Observing Cosmic Dawn with the LWA1

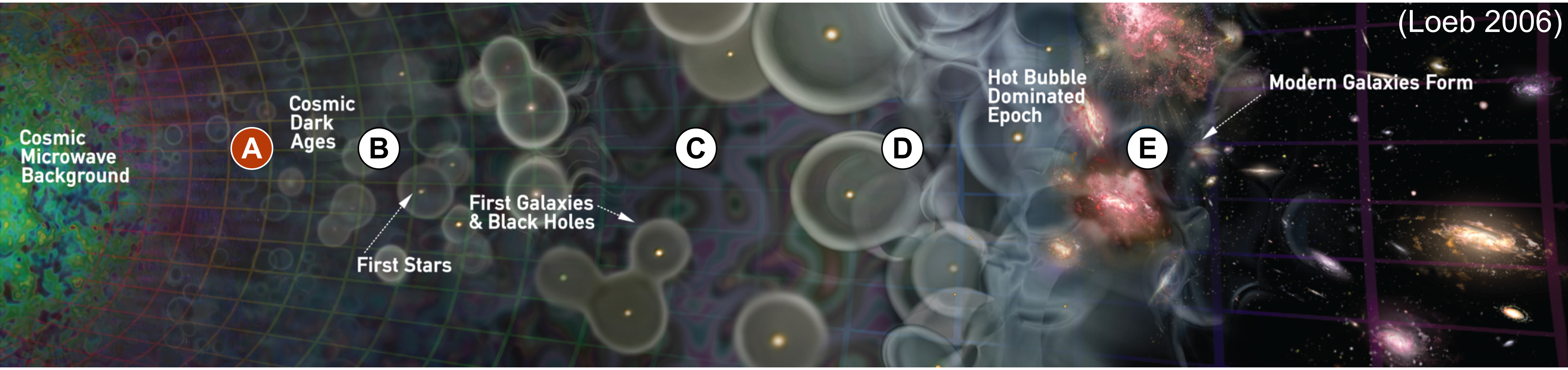
Jake Hartman, Judd Bowman, and Greg Taylor

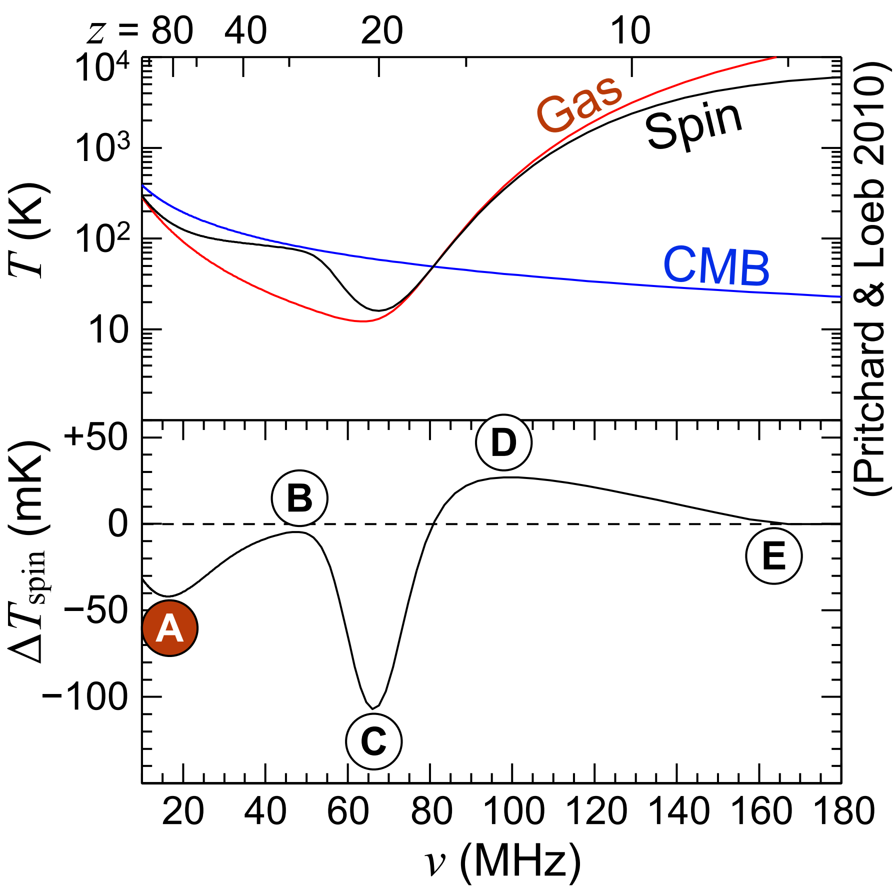
Overview

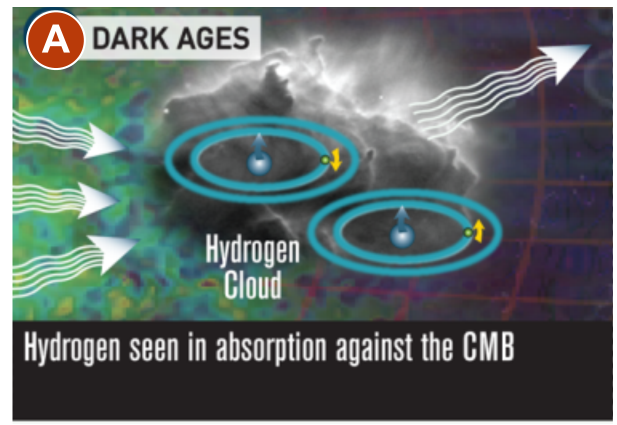
- The sky-averaged 21 cm signal: what we expect to see
- How it can be measured or constrained with the LWA1
- What we could do with additional LWA stations

- NSF AAG proposal ($250k) submitted in March; still waiting

Cosmic Dawn and Reionization







As the universe expands, falling gas density decouples $T_{\rm spin}$ from $T_{\rm gas}$.

