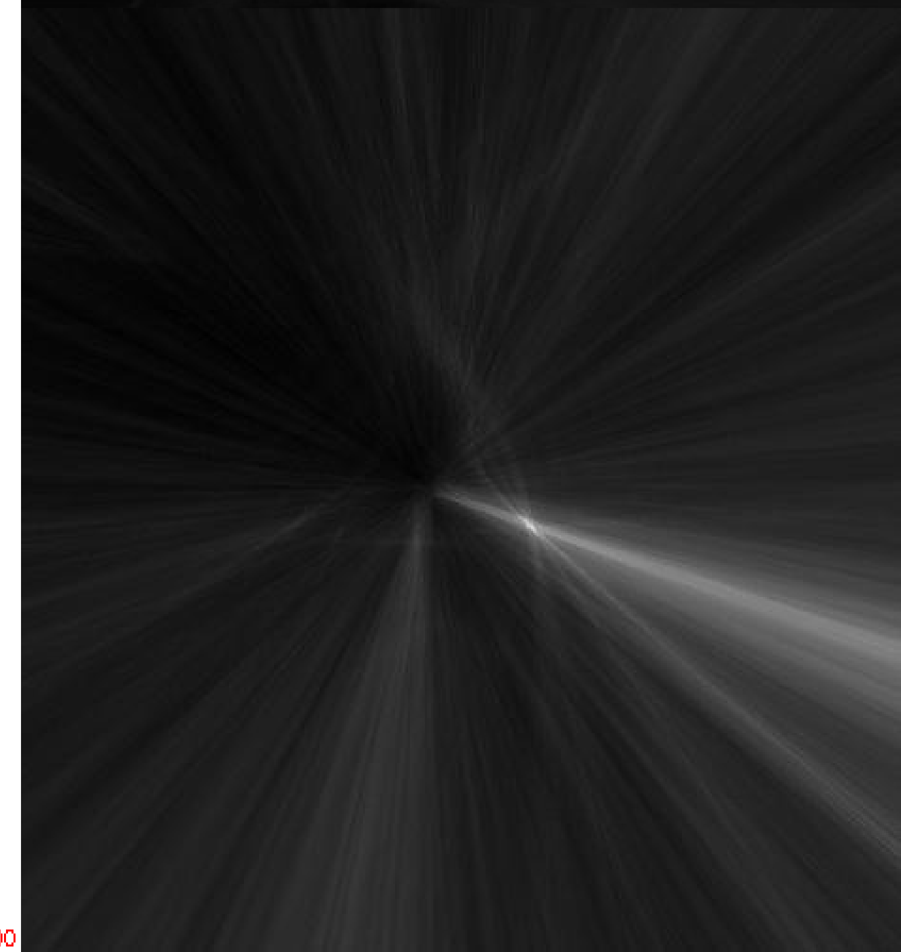

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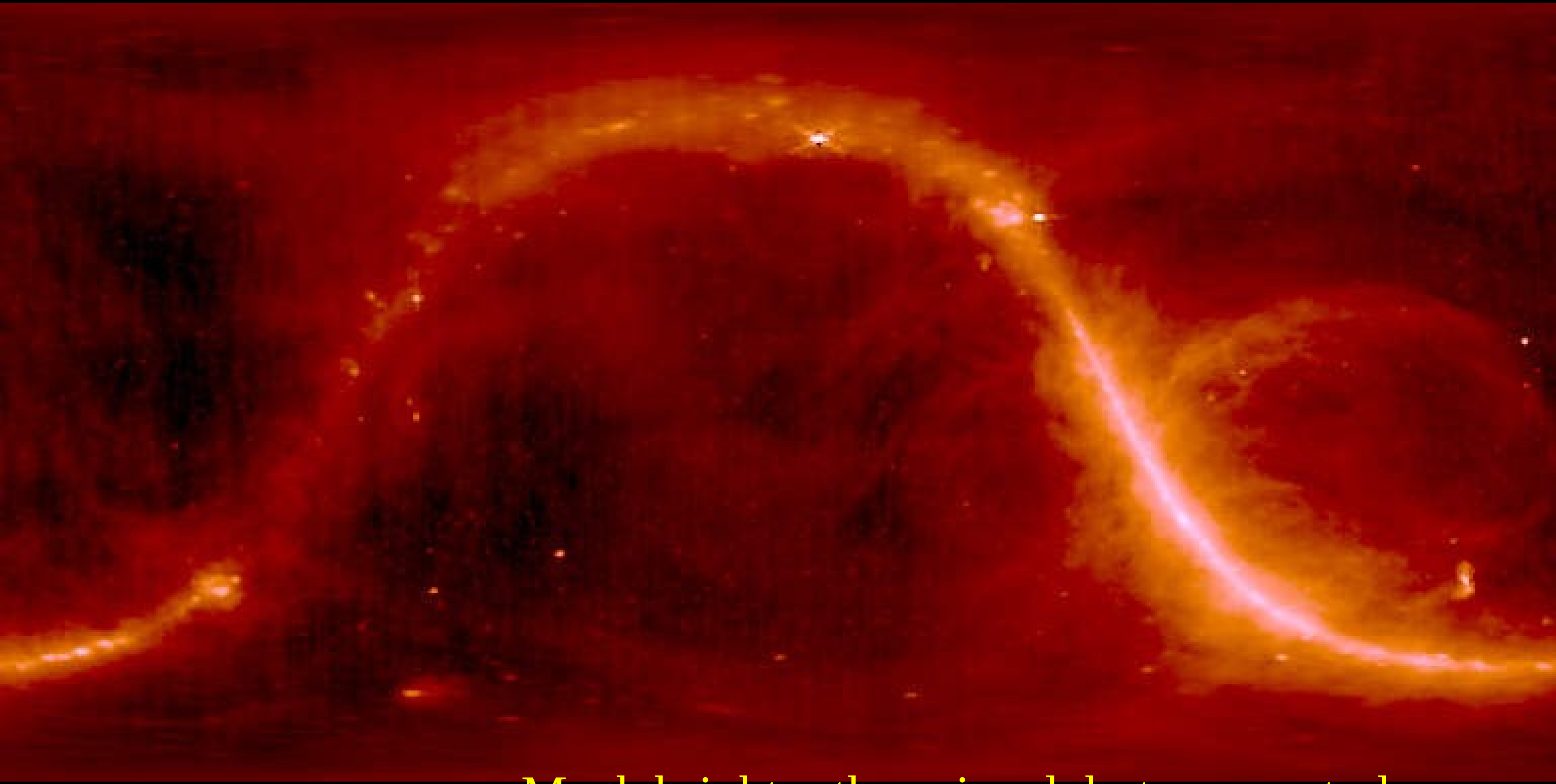
Multi-wavelength follow-up:
ultrasound, VHF, UV
Foxhunt yagi

Foreground modelling

- Main challenge is diffuse galactic foreground
- Traditional non-linear deconvolution CLEAN not well suited for diffuse structure: need IDENTICAL frequency independent mapping.
- Wide field, w-term
- Use CBI-Gridr: marginalization over unknowns.

Foreground: Galactic Synchrotron



Haslam 408 MHz

Much brighter than signal, but no spectral structure

Strategies

- RFI cancellation: physical removal, reference antennae phase closure
- Drift scanning: reduces all ground based effects
- Gated pulsar calibration: clean solution, independent of sky, RFI

Foreground

- For diffuse source, coherence bandwidth is

$$\frac{\Delta\lambda}{\lambda} = \frac{D}{L}$$

- W-term causes synthesized beam to be non-stationary: different frequencies are not related by convolution!
- Needs direct (linear) Wiener foreground filter: CBIGRIDR (Myers et al 2003). Reject data points that cannot be modelled. Avoid non-linear algorithms like CLEAN.

