# The Large-aperture Experiment to detect the Dark Ages (LEDA)

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**(for the LEDA collaboration)**

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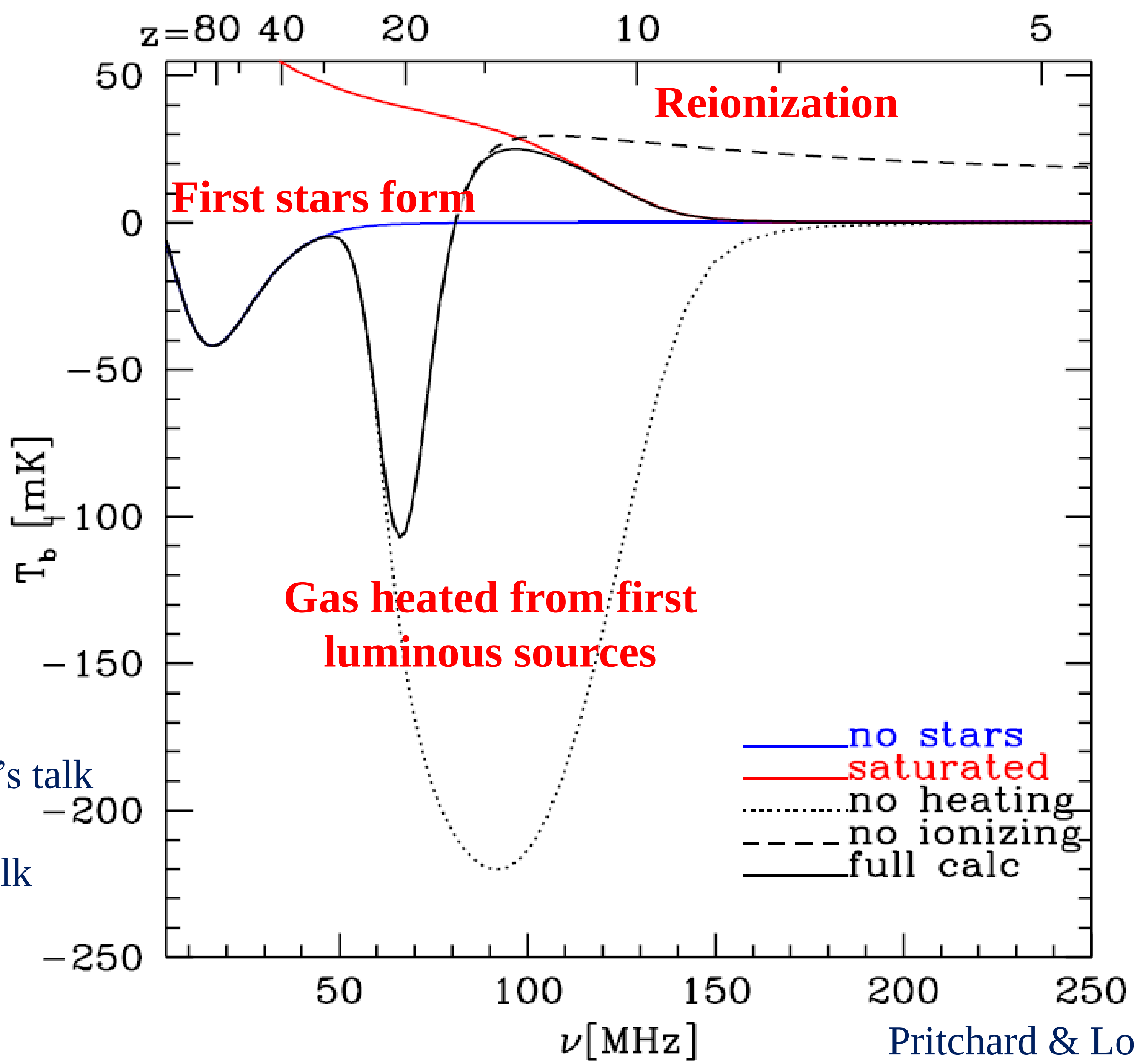
"The radio Universe @ Ger's (wave)-length", Nov 4-7 2013

# Global HI signal evolution




See also
Subrahmanyan's talk
and
Vedantham's talk

Pritchard & Loeb (2010)

# "Data model" for an HI global experiment

$$T(\nu) = \int_T dt \left[ \left( \int_\Omega d\theta d\phi A(\theta,\phi,\upsilon) T^{sky}(\theta,\phi,t,\upsilon) \right) g(t,\upsilon) + n(t,\upsilon) \right]$$

Measured spectrum

Antenna gain pattern

Receiver gain

Receiver noise

Sky signal = $T^{sky}(\theta,\phi,t,\nu) = T^f(\theta,\phi,t,\nu) + T^{HI}(\nu)$

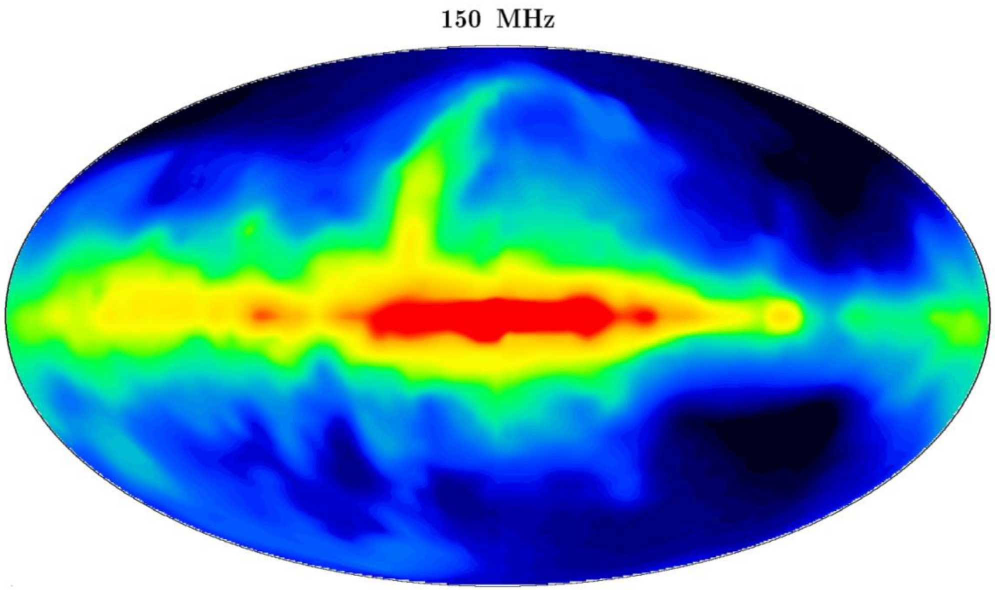
# The Experiment to Detect the Global EoR Signal (EDGES)

