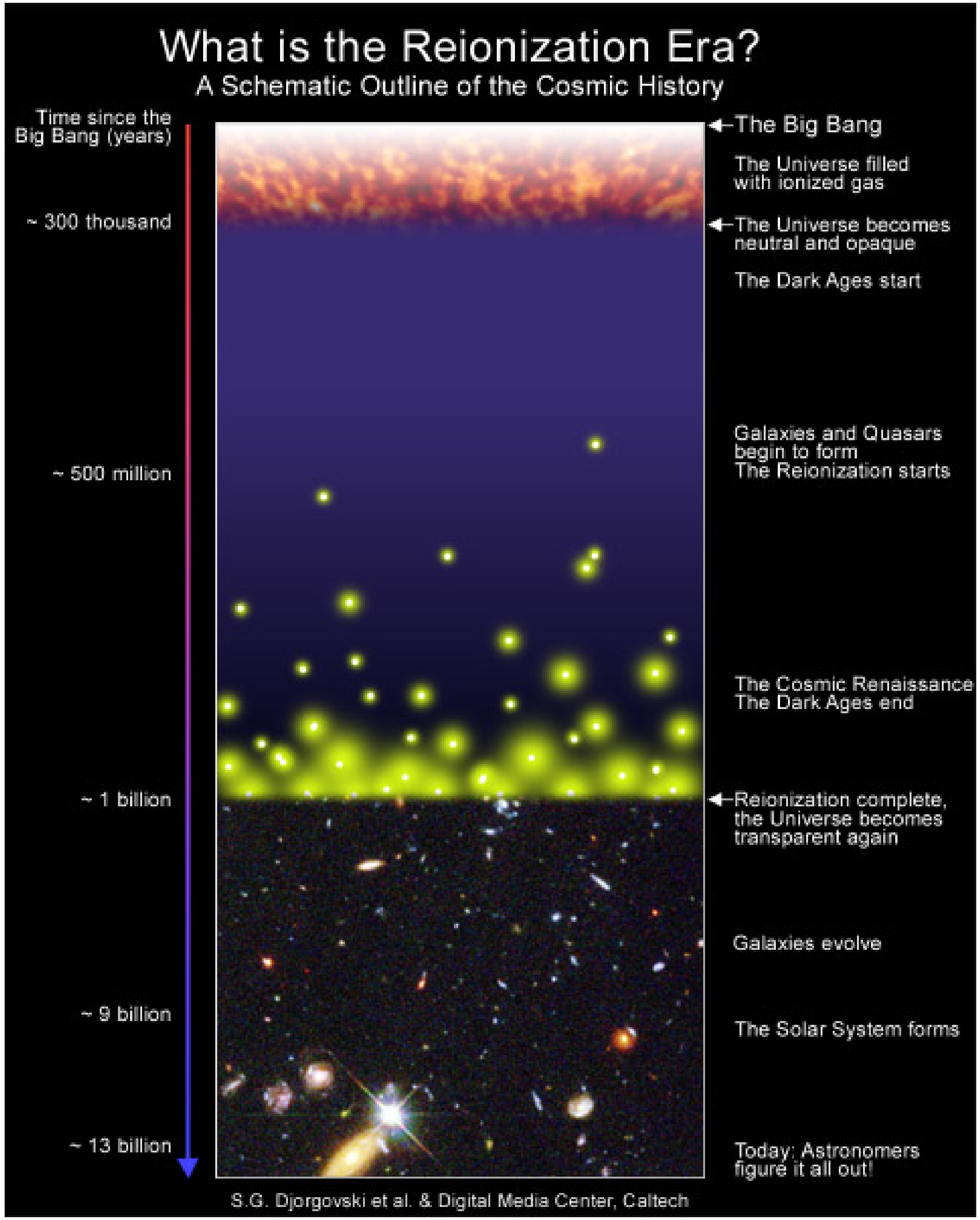
Instruments for studying the Epoch of Reionization (EOR)

Presentation to CORF

by Alan Rogers 27 May 09

Summary

- The Epoch of Reionization (EOR)
- What are the theoretical predictions for what we might be able to observe?
- Quiet site in Western Australia
- Frequency range
- “Single antenna” and imaging arrays
- RFI spectrum at “quiet” sites
- Current status of Experiment to Detect the Global EOR Step (EDGES)


What is the Reionization Era?
A Schematic Outline of the Cosmic History
Time since the Big Bang (years)
~ 300 thousand
~ 500 million
~ 1 billion
~ 9 billion
~ 13 billion
The Big Bang
The Universe filled with ionized gas
The Universe becomes neutral and opaque
The Dark Ages start
Galaxies and Quasars begin to form
The Reionization starts
The Cosmic Renaissance
The Dark Ages end
Reionization complete, the Universe becomes transparent again
Galaxies evolve
The Solar System forms
Today: Astronomers figure it all out!
S.G. Djorgovski et al. & Digital Media Center, Caltech

Theoretical predictions of "bumps" in the spectrum from the red-shifted hydrogen of the early universe

Furlanetto et al. 2004

CMB < Tspin ~ Tkinetic H1 in emission

CMB > Tspin H1 in absorption

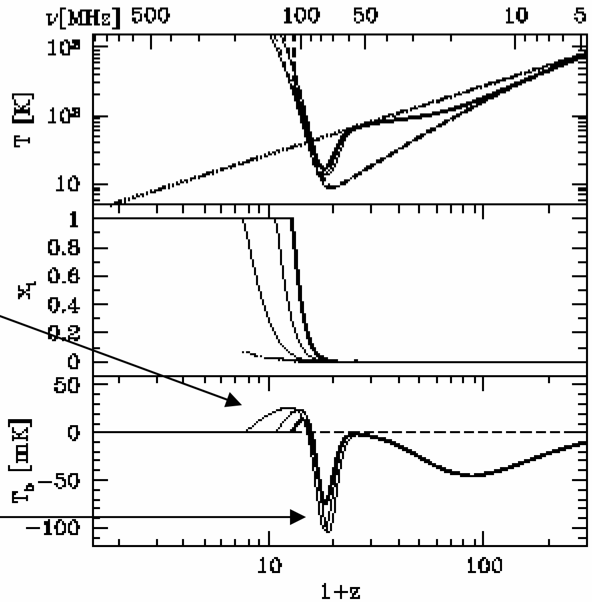


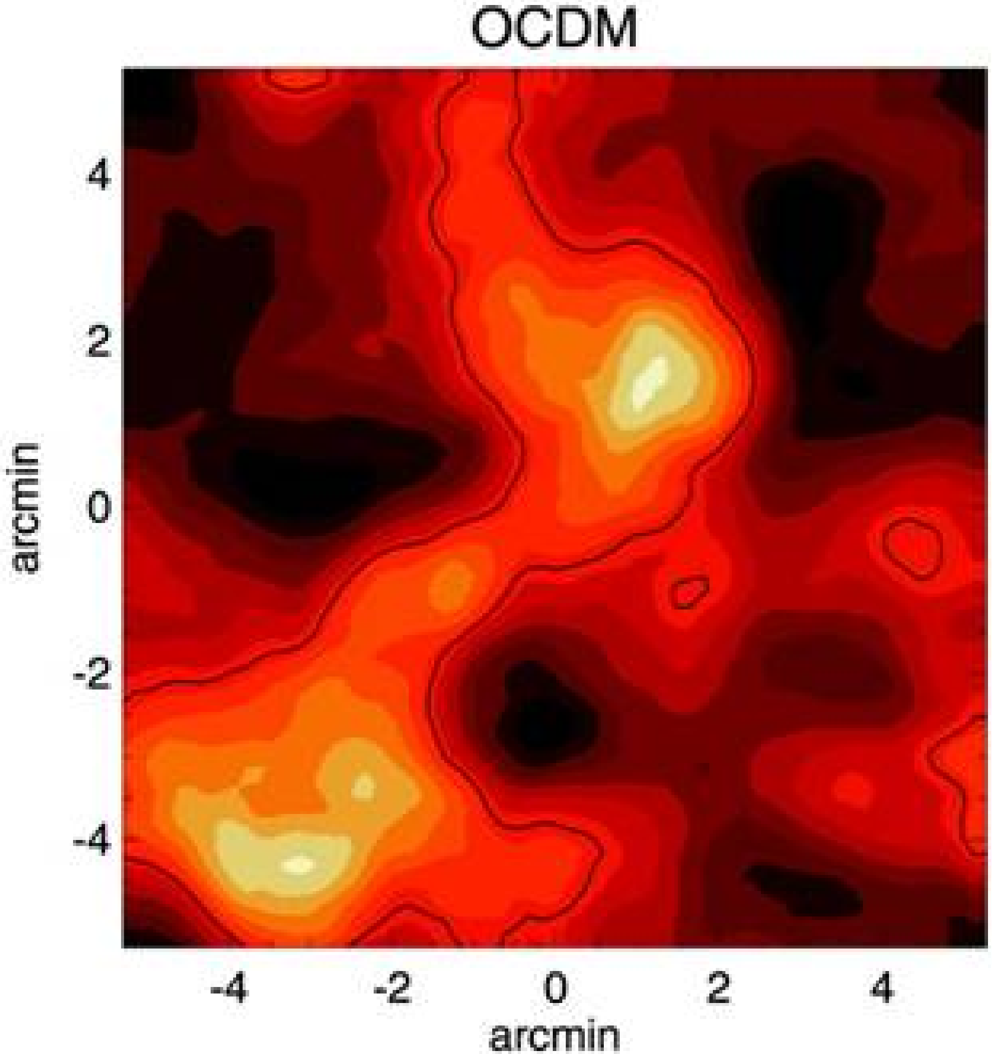
FIG. 1: *Top panel:* Evolution of the CMB temperature T_{CMB} (dotted curve), the gas kinetic temperature T_K (dashed curve), and the spin temperature T_S (solid curve). *Middle panel:* Evolution of the gas fraction in ionized regions x_i (solid curve) and the ionized fraction outside these regions (due to diffuse X-rays) x_e (dotted curve). *Bottom panel:* Evolution of mean 21 cm brightness temperature T_b. In each panel we plot curves for model A (thin curves), model B (medium curves), and model C (thick curves).