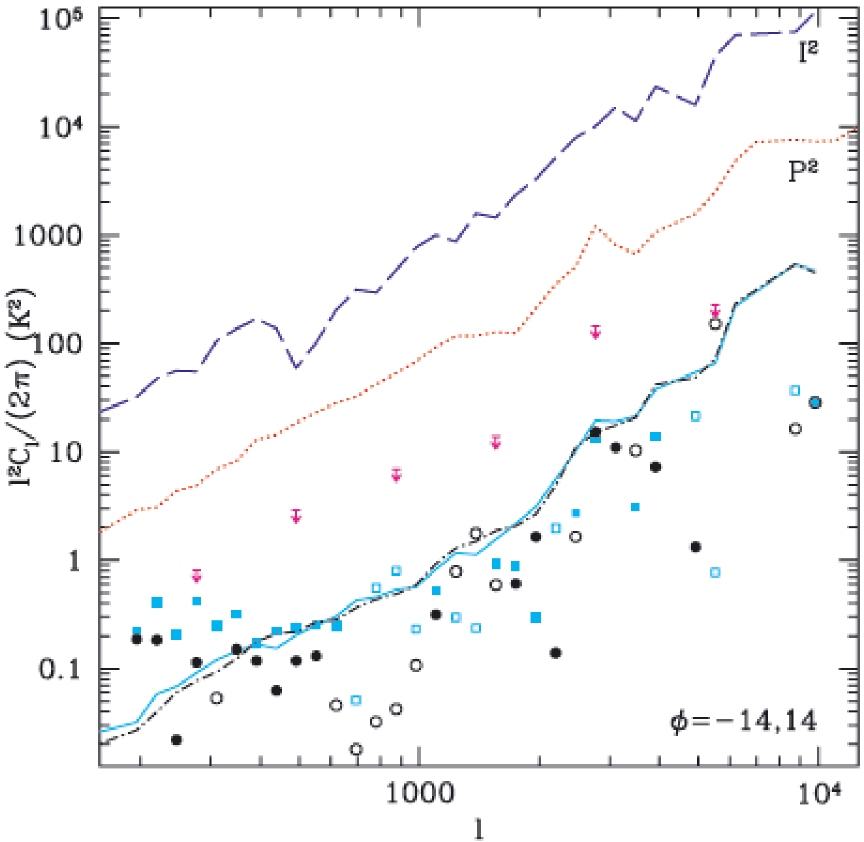


Figure 4. Power spectrum of unpolarized (I^2, long dash) and total polarized emission (P^2, dotted) over the central square degree, after subtracting the 31 brightest sources in the primary beam. This polarized signal includes leakage and thermal noise. The upper bound symbols are a 2σ estimate of polarization bound using baseline cross-correlation. They are averages of the polarization power in 1 MHz bands. The lower solid and dot–dashed lines are the total power polarization measured at $\phi = -14$ and 14 over a width $\Delta\phi = 3.5$, as determined from the map power. Using the cross-correlation technique described in the text, we plot a less conservative estimate with circles for $\phi = -14$ and squares for $\phi = +14$. Open symbols denote negative power, and filled are positive values. For details on the unit conversions, see the appendix.