J.D. Bowman (ASU) & A. Rogers (MIT)

**Table 1.** EDGES Specifications

| | |
|---|---|
| Antenna configuration | "Fourpoint" dipole (Suh et al. 2003) |
| Antenna beam (FWHM) | $\sim 80°$ |
| Instantaneous band | 90 to 205 MHz |
| Polarization | Single |
| Digitizer sample rate | 420 Ms/s |
| FFT samples | 32,768 |
| FFT spectral resolution | 12.817 kHz |
| Window function | Blackman–Harris |
| Window function efficiency | 0.5 |
| Window function resolution | 26 kHz |
| Operational dynamic range | $> 10^6$ |

# Foreground subtraction relies on their spectral smoothness…




Landecker & Wielebinski (1970)

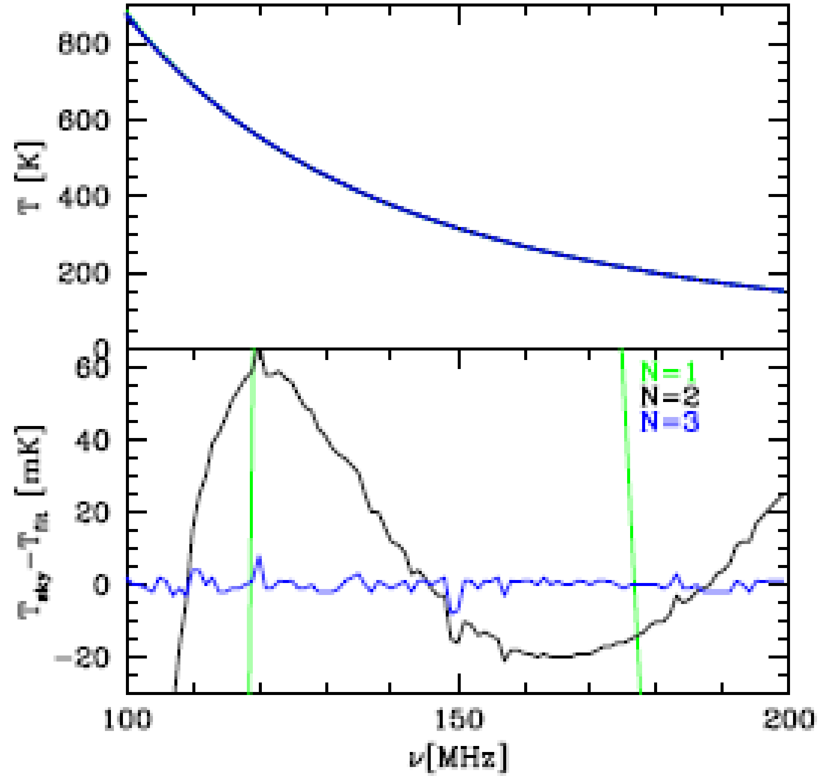
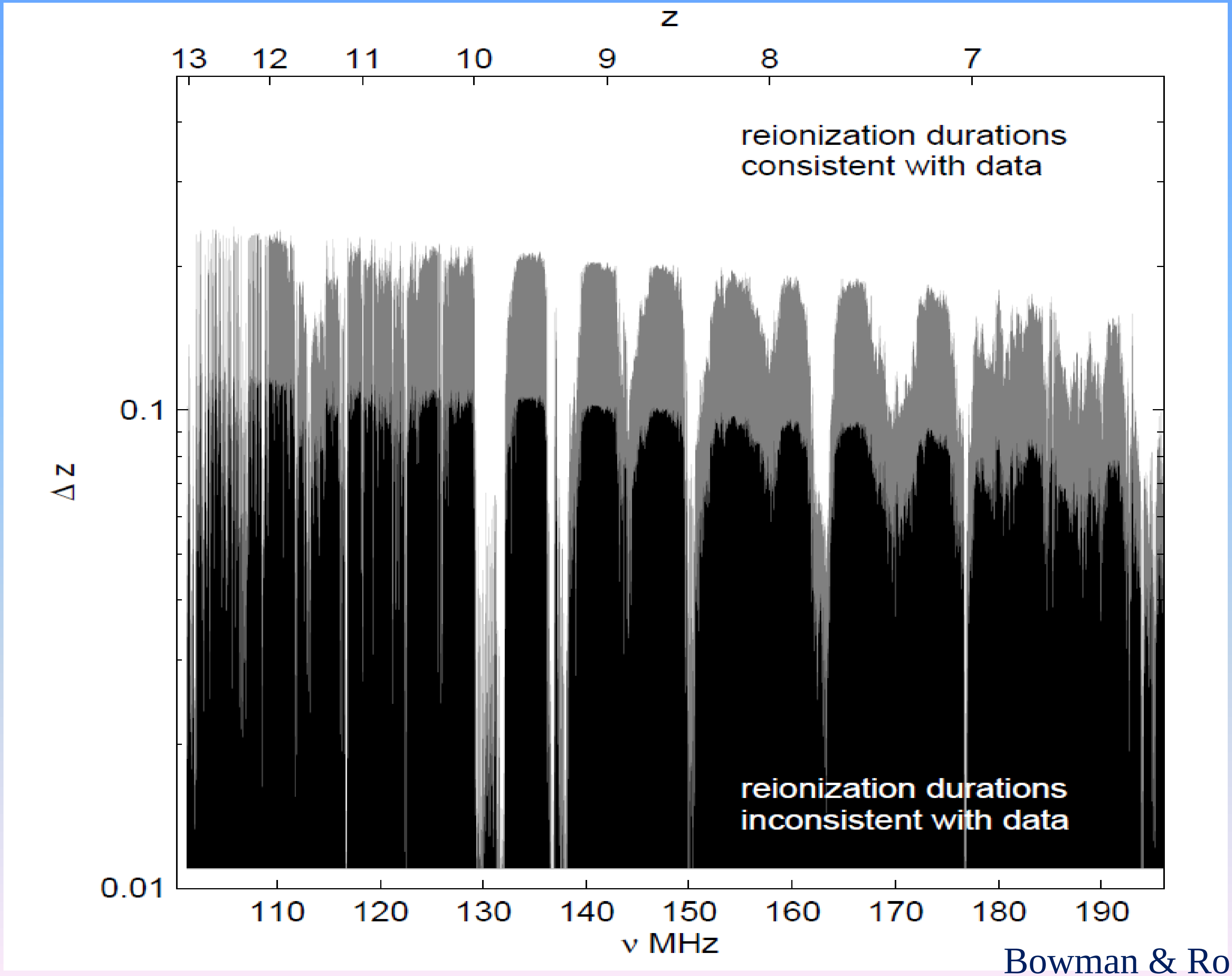



