Observing Cosmic Dawn with the LWA1

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on behalf of the LWA collaboration

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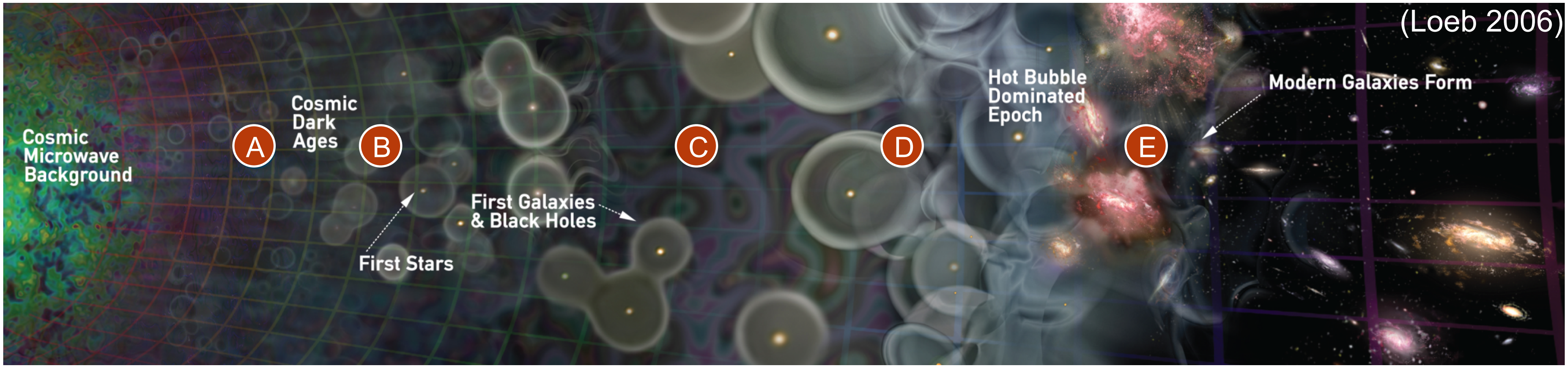
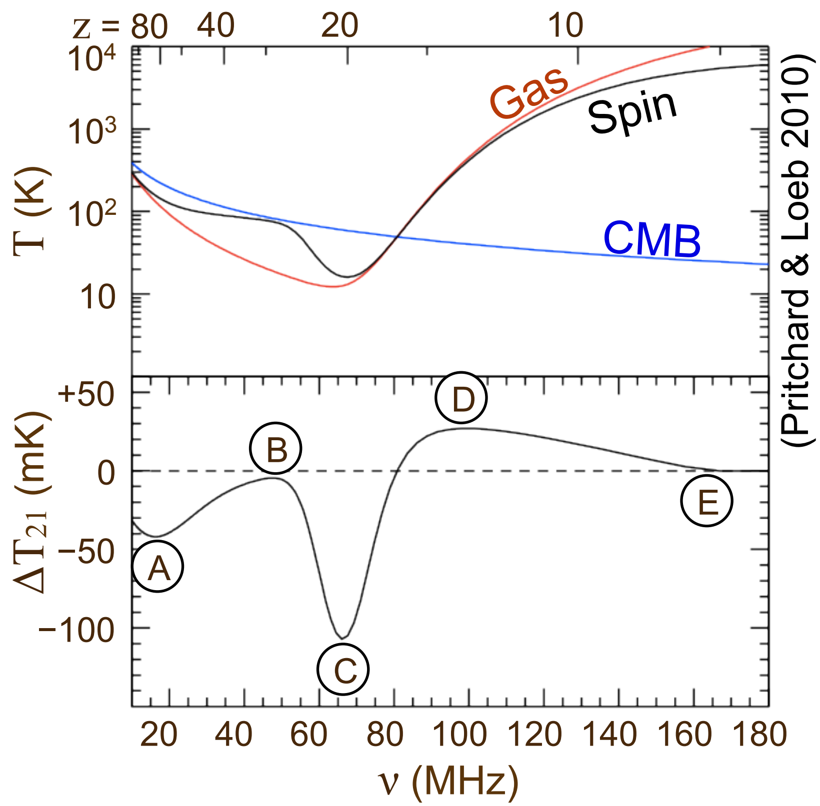
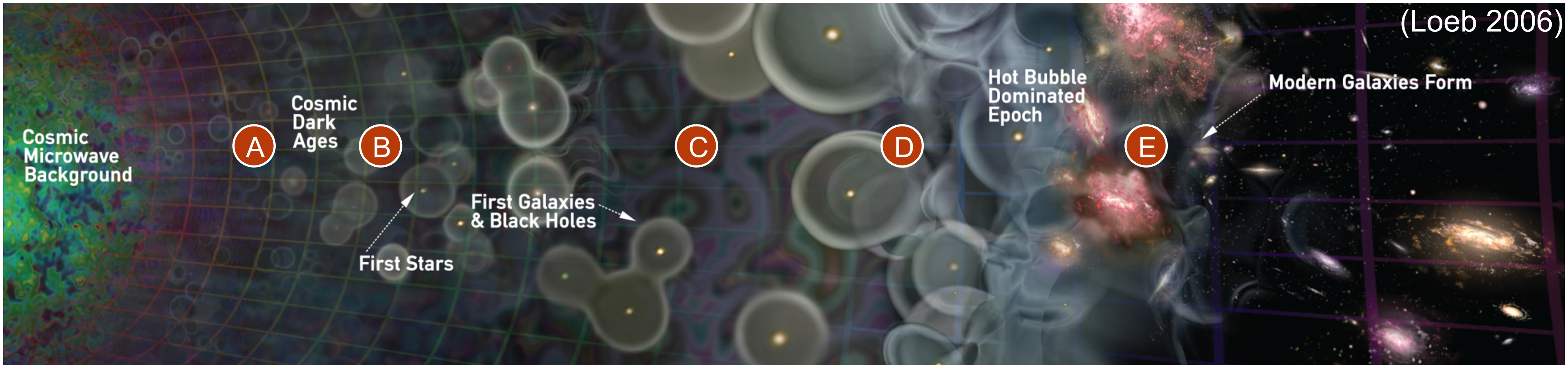
Cosmic Dawn and Reionization