lies upon reionization proceeding rapidly leading to a distinctive step-like feature in the frequency direction, which would not be expected to be produced by the spectrally-smooth foregrounds. With the assumption of

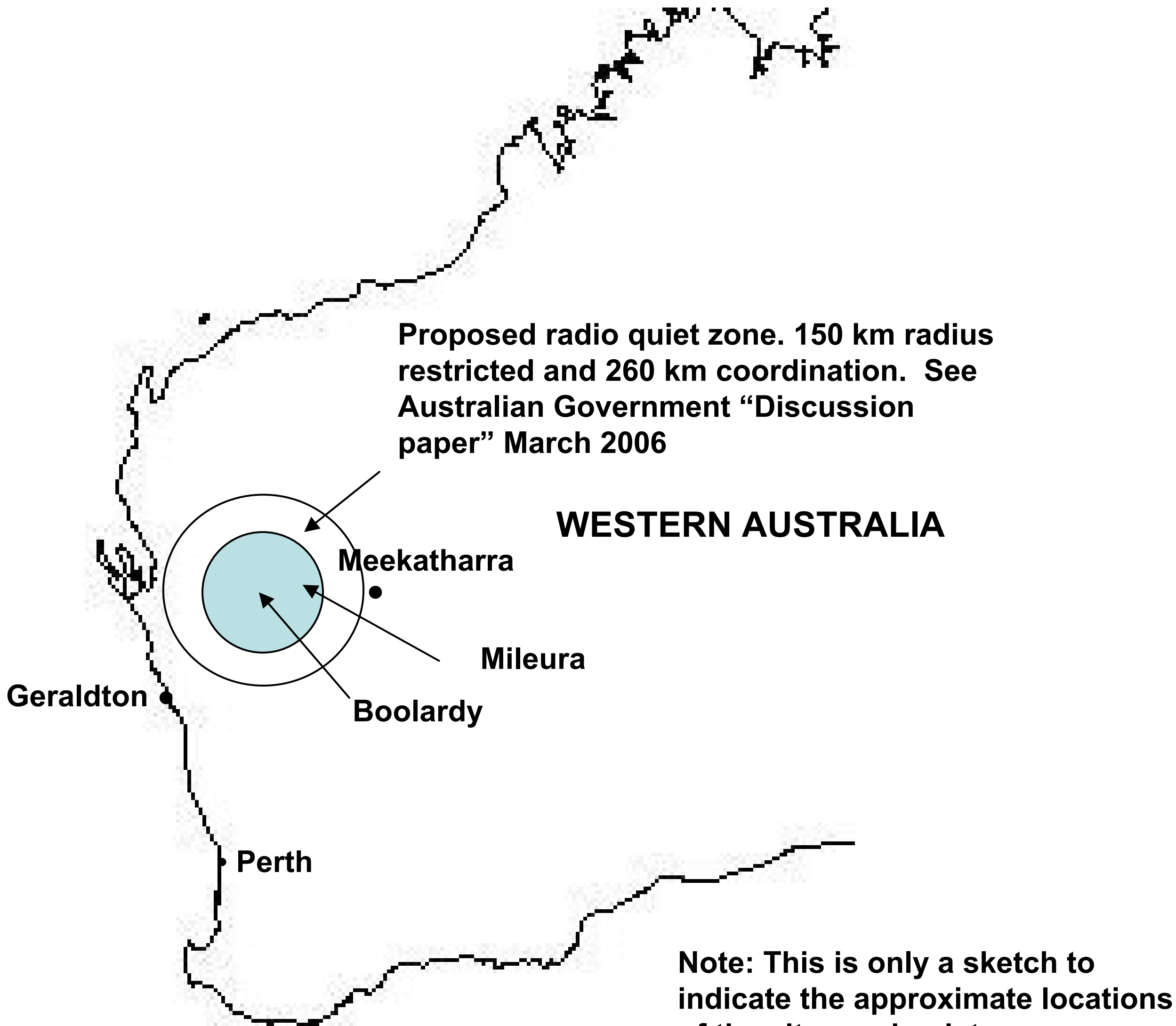
pected that many of our approximations will break down as small scale information about the sources becomes important (see for example [63] for the importance of higher order correlations on small scales during reionization). For the mean histories shown in Figure 1, we calculate the evolution of the 21 cm angle-averaged power spectrum, which is plotted in Figures 2, 3, and 4, for models A, B, and C, respectively.

The evolution of $\bar{\Delta}_{T_b}$ clearly shows three regimes: the post-reionization regime at low redshifts ($z < z_{reion}$) where the 21cm fluctuations from residual hydrogen follow the matter power spectrum, an intermediate redshift regime ($z_{reion} < z < z_{trans}$) where Ly$\alpha$ coupling produces a large signal and complicated astrophysics leads to significant scale dependence, and a high redshift collisionally-coupled regime where 21 cm fluctuations track the density field ($z > z_{trans} \approx 23$). For pedagogical purposes, let us describe the evolution on a single comoving scale (say, $k = 0.1$ Mpc^{-1}) and draw attention to the main features. Thermal decoupling at $z \sim 200$ is a gradual process and, initially, $\bar{\Delta}_{T_b}$ grows due to a combination of the growth of density fluctuations and the steady gas cooling below T_{CMB}. As the gas rarifies and cools, collisional coupling becomes less effective and, at $z \sim 60$, $\bar{\Delta}_{T_b}$ begins to decrease in amplitude. Note that the continuing growth of structure offsets the turnover on $\bar{\Delta}_{T_b}$ from the minimum of T_b, seen in Figure 1 to occur at $z \approx 90$. As collisional coupling diminishes, the signal drops towards zero. This occurs while $T_K < 30$, a regime where $\kappa_{1-0}(T_K)$ drops exponentially with T_K [32] and results in a rapid drop of the signal at $z \lesssim 40$. Before the signal drops all the way to zero, significant star-formation occurs and the resultant Lyα production leads to the beginning of Lyα coupling by $z \approx 25$. The exponential increase in the global star formation rate at these redshifts is responsible for the rapid increase in T_b

Model of the spatial structure of the H-line at the start of star formation



Simulation of redshifted 21cm emission/absorption at z~8.5, from Tozzi et al. (2000). The peak brightness is about 10 mK. The MWA EOR key project aims to characterize such structure, among other EOR diagnostics