FIG. 4: Foreground (top panel) and residuals (bottom panel) left over after fitting a N-th order polynomial in log ν to the foreground.

Pritchard & Loeb (2010)
Harker et al. (2012)
Liu et al. (2013)
Vedantham et al. (2013)

# EDGES lower limit on the duration of reionization




Bowman & Rogers (2010)

The Large-aperture Experiment to detect the Dark Ages (LEDA, PI: L.J. Greenhill, co-PIs: S. Ellingson, G. Hallinann, G. Taylor, D. Werthimer) http://www.cfa.harvard.edu/LEDA/index.html)

# LEDA

LARGE-APERTURE EXPERIMENT TO DETECT THE DARK AGES

# Simulations of the LEDA approach: coupling between the sky brightness and the dipole pattern

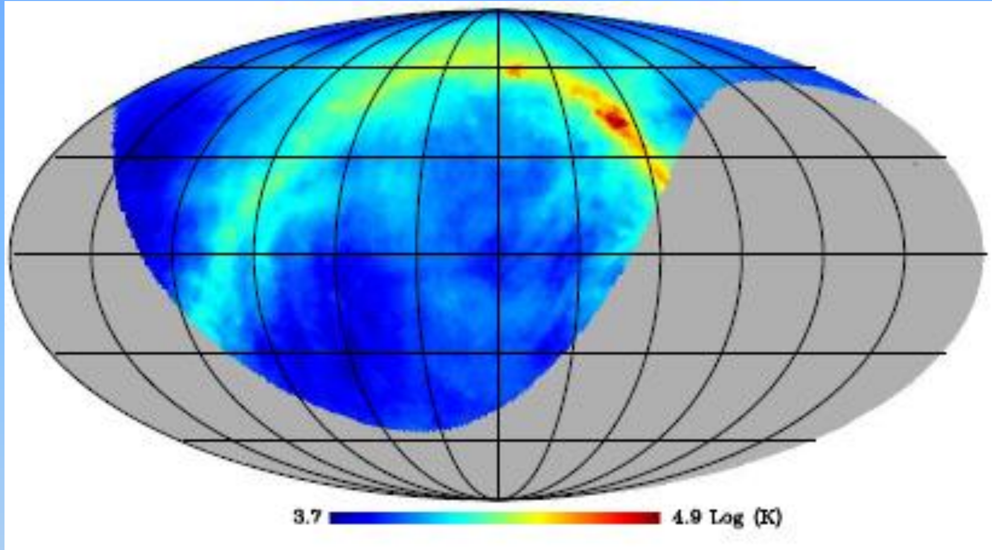
(GB, McQuinn, Greenhill)

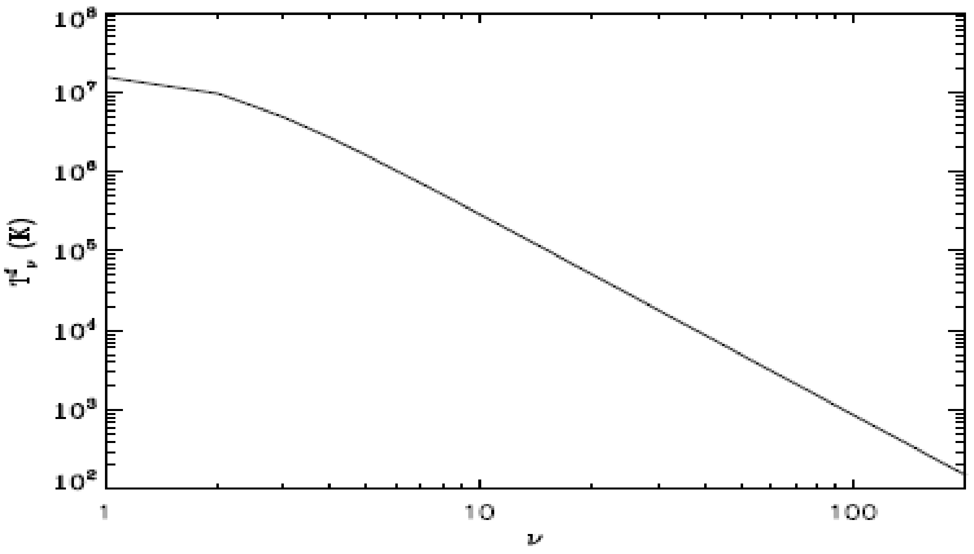
The sky model uses:

- the Landecker & Wielebinski 150 MHz all sky map;
- a spectral index map between 408 & 150 MHz;
- adds deviations from a spectral power-law to every sky pixel:

$$T^f(\nu) = \frac{1 - e^{-\tau_\nu}}{\tau_\nu} T^g \nu^{-\alpha_g} + T^e \nu^{-\alpha_e} e^{-\tau_\nu}$$

- spectral model from GALPROP;



