EDGES Memo #045

# California Institute of Technology
## Pasadena, CA 91125
**March 18, 2009**

To: EDGES Group

From: Judd D. Bowman

Subject: Deployment of EDGES prototype system at Murchison Radio-astronomy Observatory, Boolardy Station, Western Australia

**Summary:** Determining the reionization history of the universe is a major objective of observational cosmology and astrophysics. The EDGES ultra-clean spectrometer is poised to provide the first direct constraints on reionization from redshifted 21 cm emission. Results from this engineering-test field deployment are already within a factor of only ~3 of constraining realistic reionization scenarios. The observations acquired during this test yield the deepest integration to date at reionization frequencies (100-200 MHz) and represent the first time any instrument, including the MWA and PAPER, has achieved sensitivities at the level expected for 21 cm emission. As such, the observations described here already retire key risks associated with these experiments, demonstrating that it is possible to reach ~10 mK sensitivities with low-frequency radio instruments at the MRO.

**Background:** The EDGES prototype system has recently been upgraded with a new ADC board, the Acqiris DP310 (12-bit, 420 MS/s), and the addition of an out-of-band noise source injected after the comparison switch to dither the total power entering the ADC. The new system was taken to the Murchison Radio-astronomy Observatory (MRO) at Boolardy Station in Western Australia and deployed near the CSIRO on-site field office from 25-Jan-2009 through 12-Feb-2009. Ten days of high-quality around-the-clock observations were acquired with the system. In total, approximately 50 hours of sky integration were accumulated. Figure 4 shows the preliminary integrated spectrum.

**Technical performance:** We fit an $11^{th}$-order polynomial to the measured spectrum between 105-205 MHz and plot the residuals in Figure 5. The residuals are found to follow a Gaussian distribution and have 130 mK rms in 30 kHz spectral channels. After smoothing the residuals to 2.5 MHz spectral resolution, the rms is 19 mK. Figure 6 shows that the rms of the residuals as a function of integration time follows a $t^{-1/2}$ trend closely for the entire 50 hours of observations.

**Science:** A a maximum likelihood analysis was performed to test a simple model for the mean 21 cm emission during reionization. The model has only a single astrophysical parameter, the amplitude of 21 cm emission before reionization begins, and assumes that reionization spanned a period given by $\Delta z \approx 0.2$, which corresponds to the most rapid physically plausible reionization scenario (Wyithe and Loeb 2004b, 2005; Furlanetto and Oh 2005). In order to account for the power-law Galactic continuum spectrum, we include 11 nuisance parameters in this analysis that allow the $11^{th}$-order polynomial fit to be performed simultaneously and marginalized out in the final constraints. The constraints from this model are shown in Figure 7 and rule out a step-like 21 cm contribution that has amplitude $\geq$90 mK over most redshifts between $6.5<z<10$. Since the expected maximum amplitude of 21 cm emisison from a fully neutral IGM before reionization is ~30 mK, this limit is within a factor of ~3 of meaningful reionization science.

**Implications for future progress:** The 21 cm constraints found here are directly proportional to the thermal noise in the measured spectrum, thus simply integrating down by another factor of 3 will allow the EDGES prototype system to begin ruling out rapid reionization histories in the very near future. No impediment to achieving this performance with the prototype system is foreseen based on the present measurements.

Figure 1. Initial check-out of the EDGES antenna (foreground) and receiver outside the Murchison Radio-astronomy Observatory on-site field office maintained by CSIRO.