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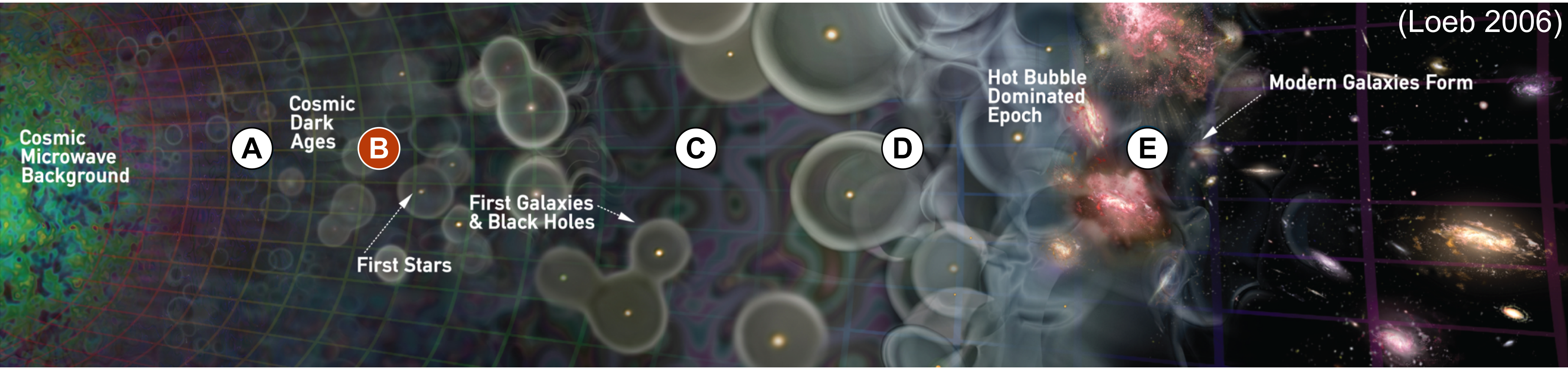
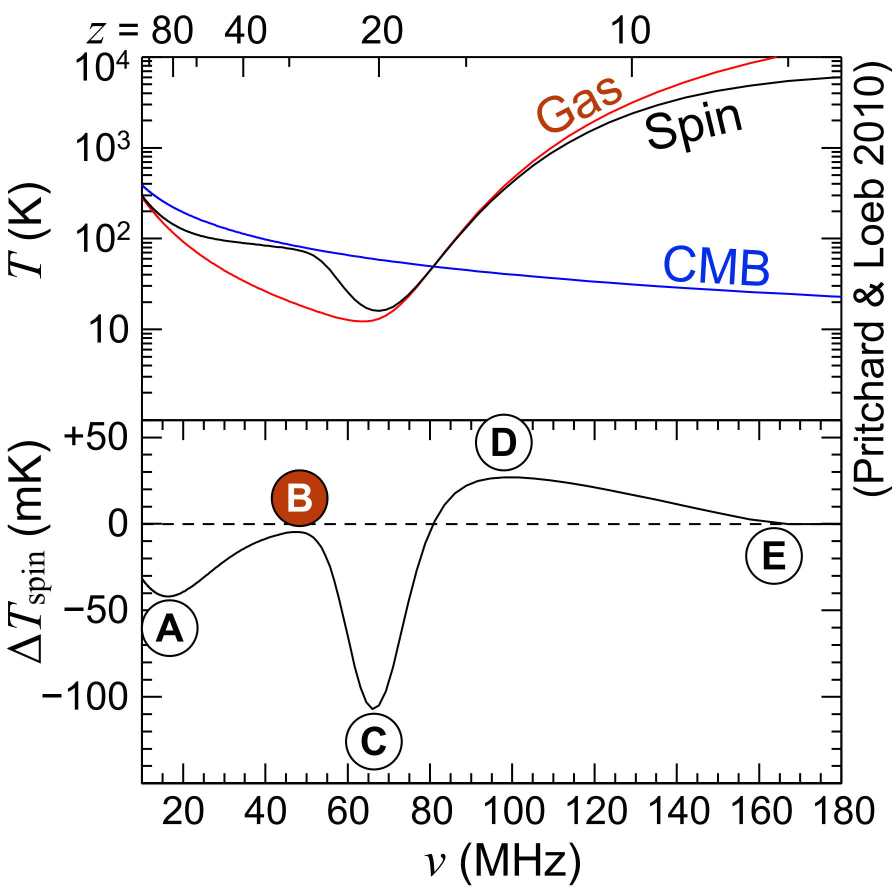
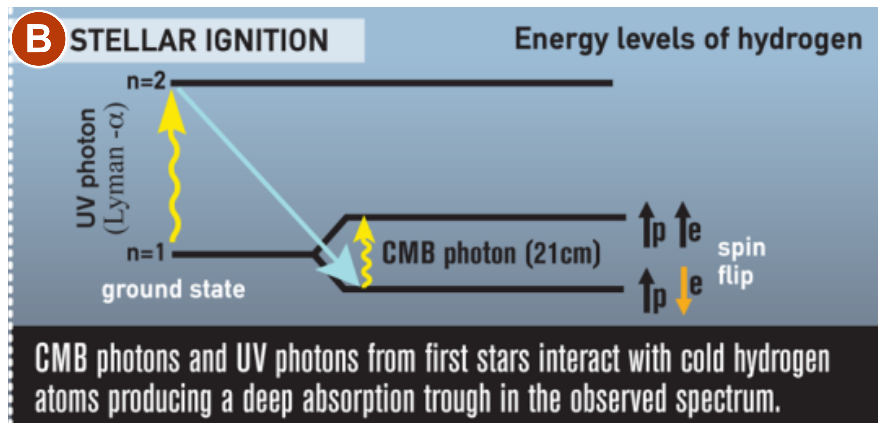
Cosmic Dawn and Reionization







Ly α photons recouple $T_{\rm spin}$ to $T_{\rm gas}$ via the Wouthuysen-Field effect.