# Simulations of the LEDA approach: dipole gain pattern models

- Ideal dipole over a ground plane:

$$A^{d}(\theta,\phi,\nu) = 2\sin(2\pi h\cos\theta)\,(1-(\sin\theta\sin\phi)^{2}$$

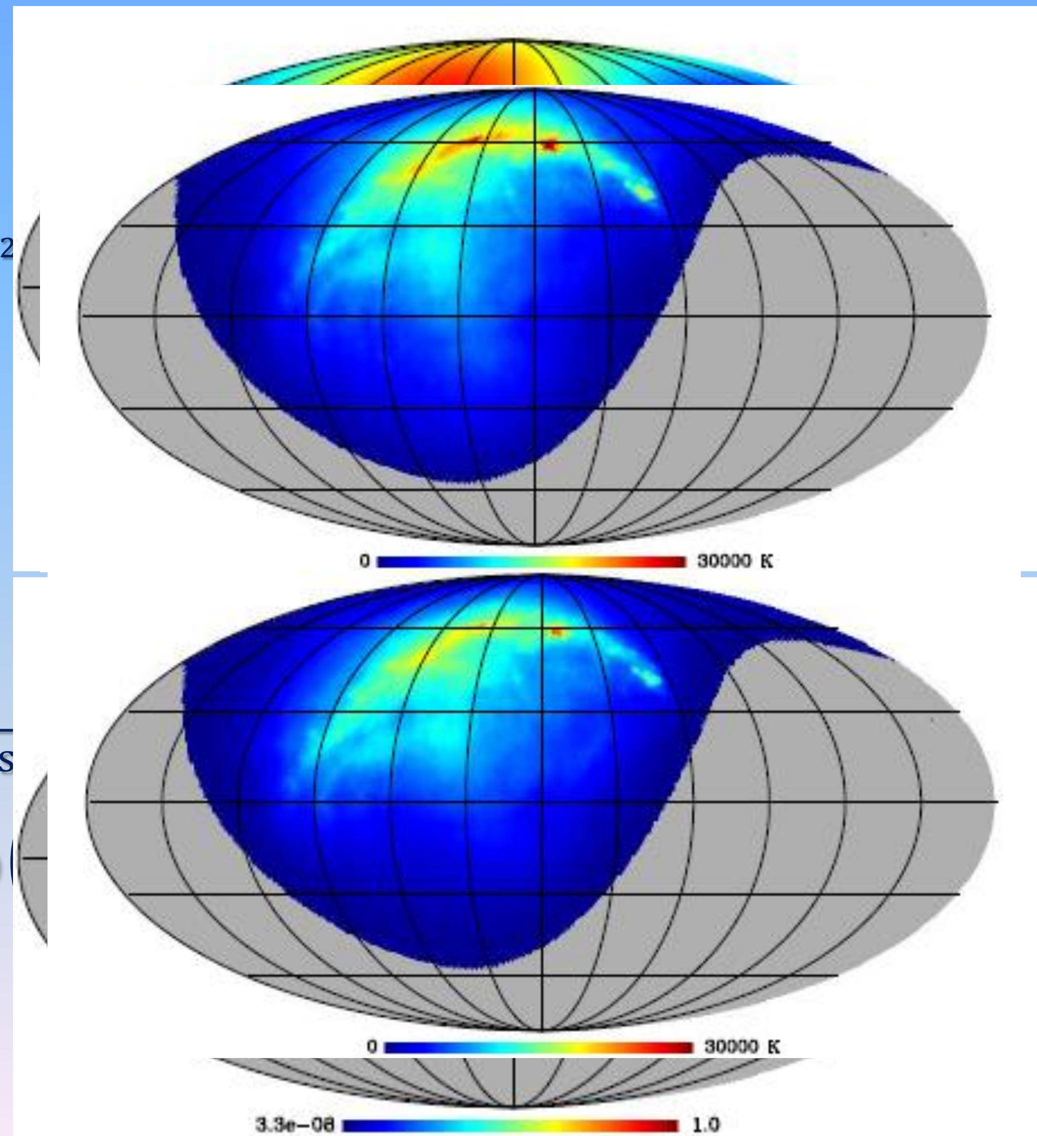
- LWA dipole :

$$A^{LWA}(\theta,\phi,\nu) = \sqrt{(p^{E}(\theta,\nu)\cos\phi)^{2} + (p^{H}(\theta,\nu)\,s}$$

$$p^{i}(\theta,\nu) = \left[1-\left(\frac{\theta}{\pi/2}\right)^{\alpha^{i}(\nu)}\right](\cos\theta)^{\beta^{i}(\nu)} + \gamma^{i}(\nu)\,($$

$$\vec{a}^{i}(\nu) = \left(\alpha^{i}(\nu),\beta^{i}(\nu),\gamma^{i}(\nu),\delta^{i}(\nu)\right)$$

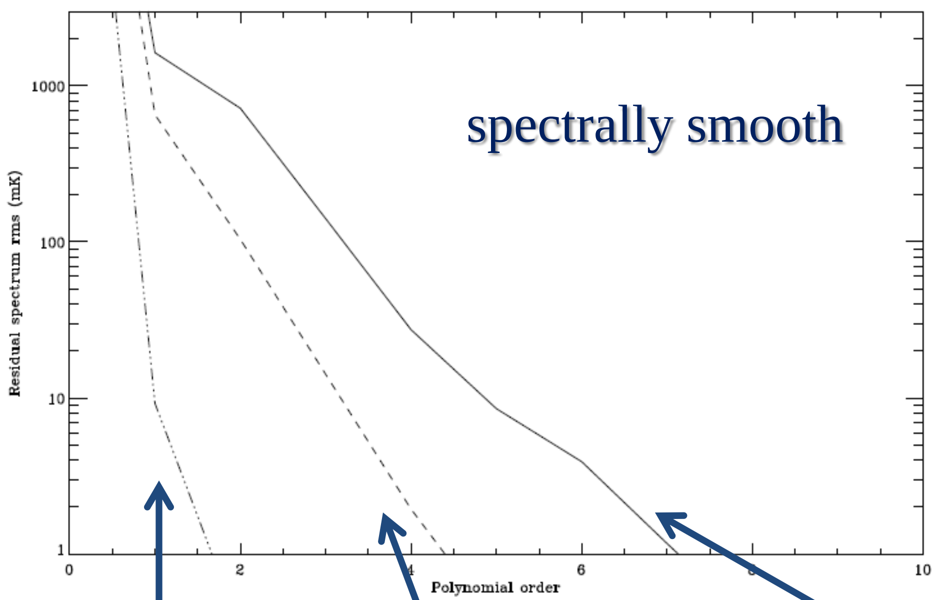
$$\vec{a}^{i}(\nu) = \sum_{n=0}^{m} a^{i,n}\left(\frac{\nu}{\nu_0}\right)^{n}$$