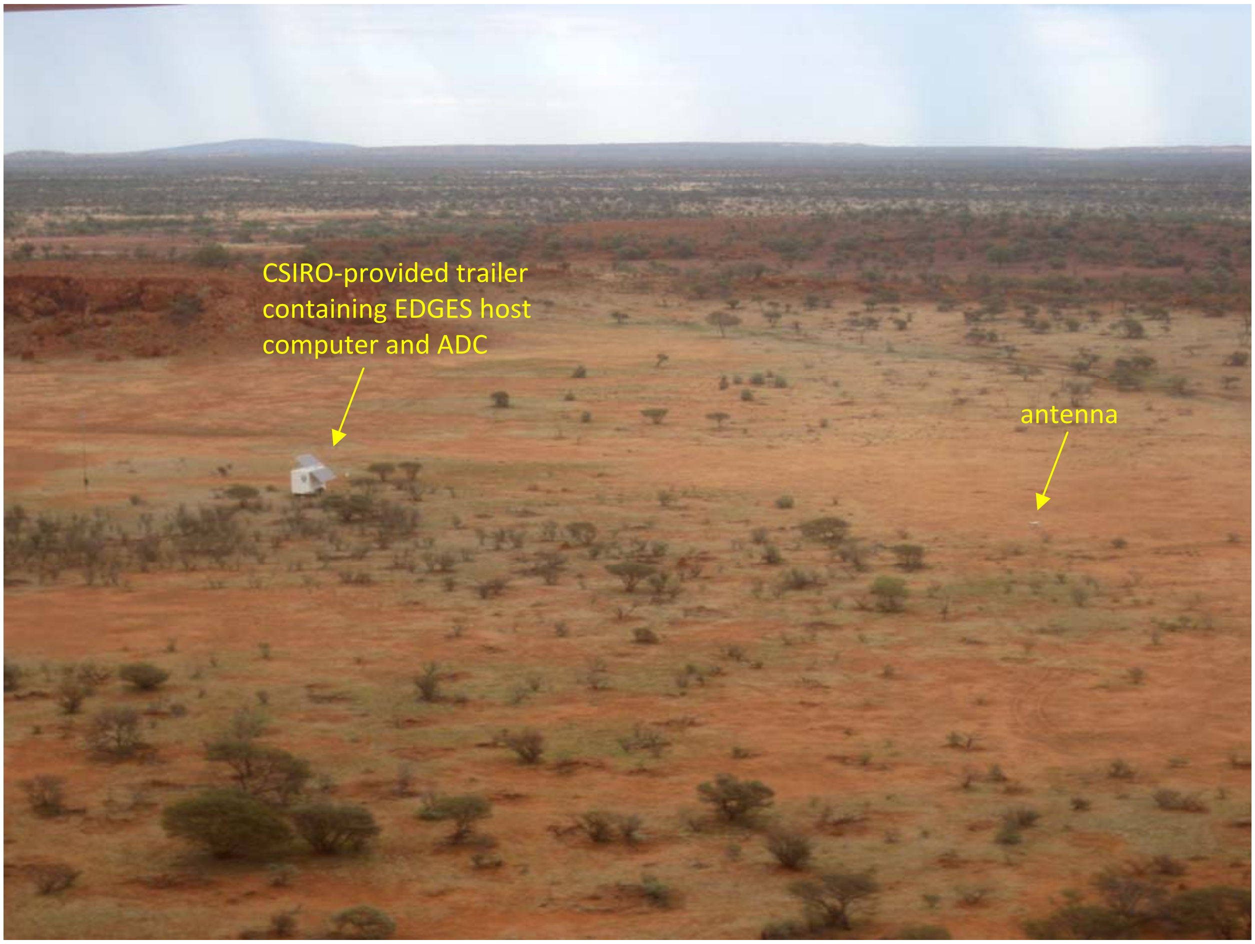


Figure 2. Operational configuration of EDGES. The antenna is about 100 meters south of the CSIRO-provided RFI-monitoring trailier, where the host computer and ADC were installed. The system was powered by the solar panels and batteries within the trailer and was able to run 24 hours per day.

Figure 3. Operational configuration of the EDGES antenna, ground screen, and analog electronics enclosure.