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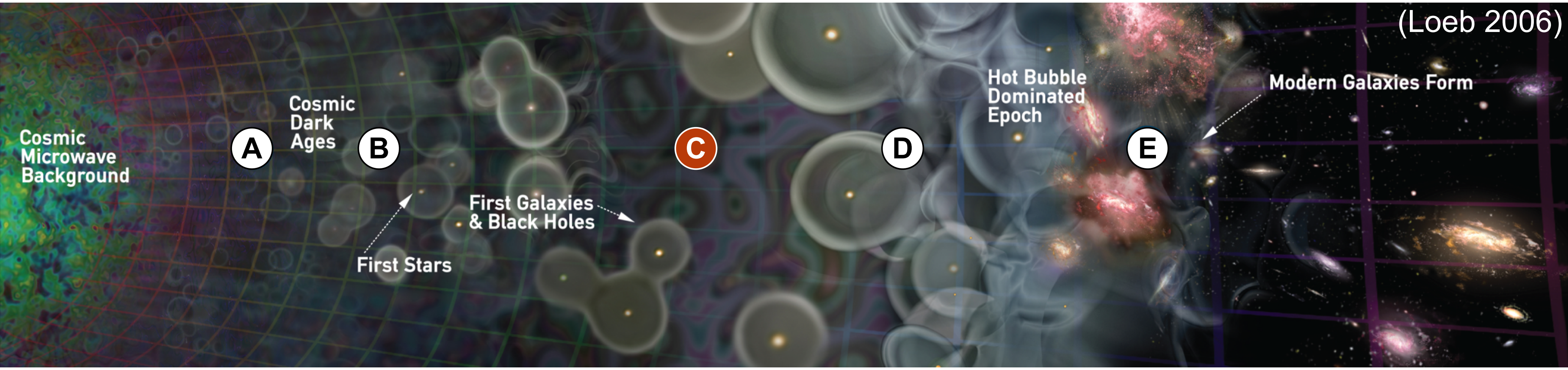