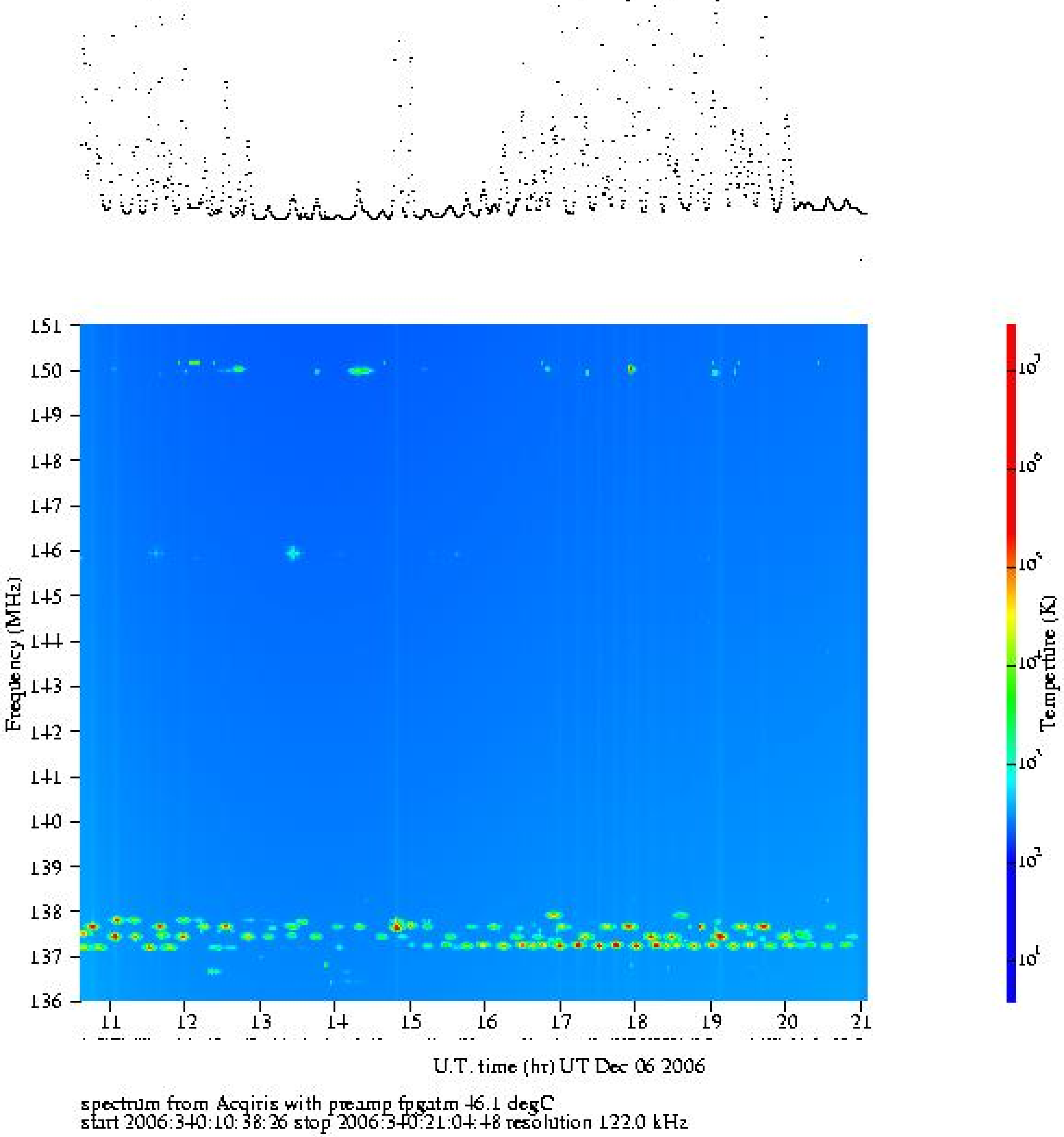
Location of Boolardy and Mileura Stations in Western Australia

EDGES expt. antenna at Mileura Dec 06

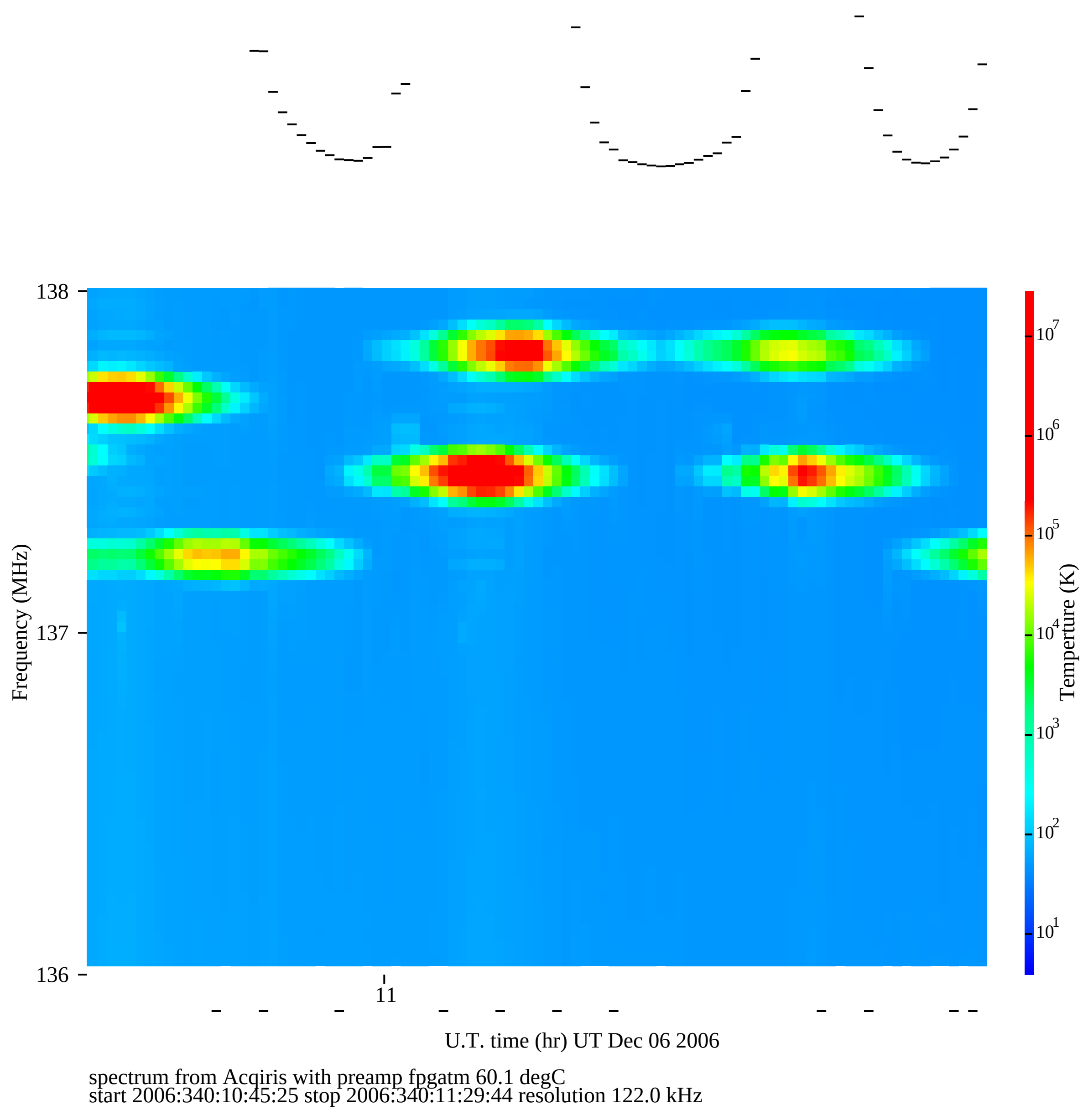
Typical scene at a “Station”

Typical terrain at Boolardy

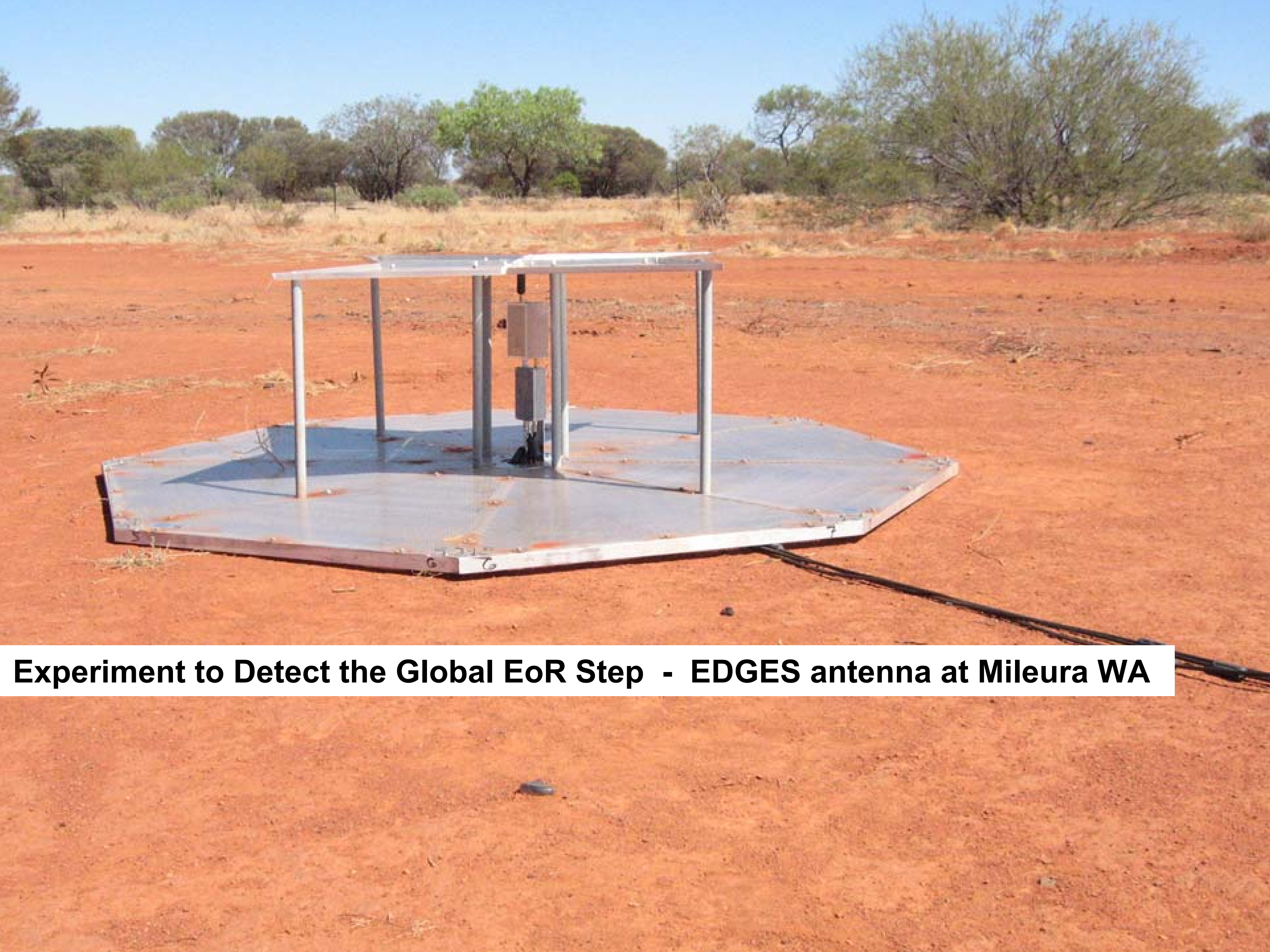
Early prototype of MWA tile



Signals from the Orbcomm 137-138 MHz along with 150 MHz beacons plus AMSAT 146 MHz at Mileura WA