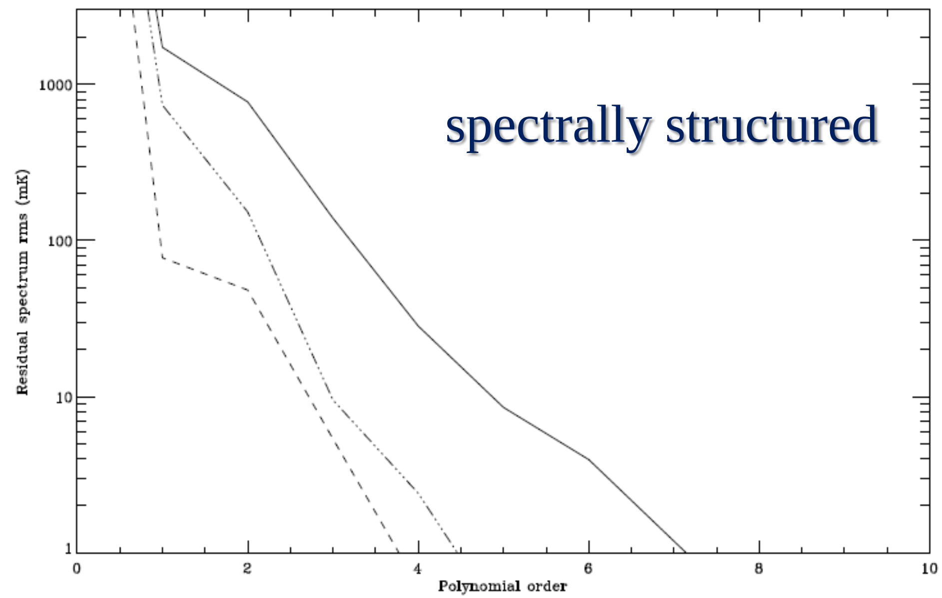


# Parametric modeling of the foregrounds + dipole gain

Foregrounds + dipole gain pattern parameterized by a n-th order polynomial along frequency:

$$\ln T(\nu) = \sum_{n=0}^{N} c^n \left(\ln \frac{\nu}{\nu_0}\right)^n$$




isotropic dipole

ideal dipole over a ground plane

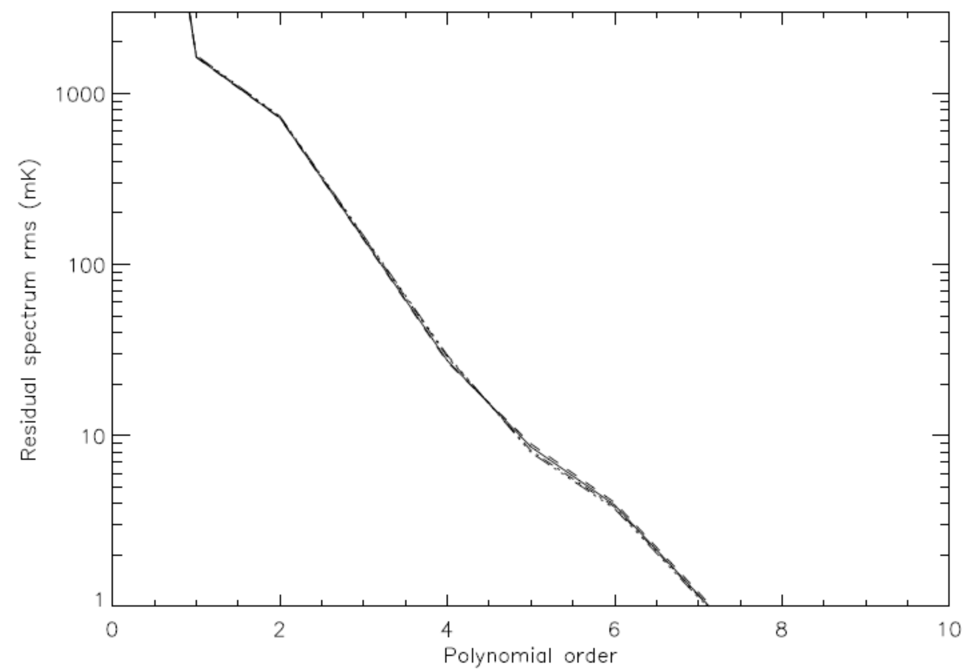
LWA dipole

# Constraining the foreground + dipole pattern with an interferometer

Observe $N_{source}$ sky sources and use them to constrain the average gain pattern. In this case it can be shown that the error per parameter is:

$$\sigma_{par} = \frac{1}{SNR_{source}\sqrt{\frac{N_{chan}N_{source}}{N_{par}}}} \simeq 2.5\% \text{ (for LEDA)}$$

such level of calibration errors does not disrupt frequency smoothness



# LEDA signal extraction

$$T(\nu) = \int_T dt \left[ \left( \int_\Omega d\theta d\phi A(\theta,\phi,\nu) \left( T^{sky}(\theta,\phi,t,\nu) + A_{HI} e^{-\frac{(\nu-\nu_{HI})^2}{2\sigma_{HI}^2}} \right) \right) g(t,\nu) + n(t,\nu) \right]$$