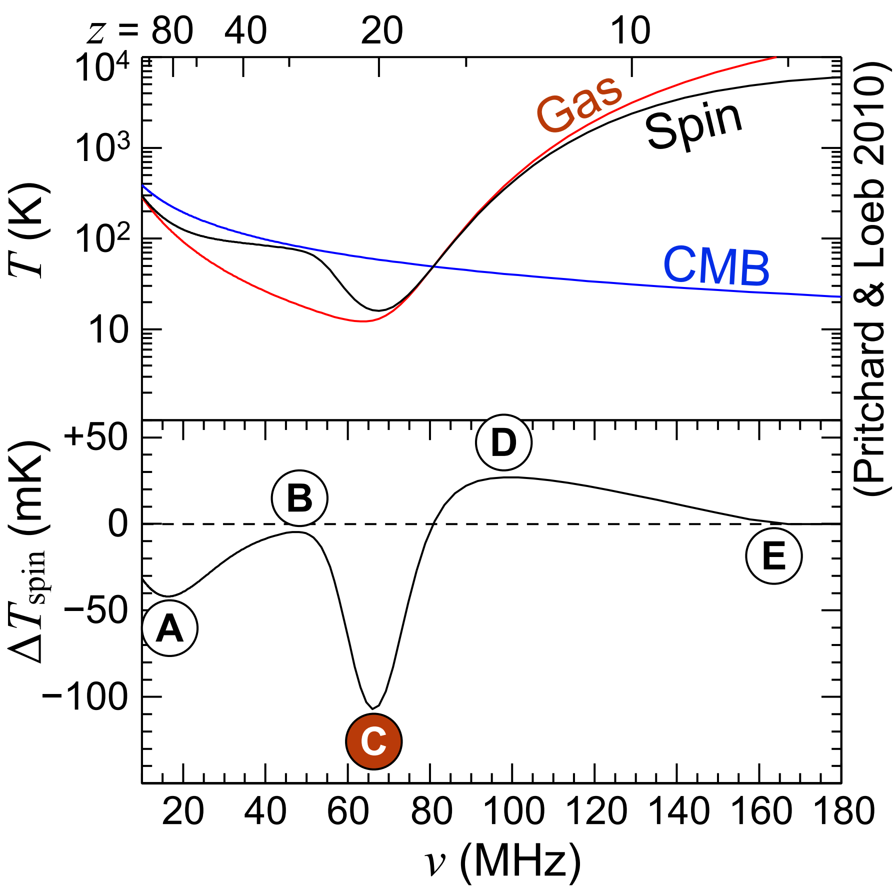

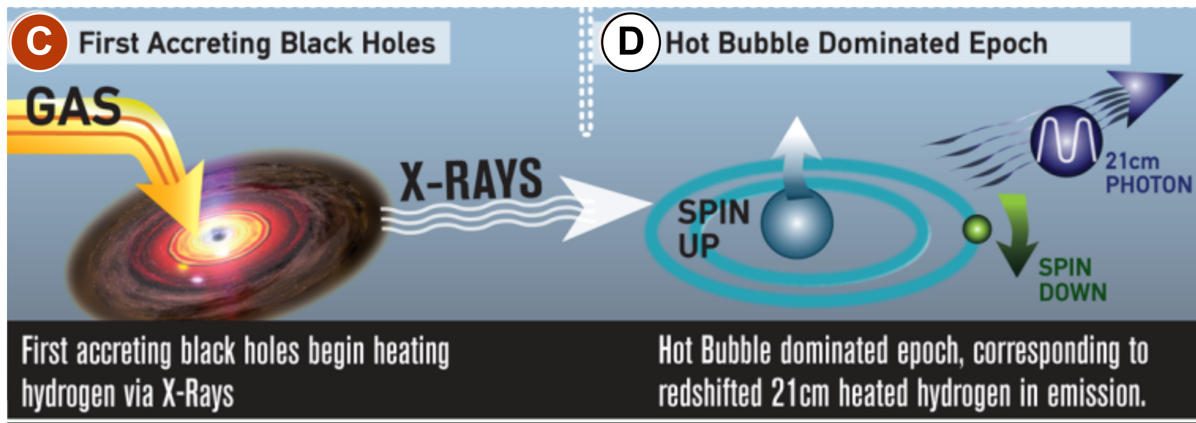

X-rays begin heating T_{gas} …
and later cause reionization.

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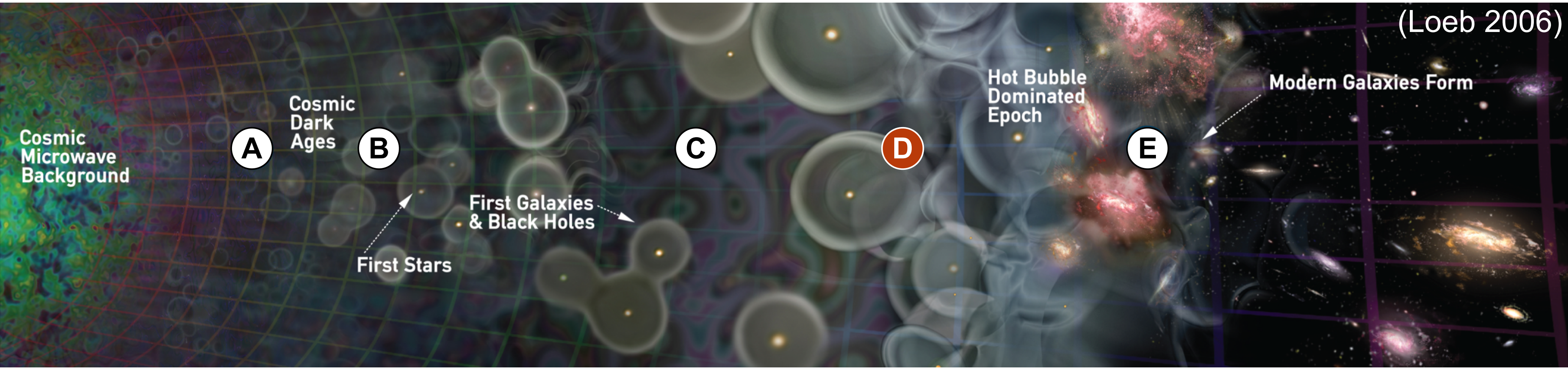
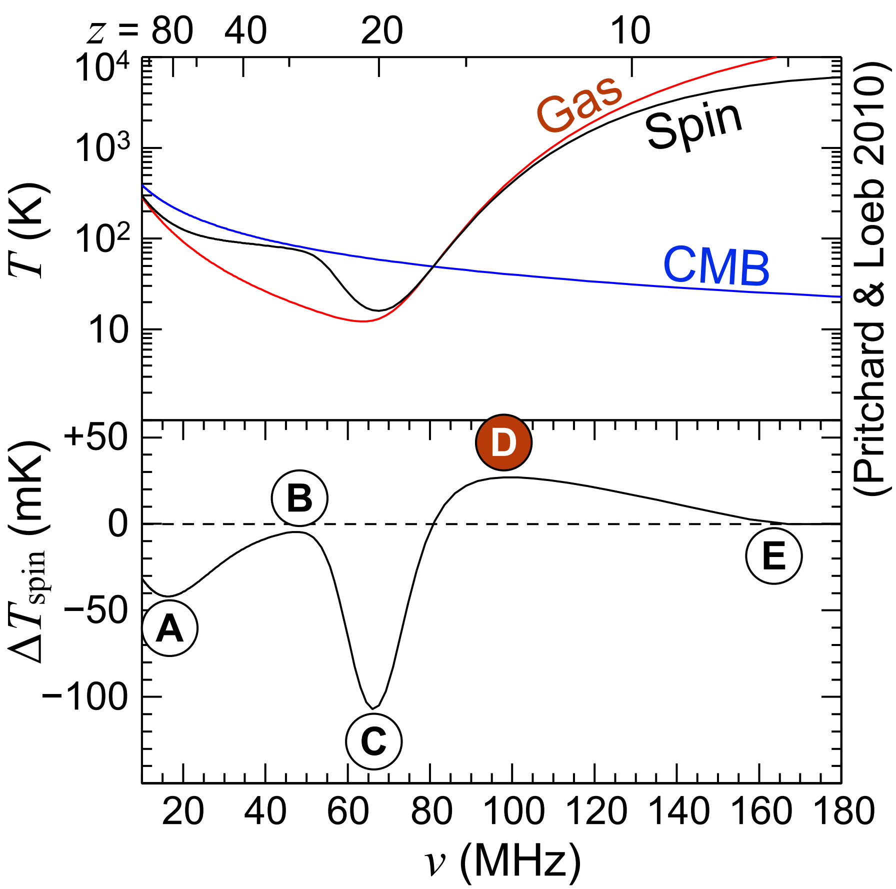
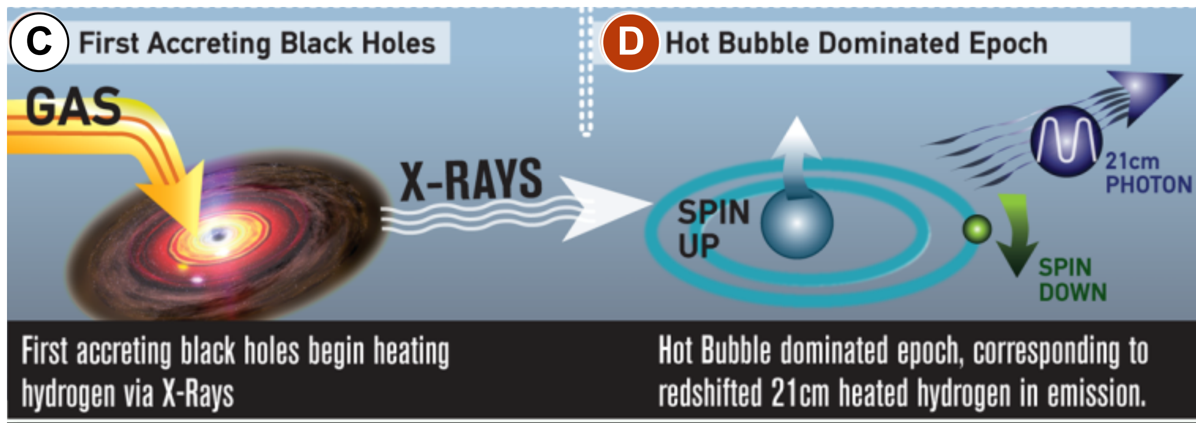
Cosmic Dawn and Reionization