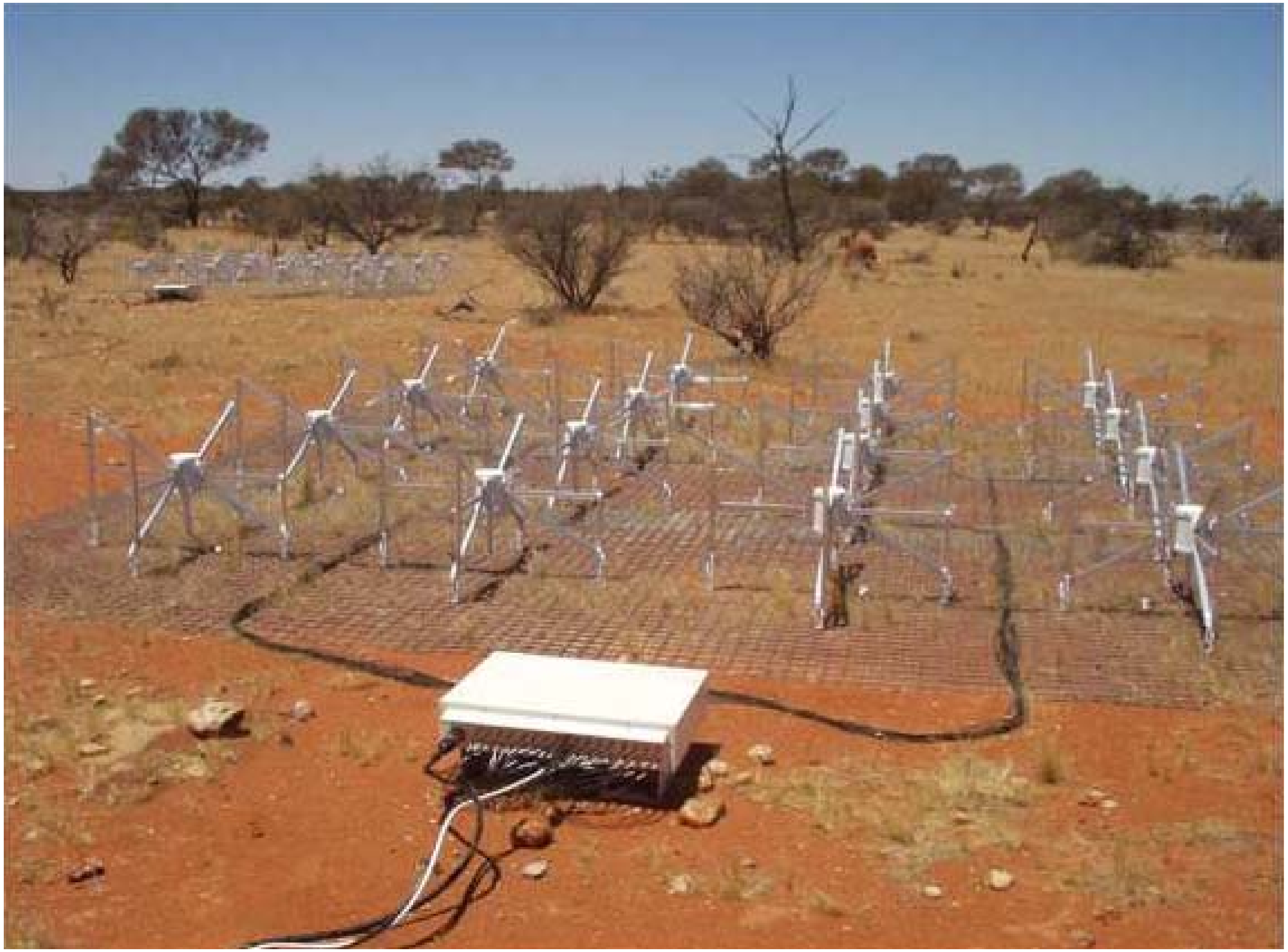
Orbcomm downlink spectra from EDGES spectrometer at Mileura Dec 2006