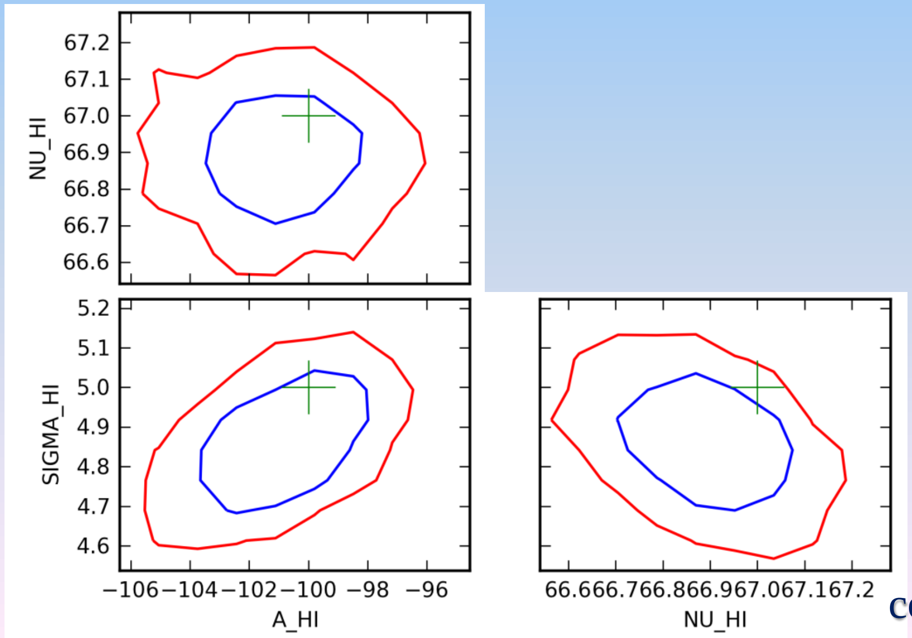
$$\sum_{n=0}^{7} c^n \left( \ln \frac{\nu}{\nu_0} \right)^n$$

from the interferometer

from the calibration source/lab modeling tests

parameterized HI signal

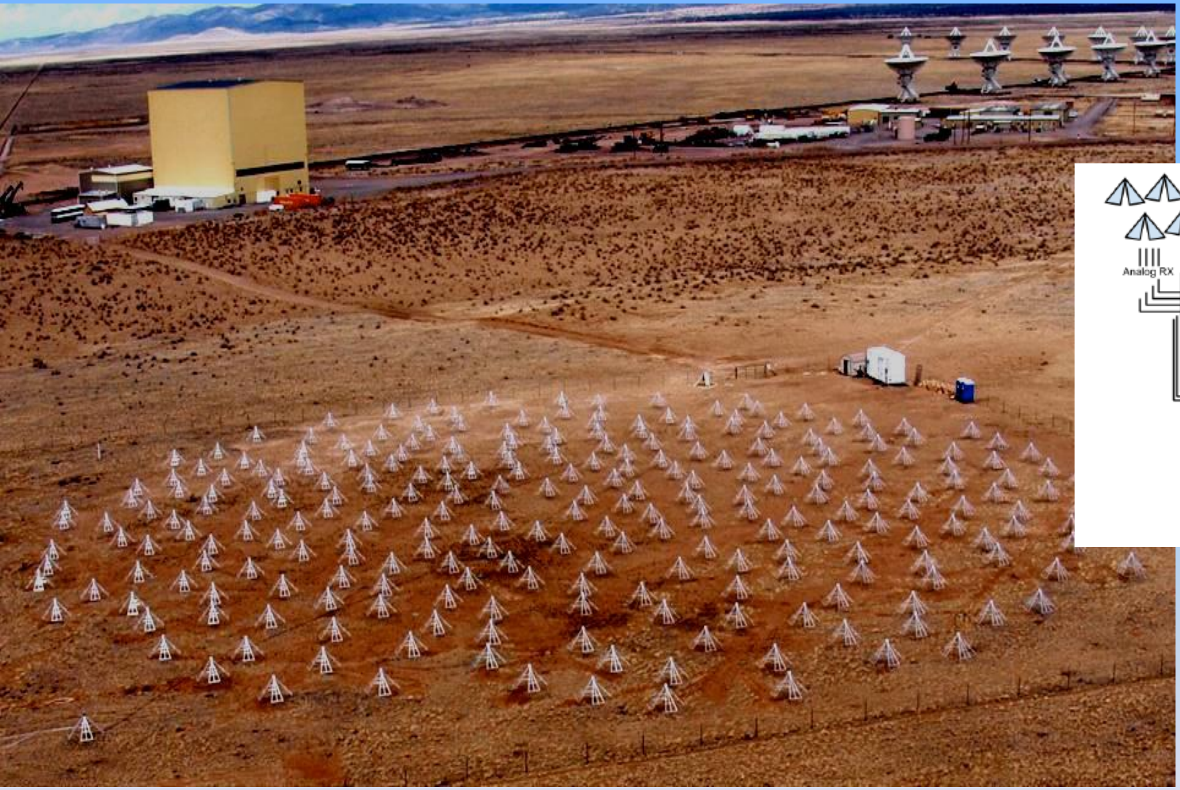
Mix everything in a MCMC…

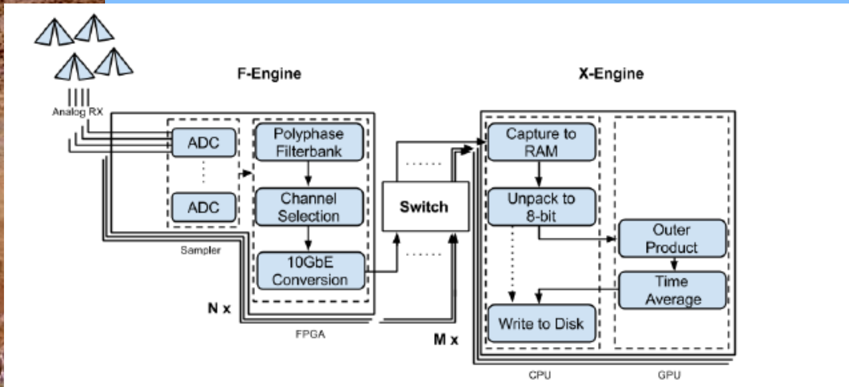



courtesy J. Zwart

# LEDA current status:

- 32 input CPU-GPU correlator deployed and successfully tested at the LWA site (Nov 2012);