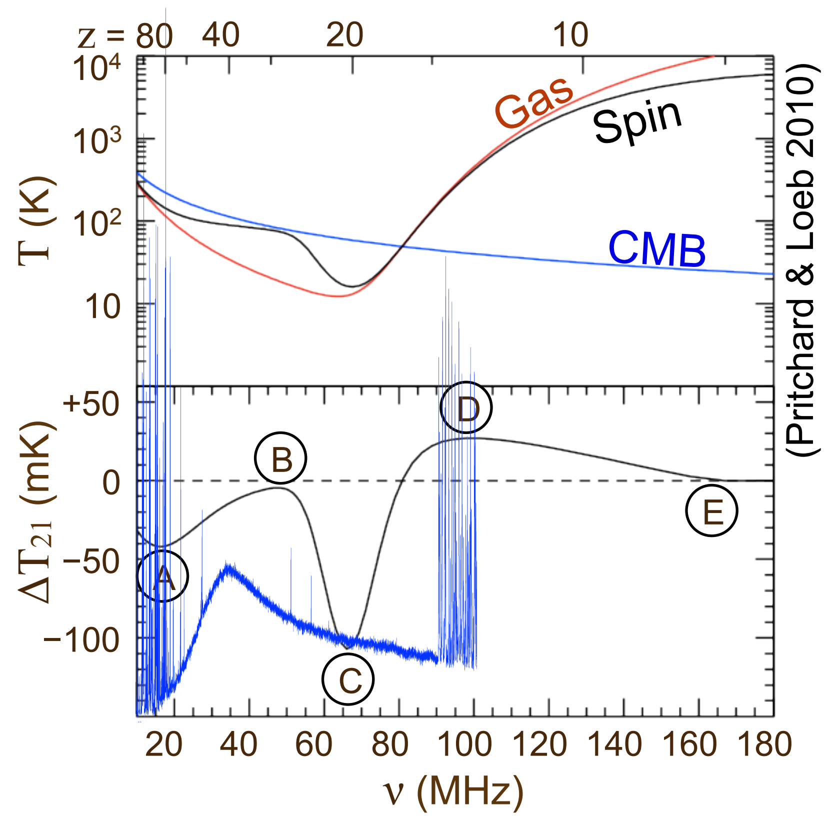




$$\Delta T_{21} \approx x_{\rm H\,I} \left(\frac{T_{\rm S} - T_{\rm CMB}}{T_{\rm S}} \right) \left(\frac{1+z}{10} \right)^{1/2} \times 30 \text{ mK}$$

Cosmic Dawn and Reionization





The frequency range of the LWA is well-matched to this measurement.