Experiment to Detect the Global EoR Step - EDGES antenna at Mileura WA

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

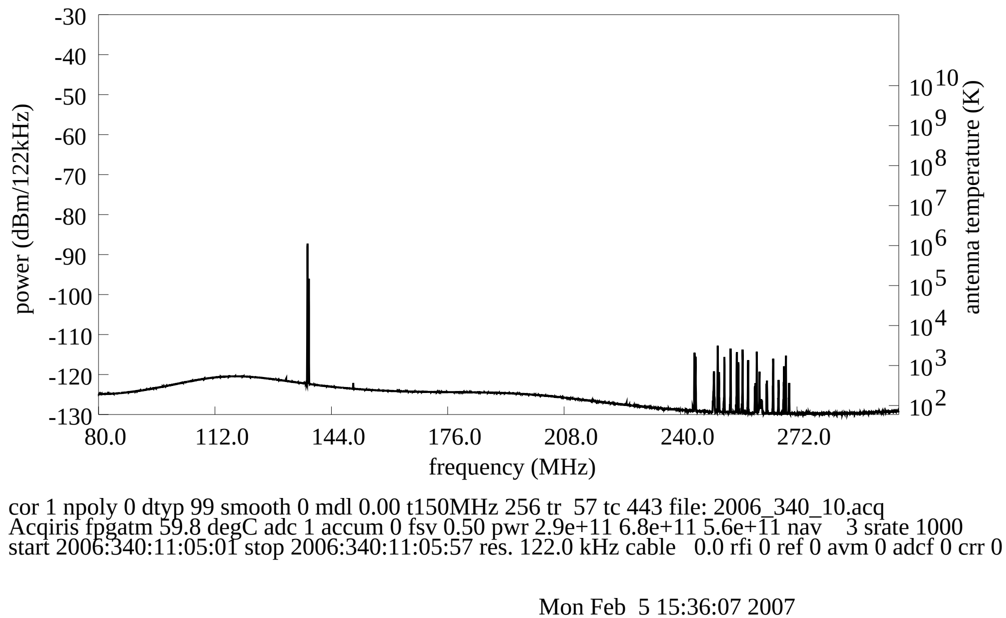
EDGES at Boolardy in February 2009



One of the 32 tiles of the MWA at Boolardy

MWA project

MWA 32 tile deployment at Boolardy WA

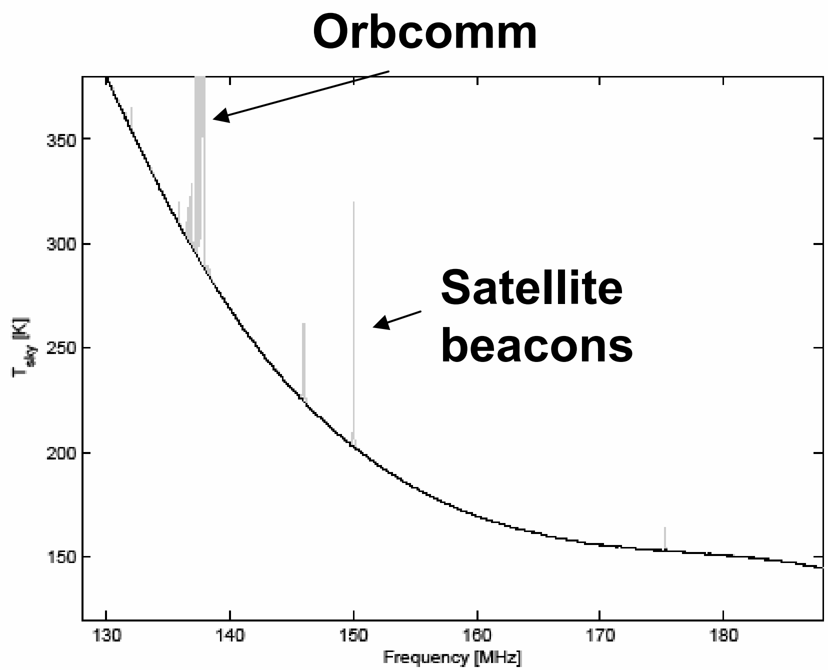


Typical spectrum EDGES at Mileura WA

using Acqiris AC240 8-bit ADC at 1 Gs/s + FPGA

Rogers and Bowman, AJ 136,641-648,2008

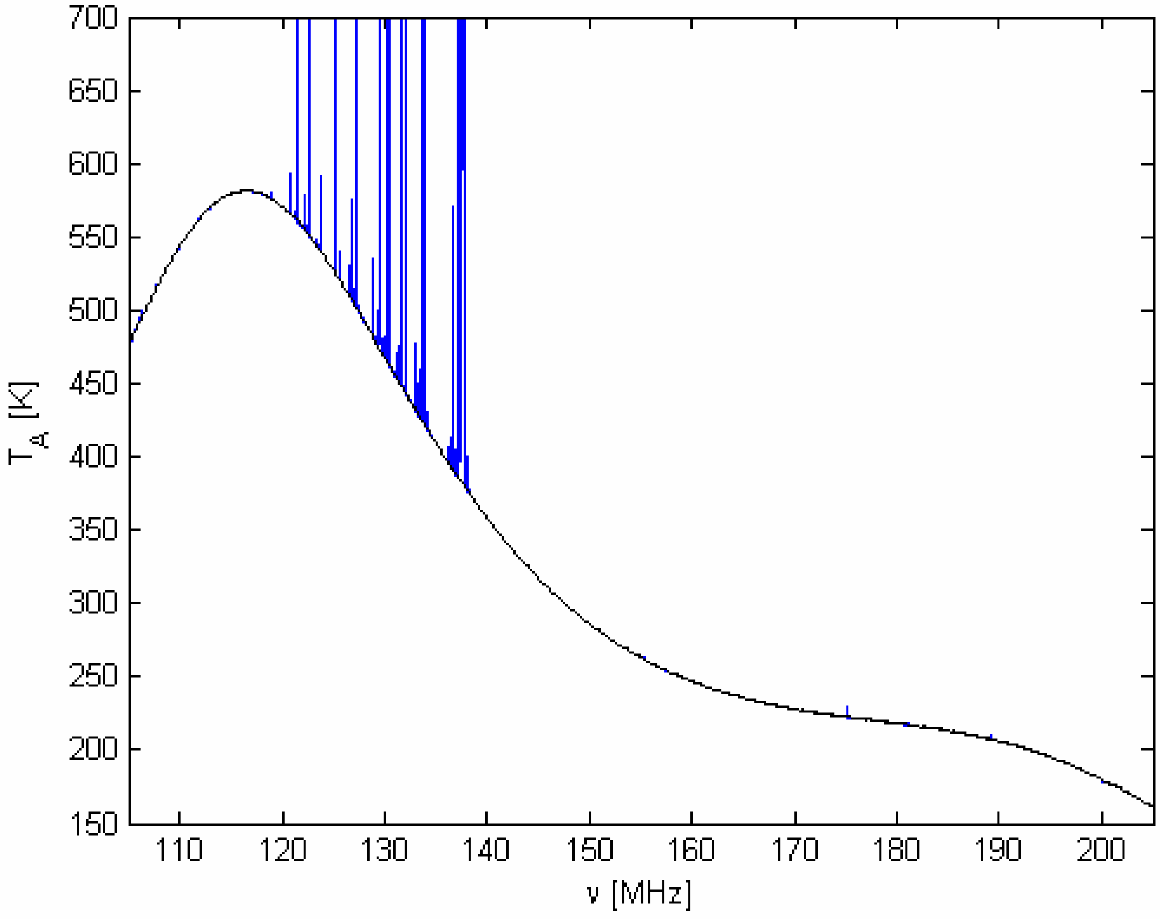
Spectral index β = 2.5 ± 0.1   100-200 MHz



Galactic background spectrum from EDGES

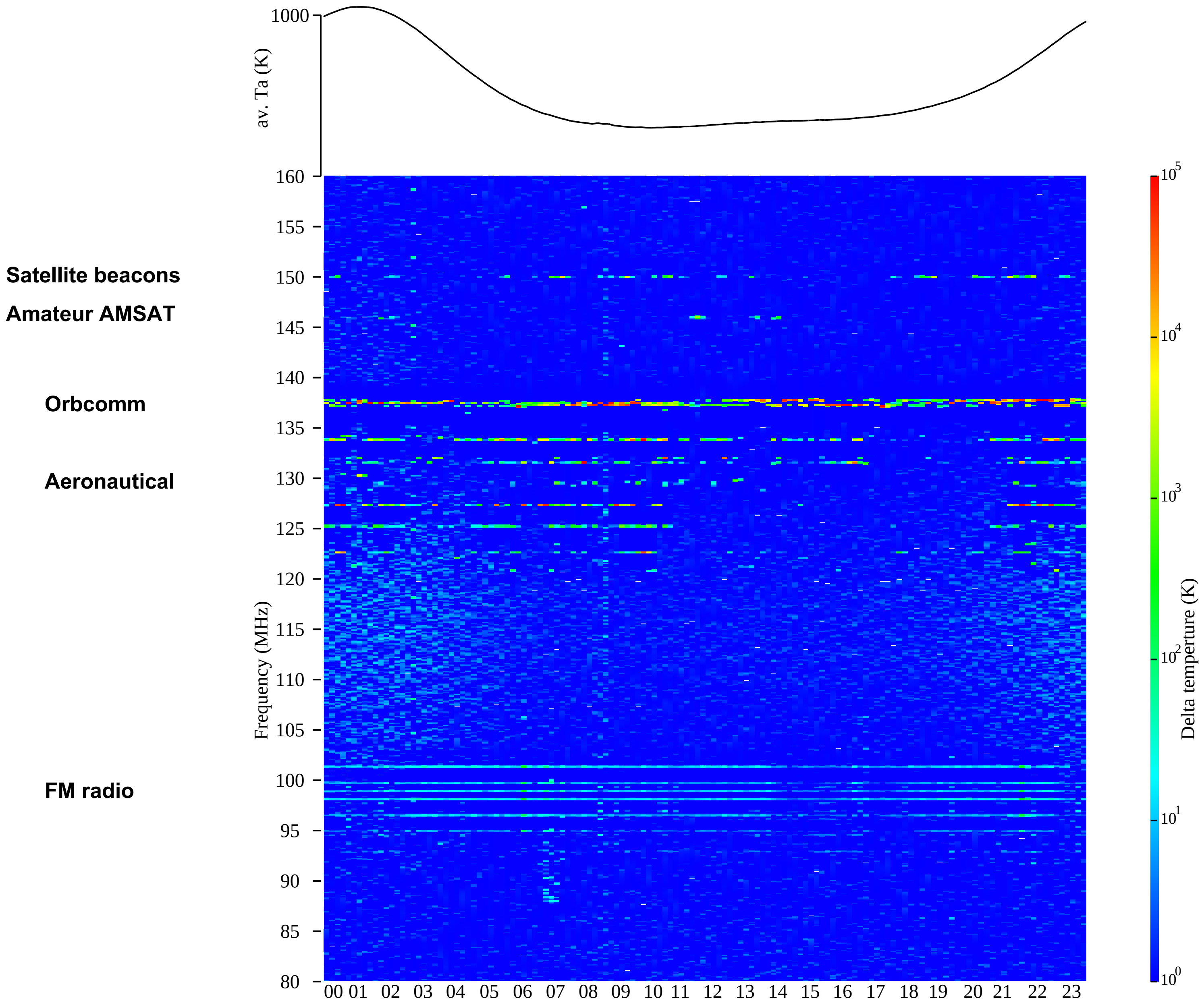
Bowman, Rogers and Hewitt, Ap.J. 676,1-9,2008