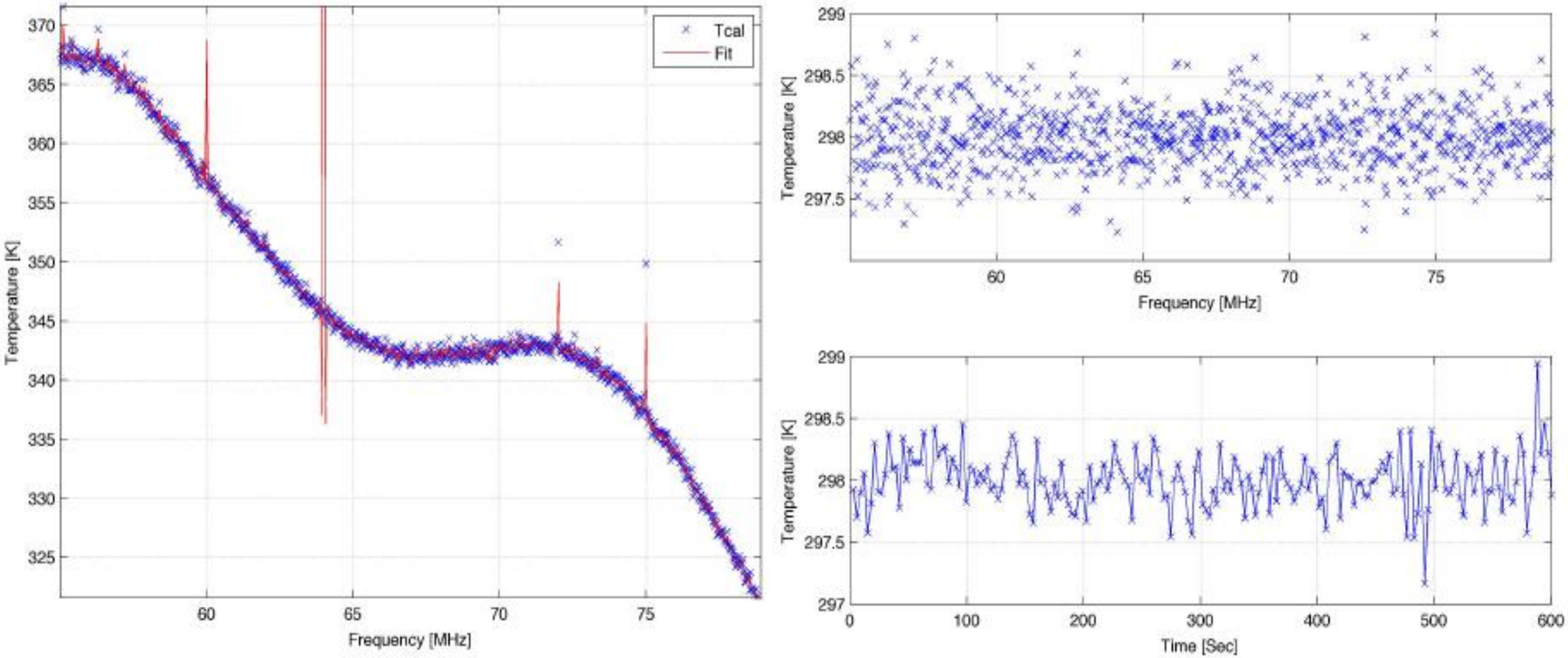





Kocz et al., JAI submitted

# LEDA current status:

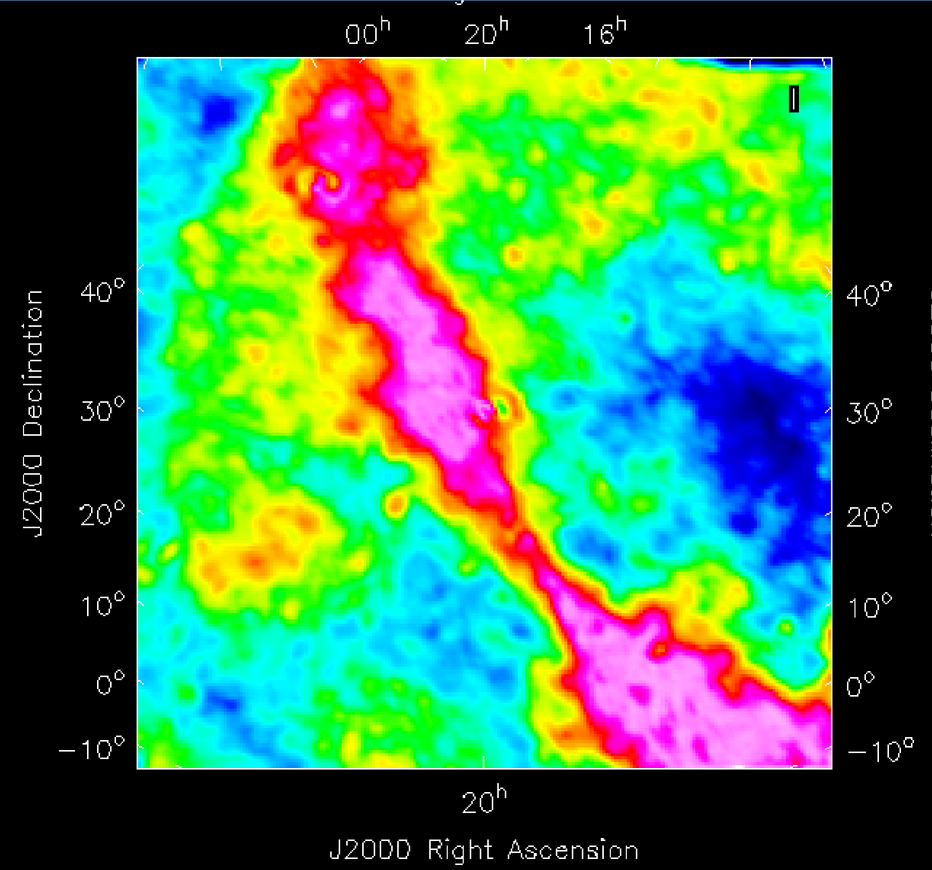
- On going development of the total power front-end…