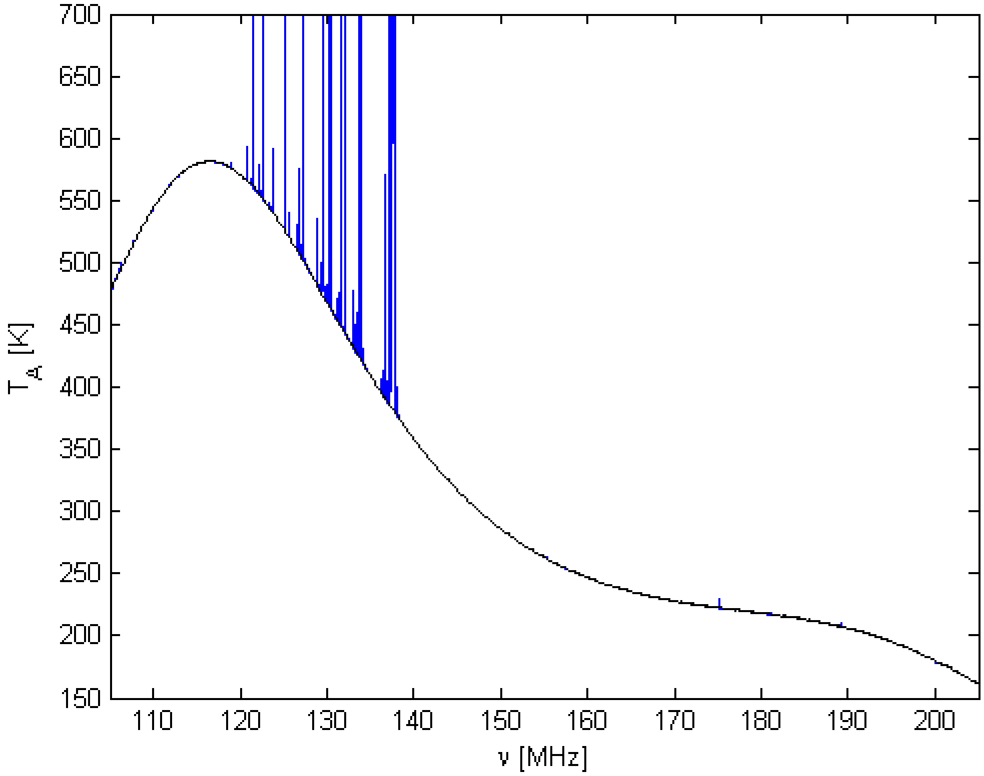


Figure 4. Integrated sky spectrum (modulated from its inherent power-law shape by the antenna reflection coefficient which falls off rapidly below 120 MHz and above 190 MHz). Blue lines indicated channels that contained RFI. The black curve indicates the spectrum after RFI excision. 10 days of observations are used in this spectrum, totaling approximately 50 hours on the sky.

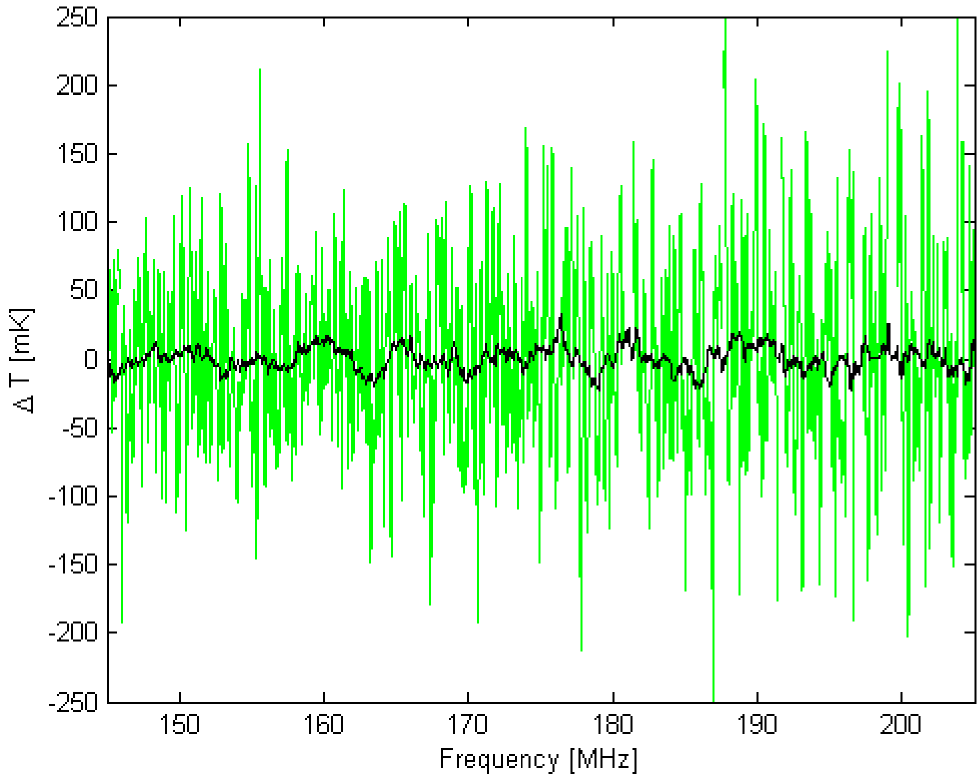


Figure 5. Residuals to 11$^{th}$-order polynomial fit across the entire 105 to 205 MHz band are shown over a subset of the full band. The green curve indicates the residuals in 100kHz spectral resolution. The black line indicates the residuals after smoothing to 2.5 MHz spectral resolution. Note that the scale is in mK. The rms of the residuals is 19 mK after smoothing.