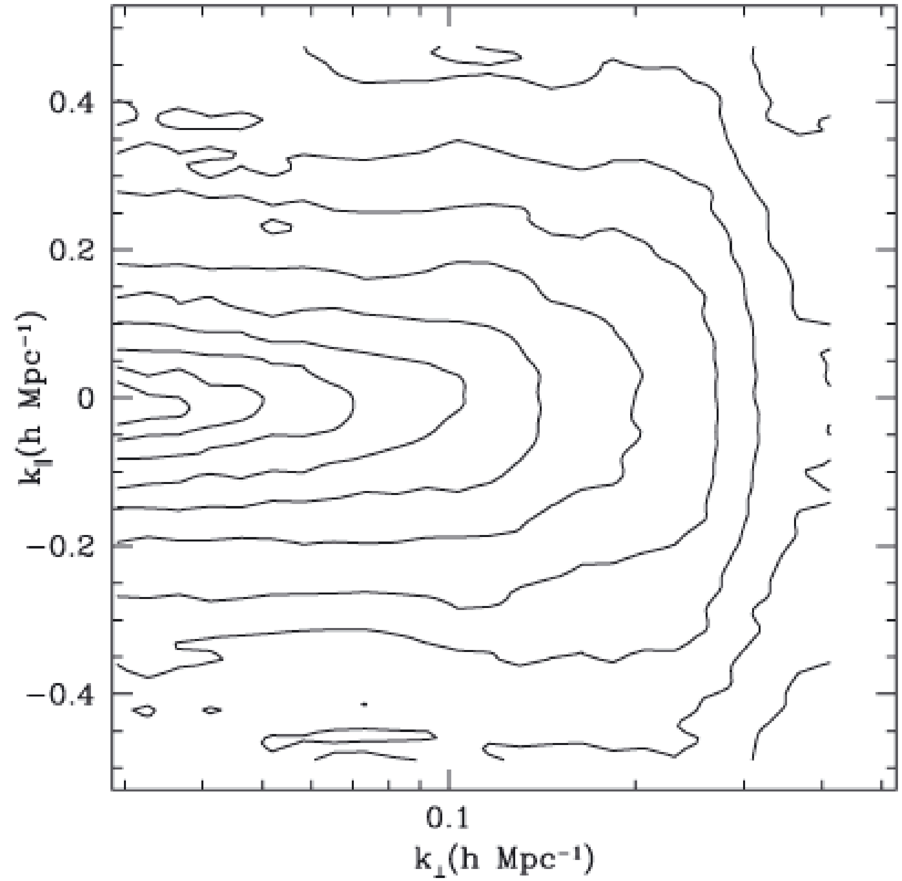


Figure 6. The 3D polarization power spectra based on our observed visibilities. These are estimated from the power of maps at fixed rotation measures. The transverse scale has been converted from angular to comoving units at $z = 8.5$. The parallel scale is converted from ϕ according to equation (A38). The contours are of Δ_P^2 (see the text), and start at 0.0069 K^2 in the left middle near $k \sim 0$, increasing logarithmically by 10 per contour level. On large scales, $k_\perp < 0.3\,h\,\mathrm{Mpc}^{-1}$ our observations set an upper limit equivalent to a few kelvins per $\ln k$ in 3D space.