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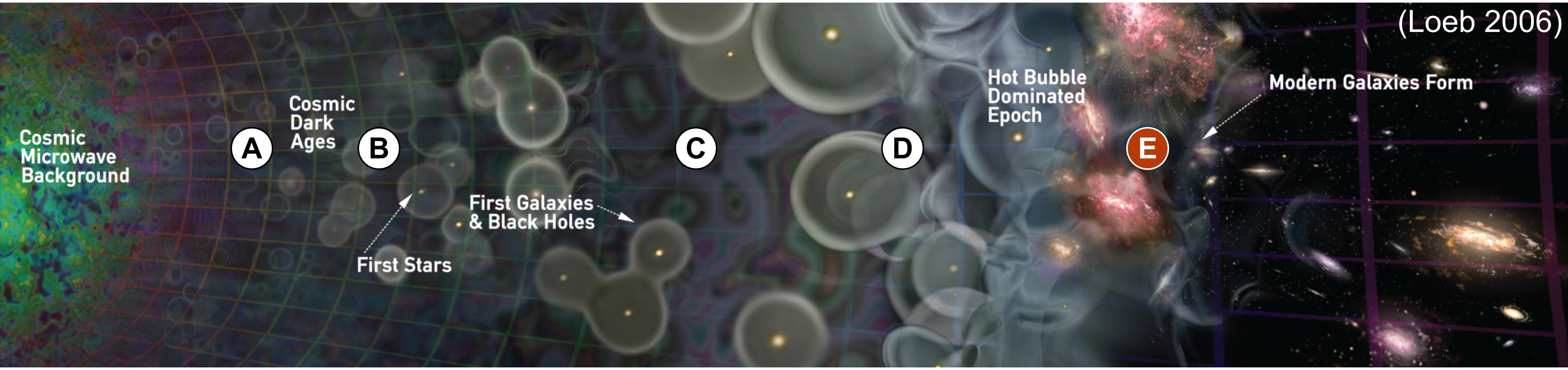
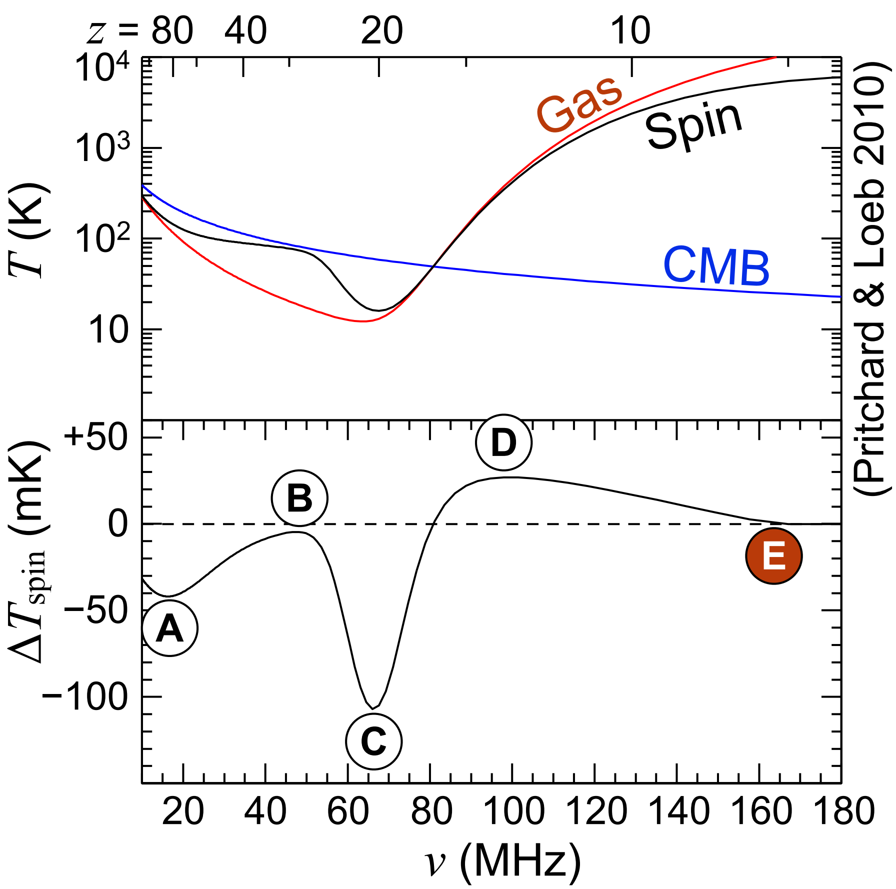
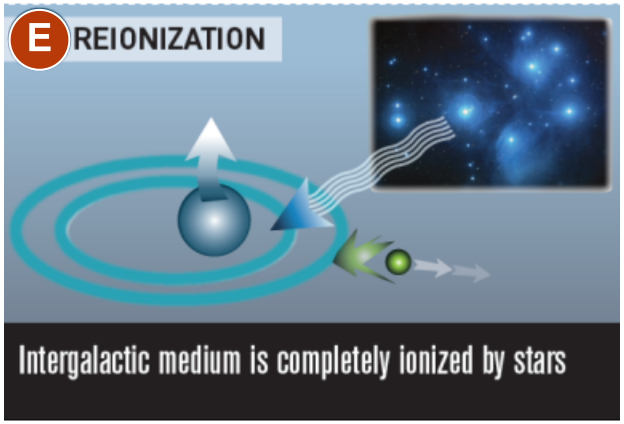
Cosmic Dawn and Reionization