We note that this residual spectrum represents the first time any instrument has integrated down to levels comparable to the expected redshifted 21 cm emission from the reionization epoch. It provides the first confirmation that it will be possible to make deep measurements at the MRO. This is relevant not only for EDGES, but for the MWA and PAPER arrays also under cunstruction at the MRO.

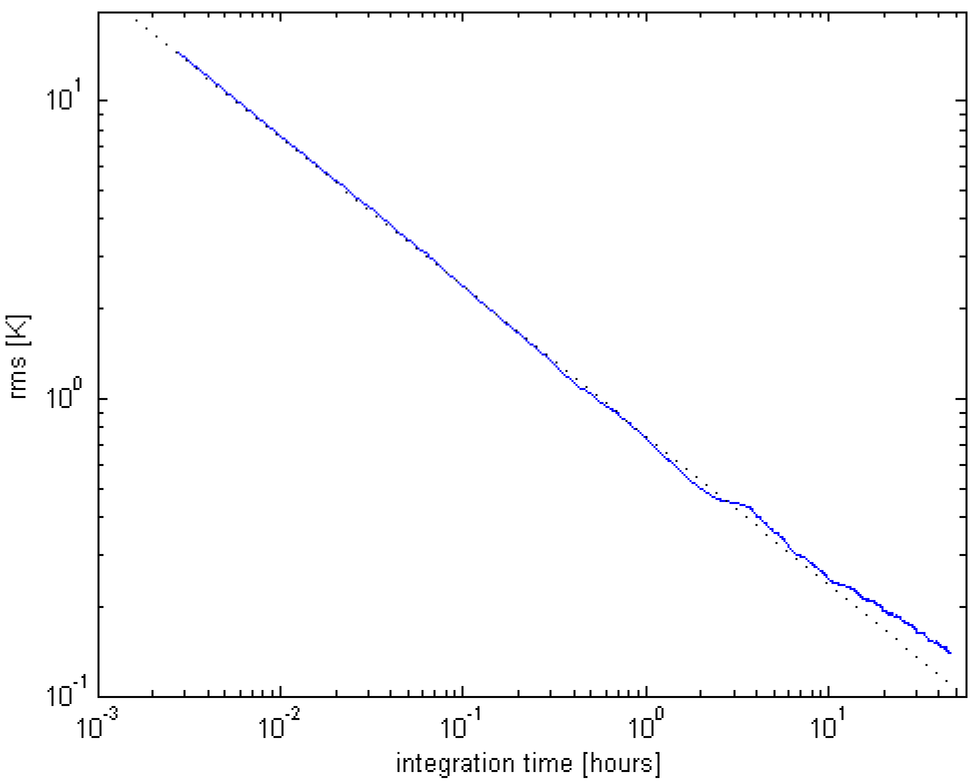


Figure 6. Residual *rms* as a function of integration time. The total integration time is nearly 50 hours. The blue line shows the *rms* of the residuals after an $11^{th}$-order polynomial fit across the 105-205 MHz band. The black dotted line indicates a $t^{-1/2}$ trend that would be expected for integrating down thermal noise with time. The deviation from the thermal trend that begins at approximately 10 hours coincides with a multi-channel burst of RFI that is not excised adequately by the current automatic algorithm and remains clearly visible in residual spectra for all subsequent times. Improvement to the excision algorithm is presently underway and is expected to eliminate this feature.