Pen et al 2009

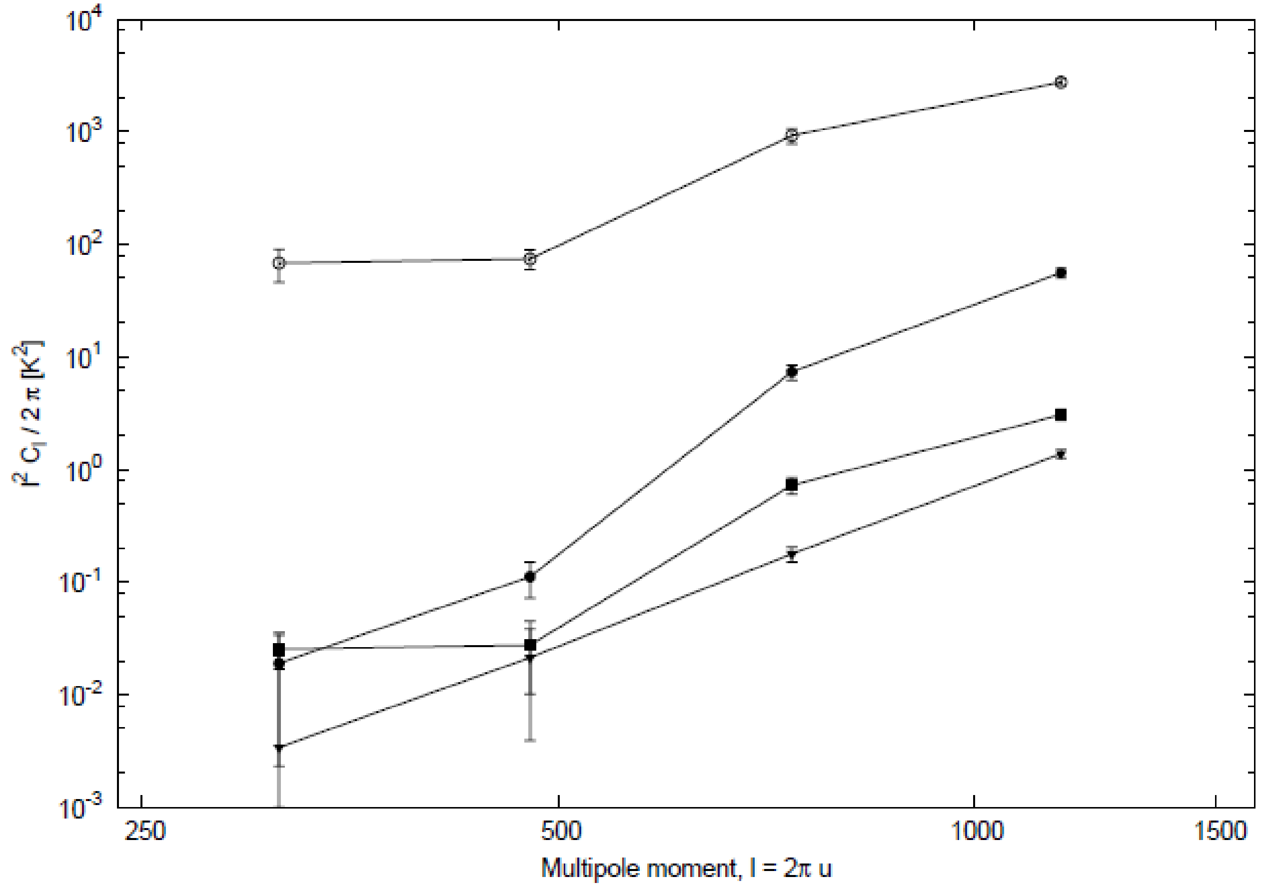
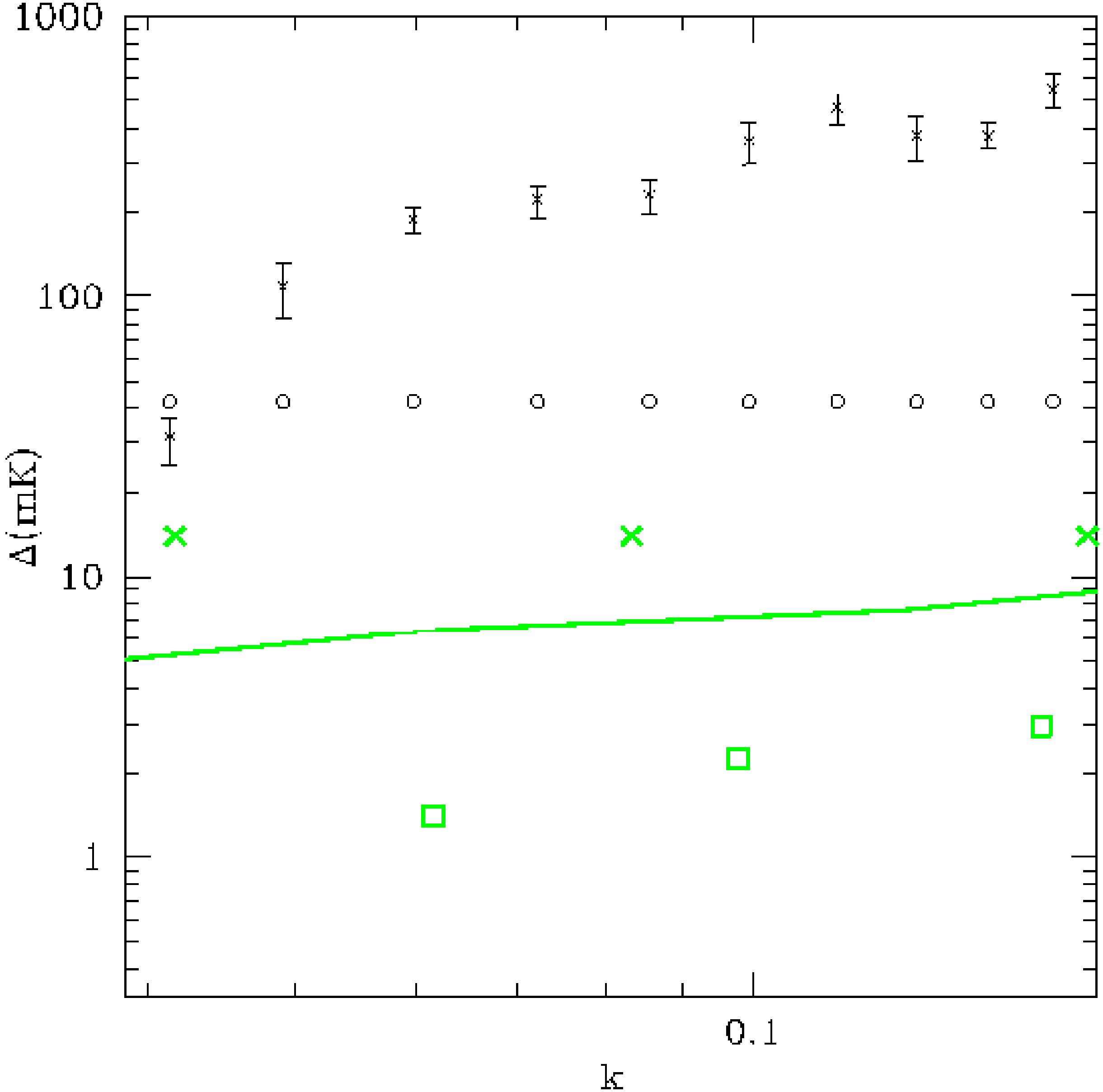


Fig. 12.— Average power spectrum in units of K^2 of all combinations of days, excluding December 11th, as a function of the multipole moment l, analogous to CMB analysis. Open circles are the power before subtracting foregrounds, filled circles are after 8 MHz mean subtraction, filled squares are after 2 MHz mean subtraction, and filled triangles are after 0.5 MHz subtraction. Error bars represent bootstrap errors on the average. Solid lines connecting the data are for visual aid only.

Pacgica 2010, in prep

Preliminary status snapshot



Cosmological Interpretation

Theoretical: atomic cooling pre-reionization mini-galaxies, mini-QSO, mini-halos. Rare objects evolve rapidly and shut off: fast evolution, $dz/(1+z) < 0.1$. Common objects are very extended. Sensitive to slope, running of $P(k)$.

- Observational extrapolations: based on post reionization objects, more massive due to high Jeans mass.

Conclusions

- Ongoing programme, simplest data set to calibrate, analyze. Pulsar calibration.
- Thermal sensitivity well matched to EoR.
- First results on foreground polarization: mostly depth depolarized.
- Main challenge: non-parametric galaxy subtraction, w-term. Beyond CLEAN.
- Sensitivity improving as RFI sources are removed
- Approaching cosmological signal on short baselines