Reionization is complete.

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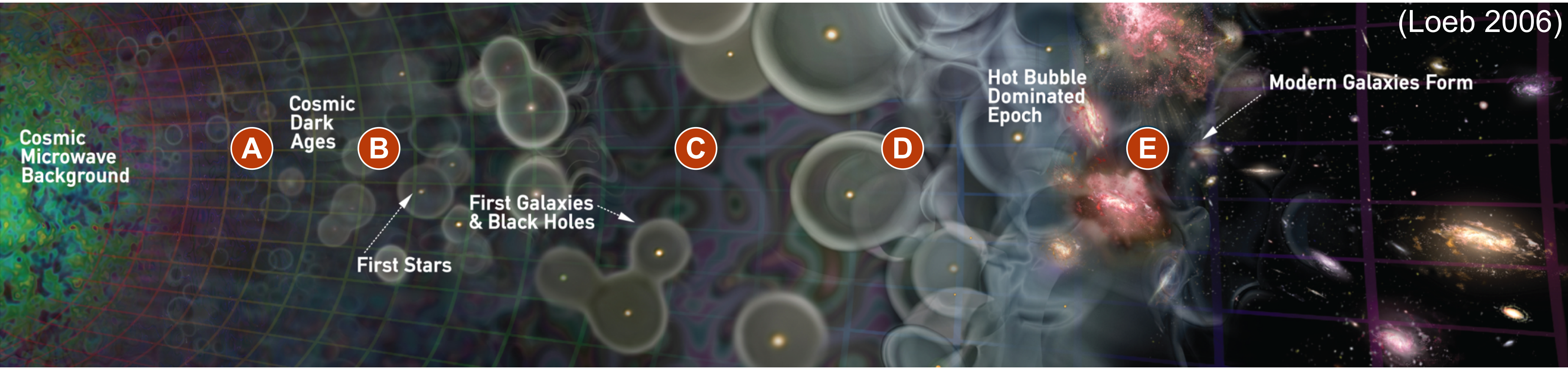
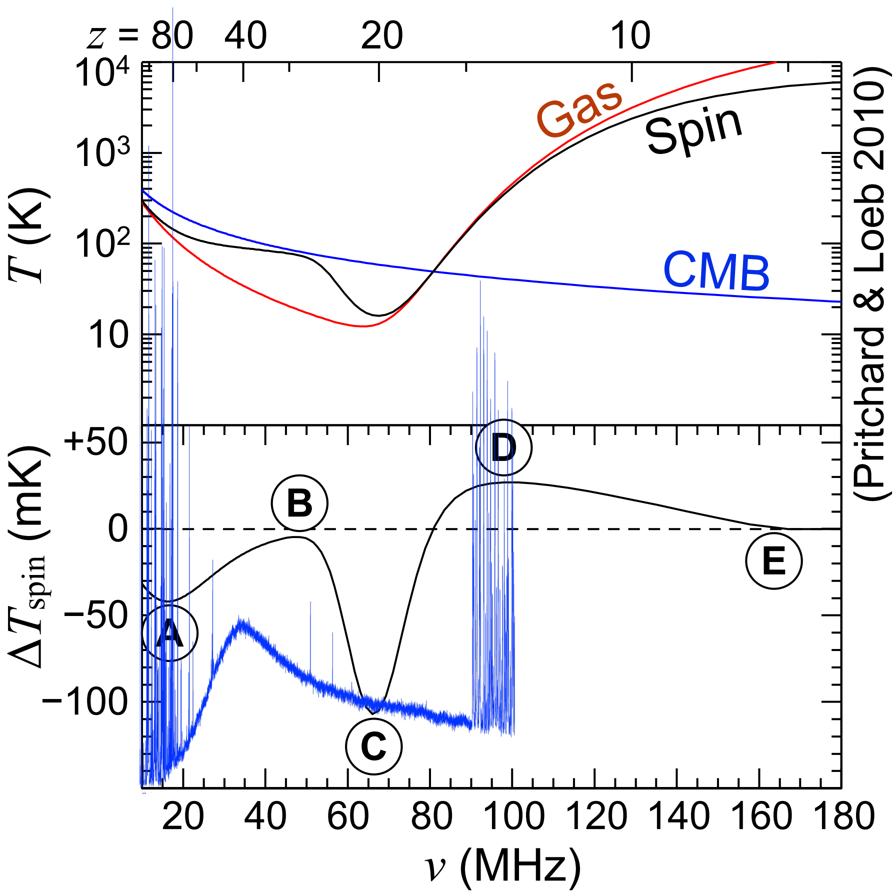
Cosmic Dawn and Reionization





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

But it requires 1 part in ~10^5 relative spectral calibration!