EOR "bump" < 450 mK



EDGES at Boolardy using Acqiris/Agilent DP310 12-bit ADC at 420 Ms/s

Feb 2009

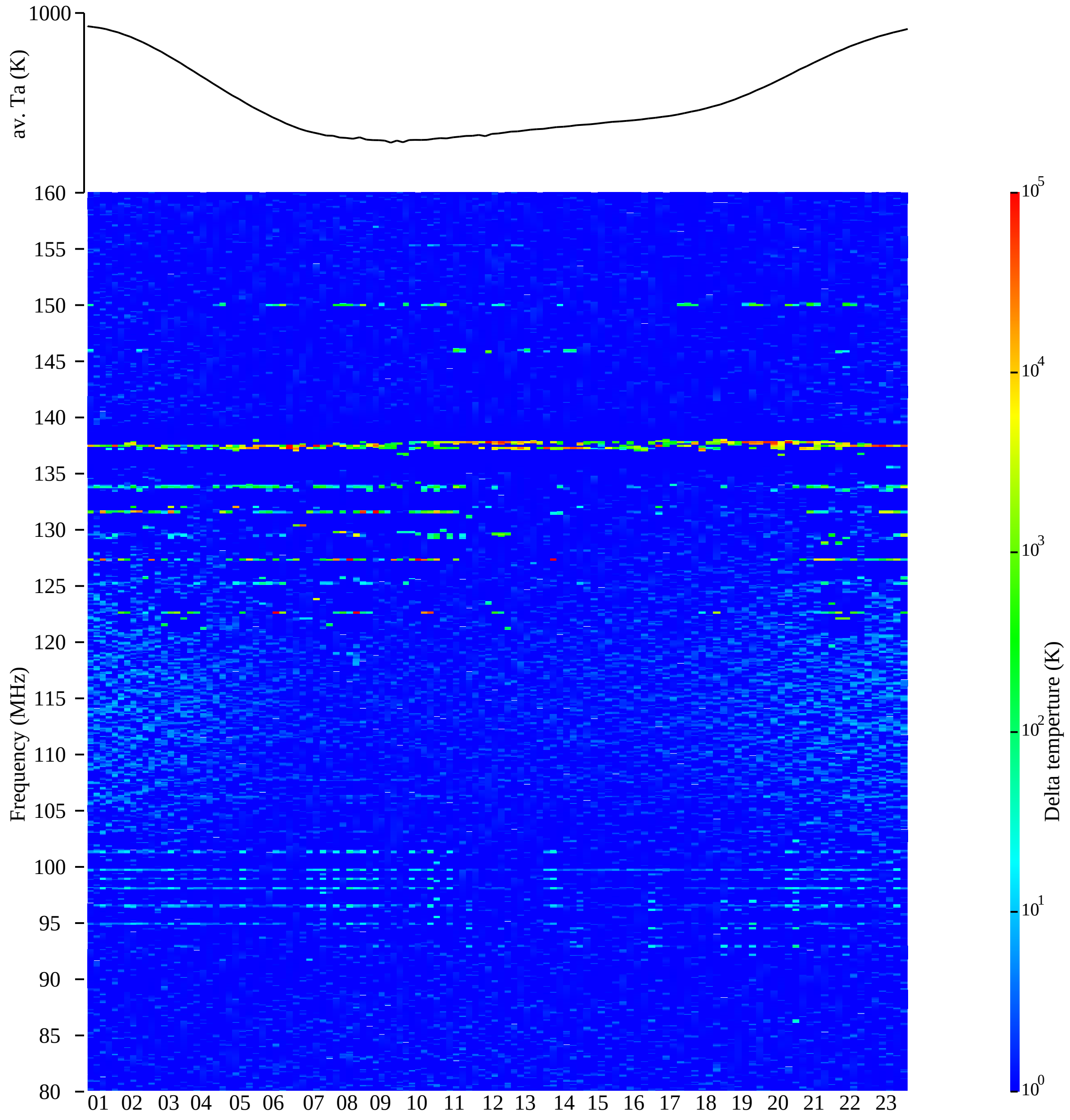


UT 00 to 24

file: boolardy/2009_034_00.acq
Fri May 15 07:06:24 2009

fstart 80 fstop 210 pfit 0 smooth 8 resol 103 kHz rfi 0.0 int 2786

Intermittent strength increase in FM from aircraft scatter



UT 00 to 24

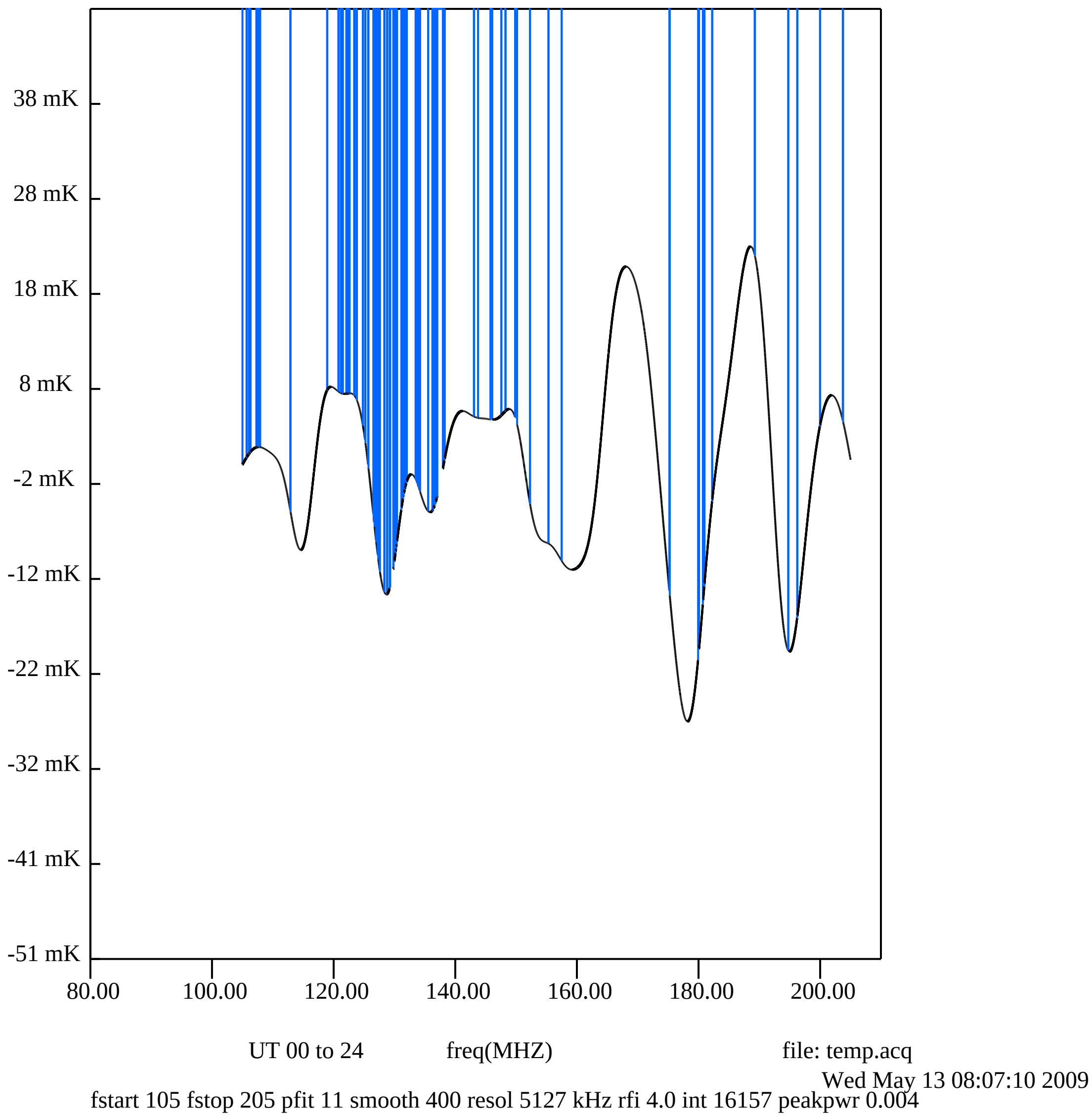
file: boolardy/2009_040_00.acq

Thu May 14 18:48:32 2009

fstart 80 fstop 210 pfit 0 smooth 8 resol 103 kHz rfi 0.0 int 2469

Blue lines are frequencies excluded from fit

5% of frequencies were excluded and 30% of the time data was excised due to strong RFI



Residual spectrum after subtraction of 11 term polynomial fit to EDGES data taken at Boolardy Feb 2009