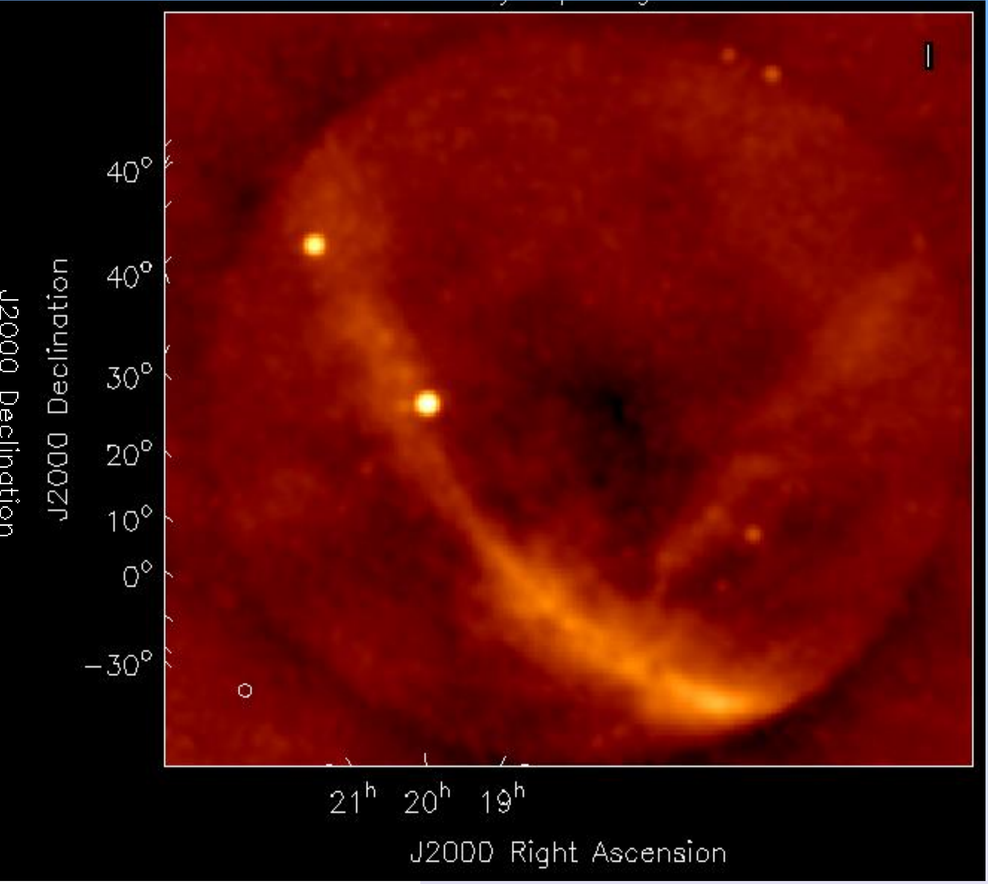



courtesy F. Schinzel & J. Craig

# LEDA current status:

- Oct 2013: successful deployment of a CPU-GPU 512 element at OVRO (Owens Valley);




−600 −400 −200

U (m)

High dynamic range imaging!

courtesy D. Price

# Conclusions

- LEDA is looking to measure the HI global signal in the 15 < z < 35 and it plans to use an interferometric array for foreground and instrument modeling;

- LEDA retains the option of measuring the global signal using lunar occultations (see Vedantham's talk for further details)

- LEDA can also be a power spectrum mac

THANK YOU!

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PROBING THE DARK AGES AT Z~20: THE SCI-HI 21 CM ALL-SKY SPE

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*Draft version November 4, 201*

ABSTRACT

We present first results from the SCI-HI experiment, whi -sky-averaged 21 cm brightness temperature in the redshift range 14.8< $z$ < consists of a single broadband sub-wavelength size antenna and a sampling syst e data processing and recording. Preliminary observations were completed in June a Guadalupe, a Mexican biosphere reserve located in the Pacific Ocean. The data was cleane excise channels contaminated by radio frequency interference (RFI), and the system response was calibrated by comparing the measured brightness temperature to the Global Sky Model of the Galaxy. We present our results, discuss the cosmological implications, and describe plans for future work.

Several ongoing experiments are expected to measure the signal!

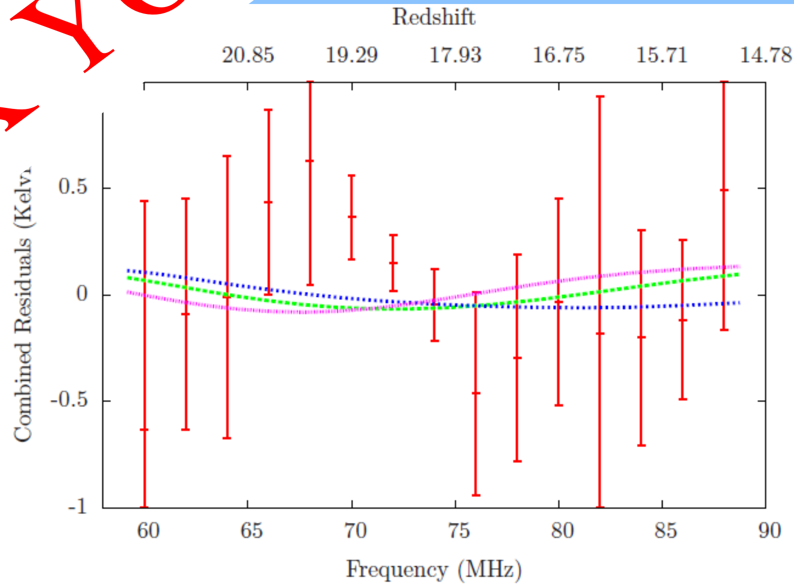


FIG. 5.— Combined residuals from 4.4 hours of integration time. The prediction of three reionization models are also plotted, differing in their star formation efficiency and X-ray heating. The mean brightness temperature is subtracted from each of the theoretical models.