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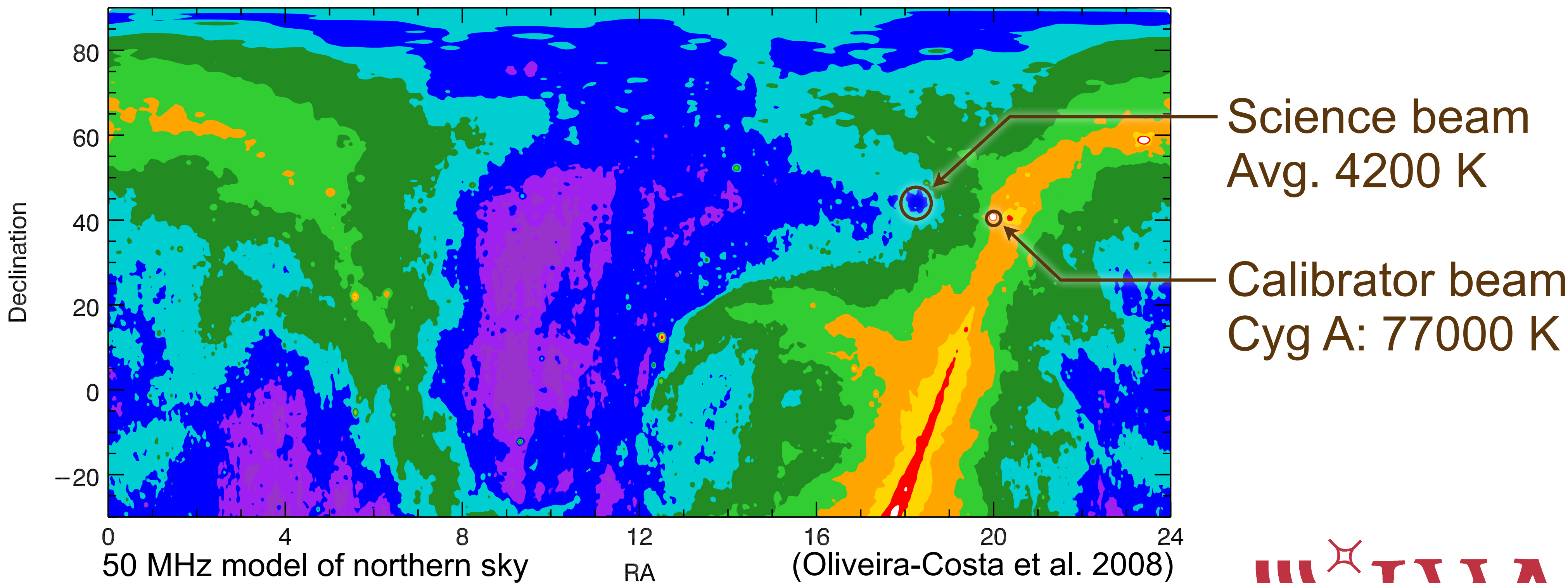
Cosmic Dawn with the LWA1

- Observations use all four beamformers to make two effective beams, each covering 28–88 MHz
- 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)

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Bandpass calibration

- Benefits: ability to repeat measurements, same signal path
- Observed power in each beam:

$$p_{\rm sci}(\nu) = \; g_{\rm sci}(\nu)\,[T_{\rm sci}(\nu) + \Delta T_{21}(\nu)]$$
$$p_{\rm cal}(\nu) = \; g_{\rm cal}(\nu)\,[T_{\rm cal}(\nu) + \Delta T_{21}(\nu)]$$

($g_{\rm sci/cal}$ = gain, $T_{\rm sci/cal}$ = foreground power)

- Simultaneous beams mean same signal path, so shared $g_i(\nu)$
- Beam gain terms change slowly, are smooth, and are predictable with knowledge of station's EM properties
- Foreground terms must be modeled but should be smooth, with 0–1 inflection points in our bandpass (vs. 3–4 inflection points for the expected 21 cm signal
- Uncertainties due to bandpass calibration should be ~10 mK with 100 hr integration, enough to constrain z ~ 20 feature

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Frequency dependence of sidelobes

- Must prevent frequency-dependent variations in the beams' sidelobes from coupling with foreground structure
- Defocusing the science beam
  - + Averages over more foreground; can lower sidelobe power
  - + Requires different antenna weighting between beams
- Steering sidelobes away from bright sources
  - + Requires excellent model of the electrodynamic profile of station
- Shimmering sidelobes
- Optimal beamforming: accounting for mutual coupling, etc.
  - + Requires excellent model of the electrodynamic profile of station

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Additional scientific 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