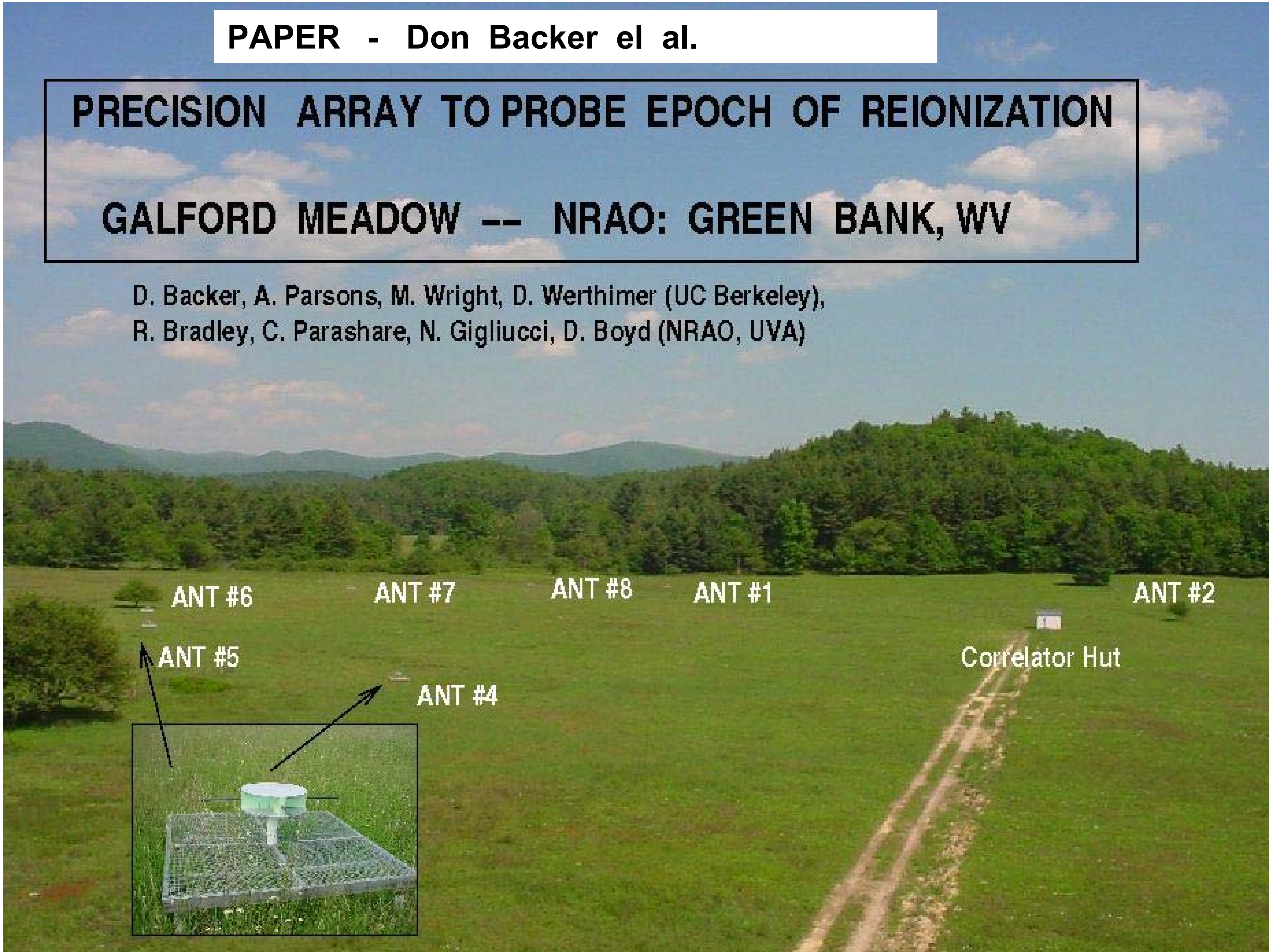
Frequency range MHz	Use	Observed
56-70	TV	
70-85	Fixed Mobile	
85-108	FM Broadcast	Weak signals from Geraldton
108-137	Aeronautical	Intermittent signals from aircraft*
137-138	Satellite downlink	Orbcomm
138-144	Mobile	
144-148	Amateur radio	Signals from amateurs plus AMSTAT
148-149.9	Satellite	
149.9-150.05	Satellite beacons	Signals from satellites
150.05-153	Radio Astronomy	
153-174	Mobile	
174-230	TV	Weak signal at 175 MHz
230-235	Aeronautical navigation	
235-273	Satellite downlink	Defense use

***includes digital communication from ACARS – Aircraft Communication Addressing and Reporting System.**

Summary of RFI at Boolardy measured with Zenith pointed antenna

Current EOR experiments

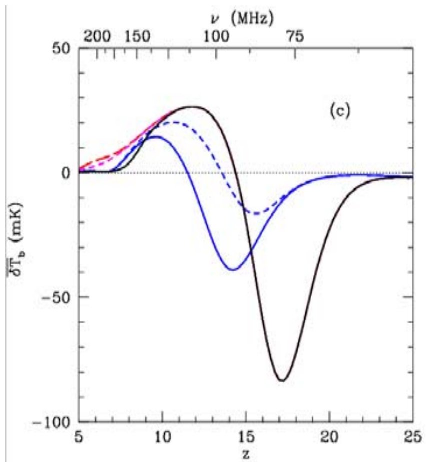
- MWA – Murchison Widefield Array
- PAPER – Precision Array to Probe Epoch of Reionization
- CoRE - Cosmological Re-Ionization Experiment
- EDGES – Experiment to detect Global EOR Step

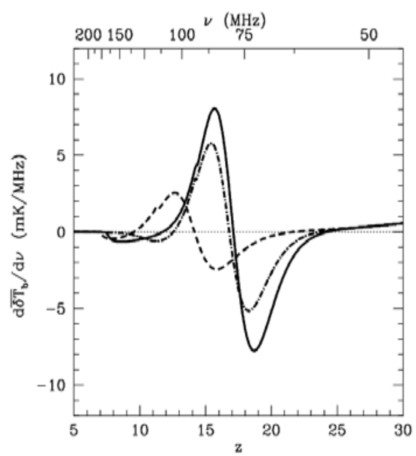

PAPER - Don Backer el al.
PRECISION ARRAY TO PROBE EPOCH OF REIONIZATION
GALFORD MEADOW -- NRAO: GREEN BANK, WV
D. Backer, A. Parsons, M. Wright, D. Werthimer (UC Berkeley),
R. Bradley, C. Parashare, N. Gigliucci, D. Boyd (NRAO, UVA)
ANT #6
ANT #7
ANT #8
ANT #1
ANT #2
ANT #5
ANT #4
Correlator Hut

CoRE Antenna - **Ron Ekers et al.**

- 2-arm log-spiral winding
  - 4 arm variation is possible
- Support structure
  - Styrofoam pyramid
  - Foam, glue and paint tested using the Australia Telescope interferometer

Measuring the Global Signal?