But it requires 1 part in $\sim 10^6$ relative spectral calibration!

LWA Long Wavelength Array

The first LWA station (LWA1)

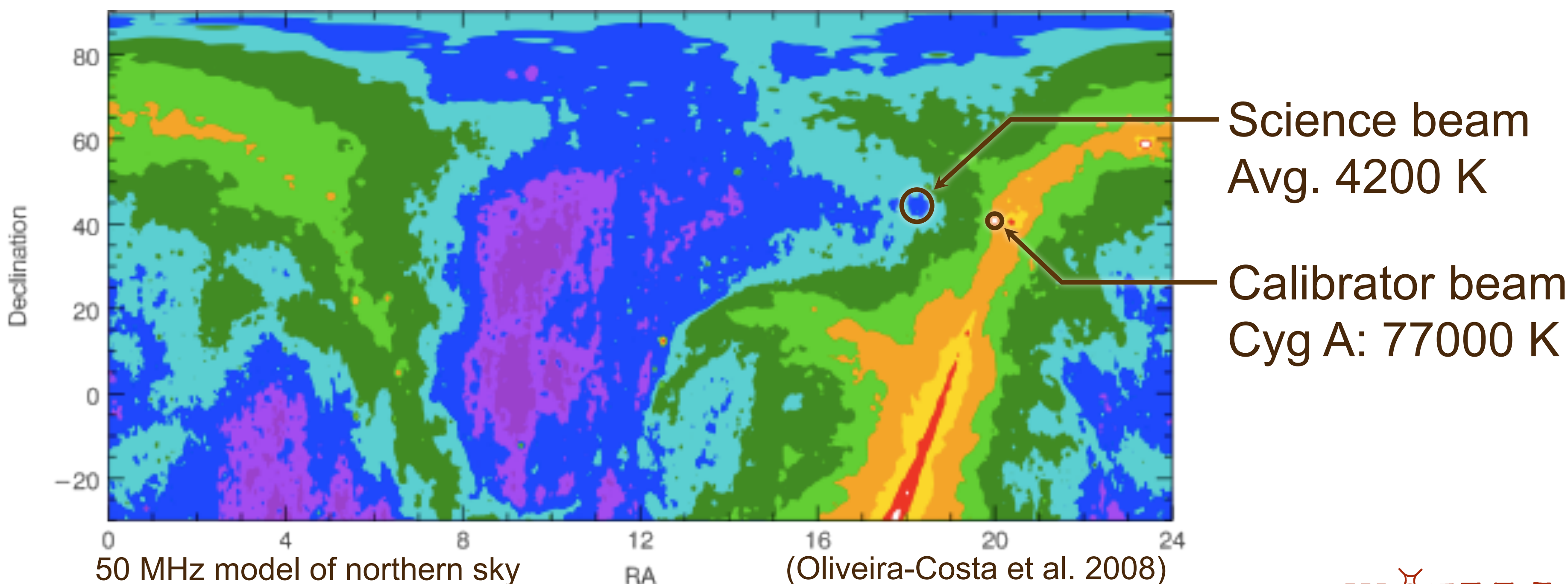
- 256 dual-pol antennas within 110 m diameter
- 10–88 MHz; > 4:1 sky:noise dominance for 25–87 MHz
- Complete and operating

Beamformed observing

- Four simultaneous, independently steerable beams
- Two ~16 MHz BW tunings per beam; full Stokes
- Co-aligned beams: two 64 MHz BW beams, here 20–84 MHz

Cosmic Dawn with the LWA1

- We use all four beamformers to make two simultaneous beams, each 20–84 MHz, for ≳100 hour integrations
- Science beam targets a relatively cold region of the sky
- Calibrator beam targets a bright, smooth spectrum source
- Beams are large enough to average over angular variations