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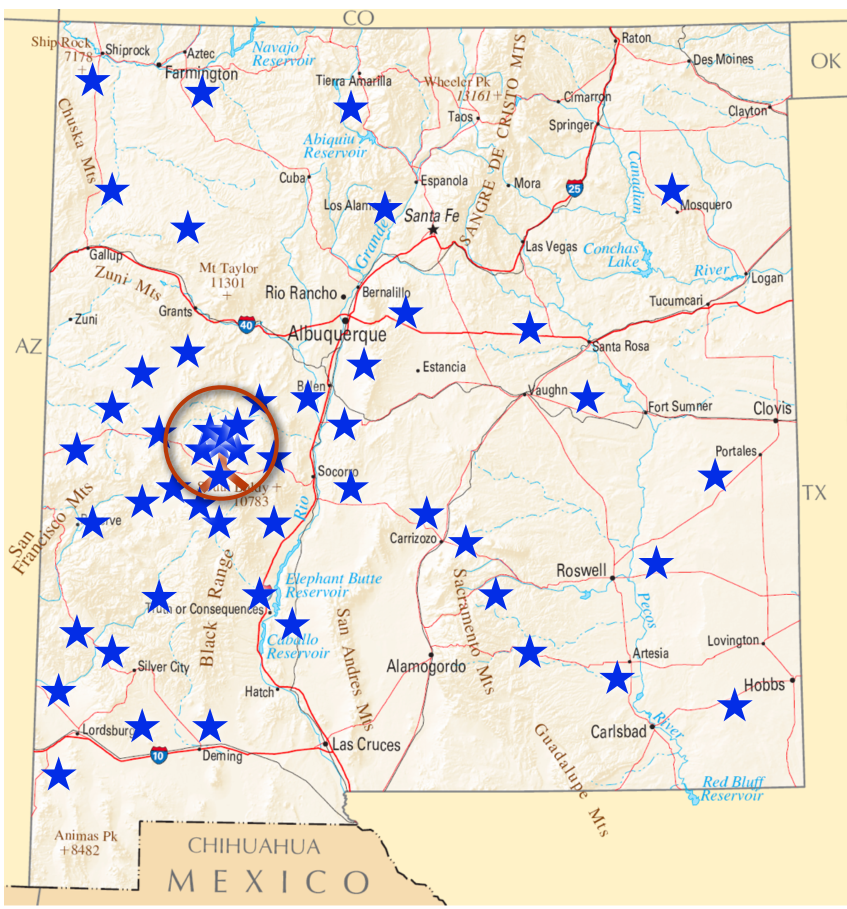
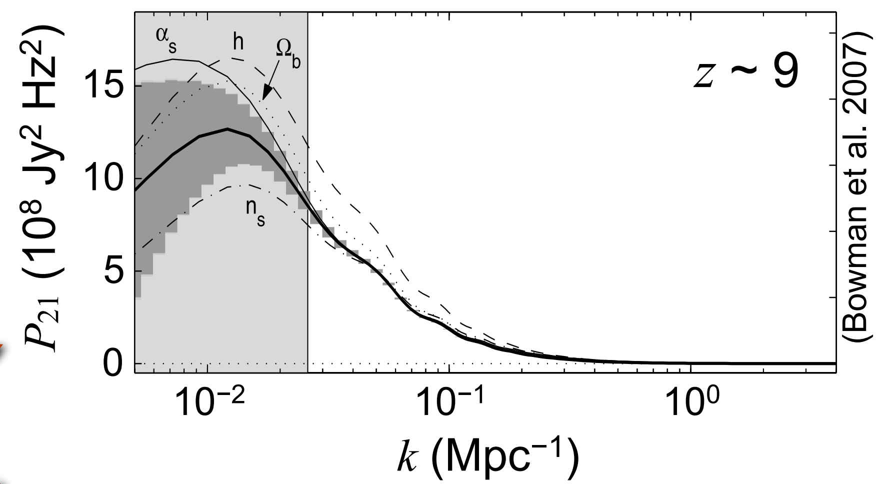
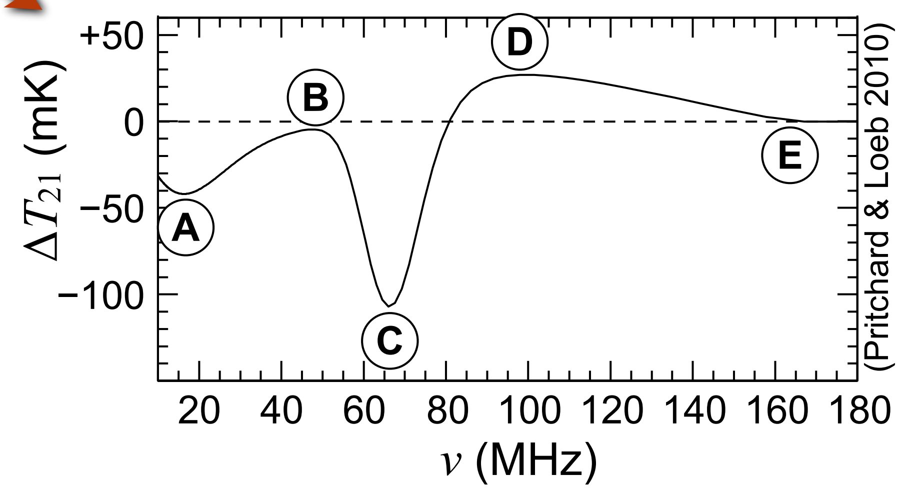
New worlds, new horizons? New stations!

- Core of 16 stations within a 10 km diameter:
  ~1.6 arcmin resolution at 65 MHz ⇒ $k < 8$ Mpc^{-1} at $z = 20$
- Both frequency and angular spectra: *no one else can do this!*
- Spatial variability of the heating by first stars, black holes
- “Purer” cosmology than the reionization experiments







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
- Will develop 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

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