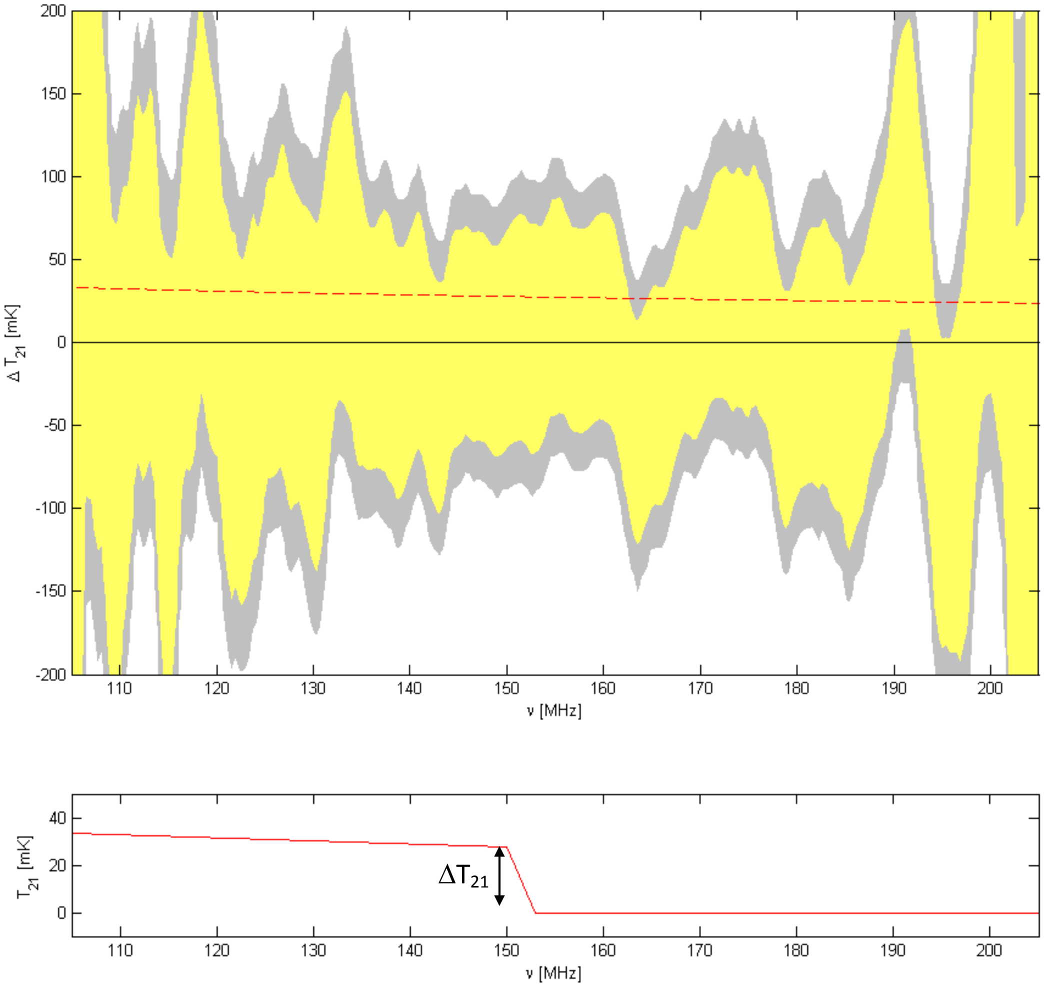


Figure 7. Derived constraints on the maximum brightness temperature contribution due to redshifted 21 cm emission before reionization. The yellow region gives the 68% confidence range, the gray region gives 99% confidence. The red dashed line indicates the theoretical expectation for the mean 21 cm emission from a fully neutral IGM as a function of redshift.

The constraints assume a rapid (but physically plausible) reionization scenario spanning $\Delta z \approx 0.2$ as illustrated at a single redshift in the lower panel. The model has only a single astrophysical parameter, the amplitude of 21 cm emission before reionization begins. In order to account for the power-law Galactic continuum spectrum, we include 11 nuisance parameters in this analysis that allow the $11^{th}$-order polynomial fit to be performed simultaneously and marginalized out in the final constraints.

The current measurements are able to rule out a ≥90 mK step-like feature in the measured spectrum over most of the band between 135-190 MHz, corresponding to redshifts $10>z>6.5$. Thus, the current constraints are within only a factor of ~3 from yielding the first direct astrophysical limits on reionization from redshifted 21 cm emission.

## REFERENCES

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