50 MHz model of northern sky (Oliveira-Costa et al. 2008)

LWA Long Wavelength Array

Bandpass calibration

$$p_{\rm sci}(\nu) = g_{\rm sci}(\nu)\left[T_{\rm sci}(\nu) + \Delta T_{21}(\nu)\right]$$

$$p_{\rm cal}(\nu) = g_{\rm cal}(\nu)\left[T_{\rm cal}(\nu) + \Delta T_{21}(\nu)\right]$$

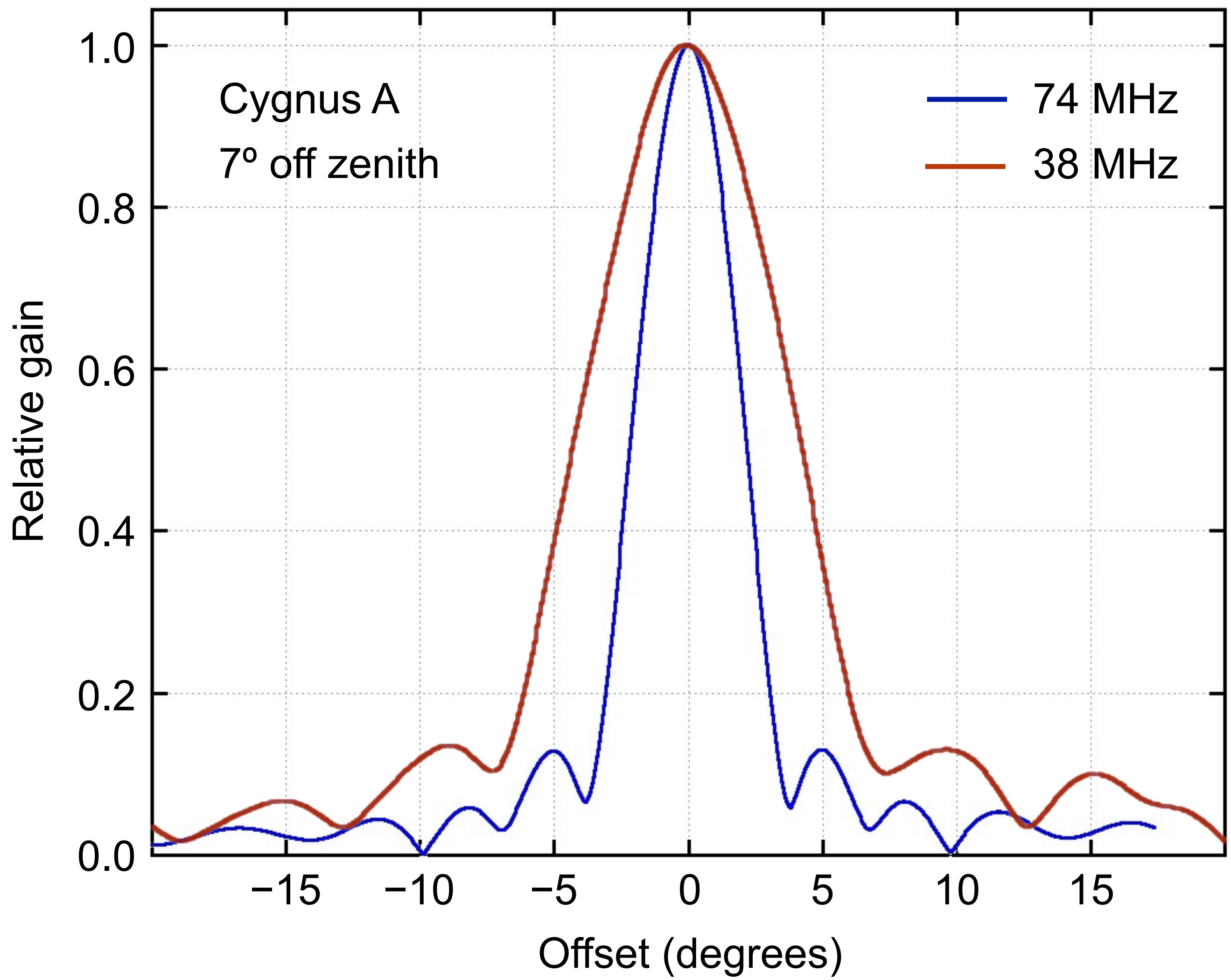
$g_{\rm sci/cal}$ $T_{\rm sci/cal}$

$g(\nu)$

Long Wavelength Array

Frequency dependence of sidelobes

Goal: prevent frequency-dependent variations in sidelobes from coupling foreground angular structure into spectrum



Frequency dependence of sidelobes

Goal: prevent frequency-dependent variations in sidelobes from coupling foreground angular structure into spectrum

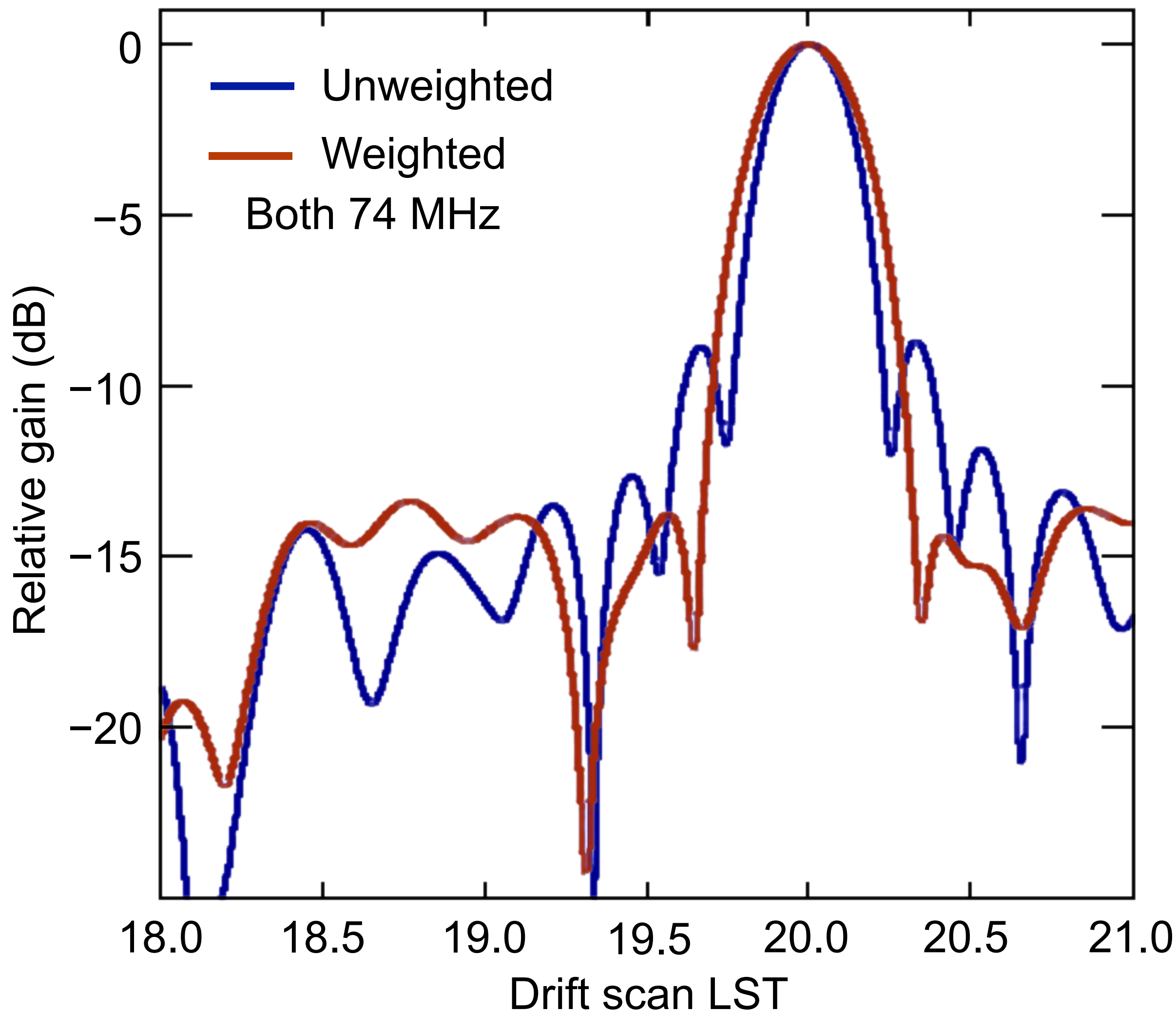
Techniques:

- Defocusing primary beam averages over more foreground, can lower sidelobe power — option of heterogeneous beams

LWA
Long Wavelength Array

Frequency dependence of sidelobes

- Defocusing primary beam averages over more foreground, can lower sidelobe power — option of heterogeneous beams



Frequency dependence of sidelobes

Goal: prevent frequency-dependent variations in sidelobes from coupling foreground angular structure into spectrum

Techniques:

- Defocusing primary beam averages over more foreground, can lower sidelobe power — option of heterogeneous beams
- Steering sidelobes away from bright sources
- Sidelobe blurring by continuously varying weighting coefficients to constantly "shimmer" sidelobes
- Optimal beamforming by accounting for mutual coupling (Ellingson 2011)

LWA
Long Wavelength Array

Other issues / benefits

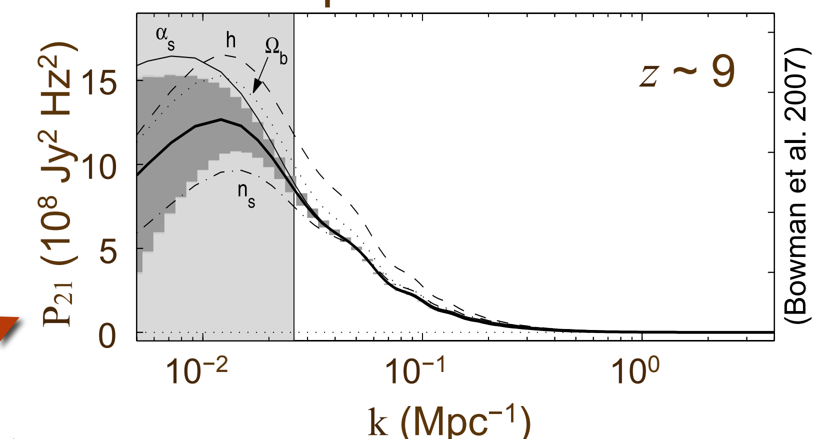
- Development of novel beamforming techniques should be of general interest to low-frequency radio community
- Excellent spectra of the calibrator sources
- A deep transient survey in targeted science fields
- Ionospheric absorption / TEC variability
- RFI

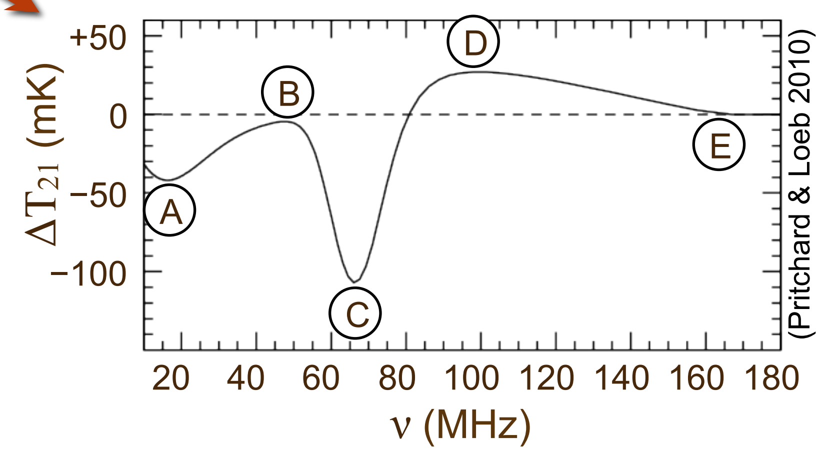
LWA
Long Wavelength Array

New worlds, new horizons? New stations!

- Core of 16 stations within a 10 km diameter:
  ~1.6 arcmin resolution at 65 MHz gives k < 8 Mpc^{-1} at z = 20
- Both frequency and angular spectra
- Spatial variability of the heating by first stars, black holes
- "Purer" cosmology than the reionization experiments

Deep Springs Valley, near OVRO / CARMA





Summary

- LWA1 offers a novel method to measure or constrain the all-sky 21 cm signal using large beams
- Bandpass calibration accomplished by comparing science and calibrator beams
- Currently testing advanced beamforming techniques
- Could begin measuring or constraining the early universe with ~100 hours of integration
- Cosmic dawn tomography: a strong argument for more stations