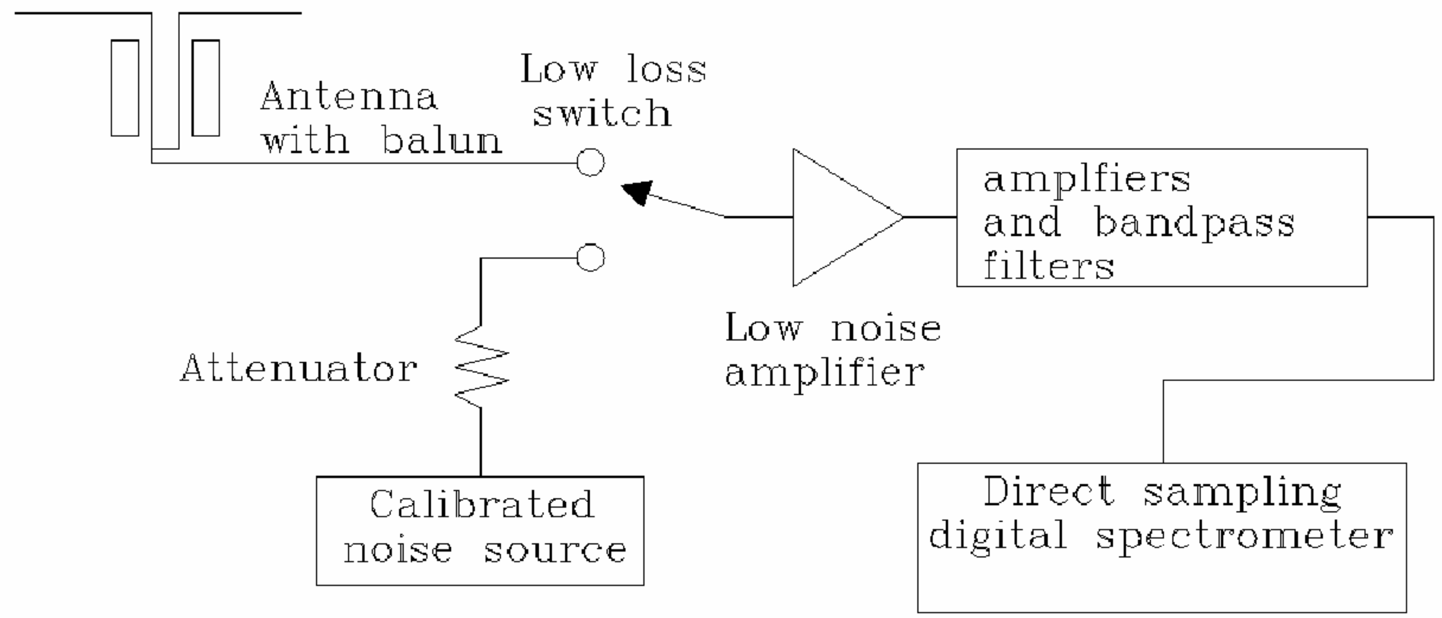


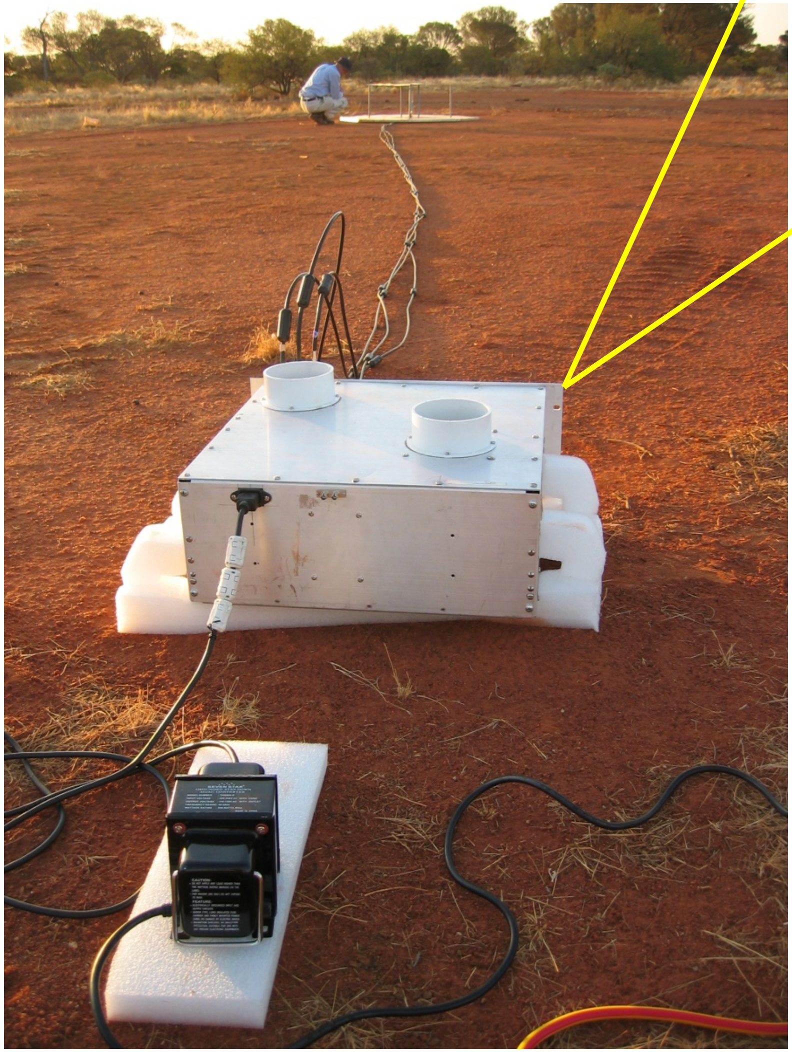
SF (2006)

- Signal gradient is few mK/MHz
- Foregrounds vary as (near) power law
  - Synchrotron, free-free
  - Gradient is few K/MHz
- CoRE-ATNF, EDGES experiments are trying
  - Distinctive shape may help

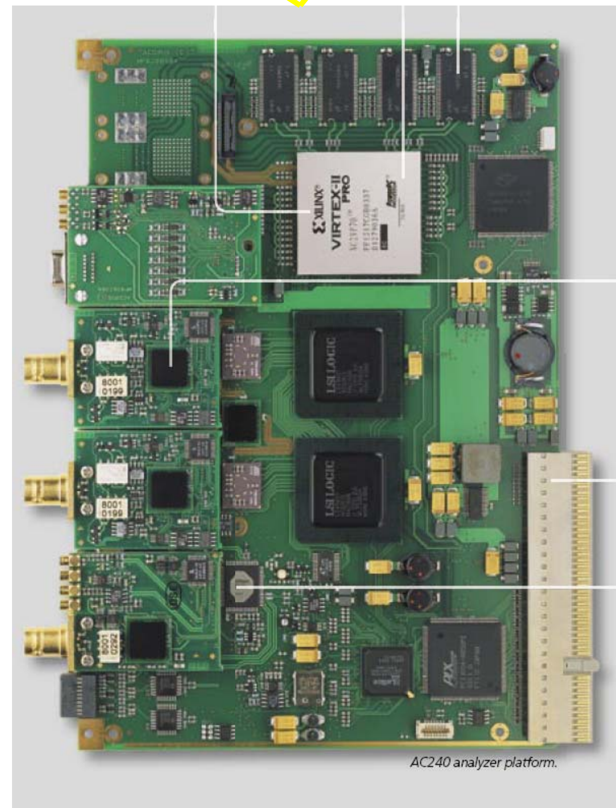
From talk by Ron Ekers at 21cm conference at CFA 2008

EDGES: System Overview

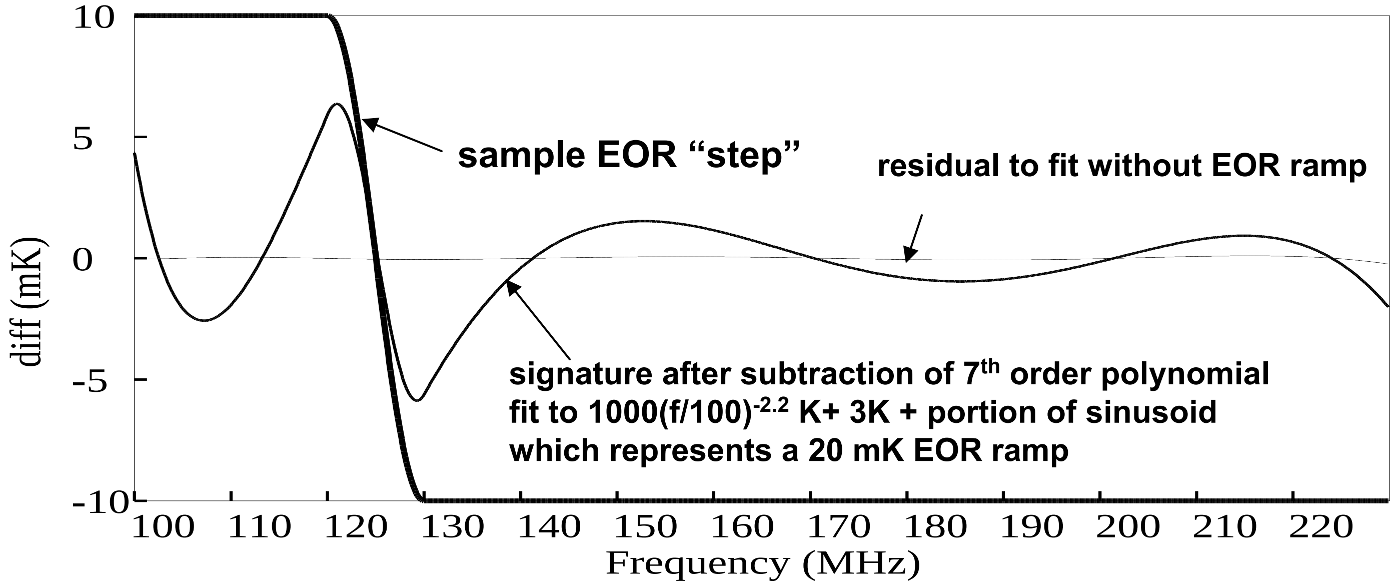




EDGES system used at Mileura station in December 2006



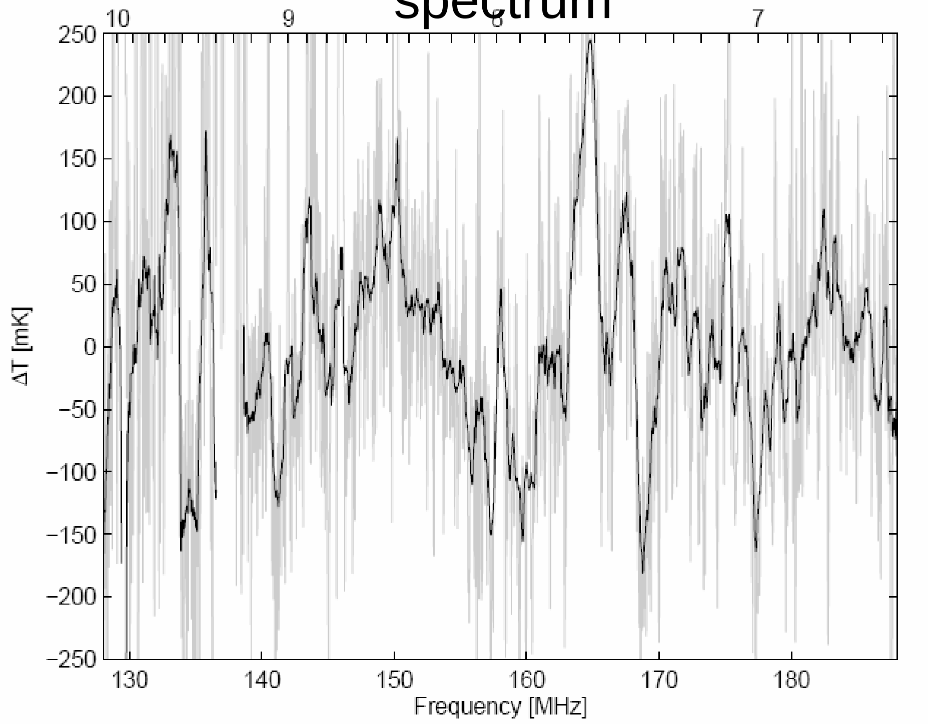
Acqiris AC240: 8-bit, 1 GS/s



Wed Dec 21 18:15:42 2005

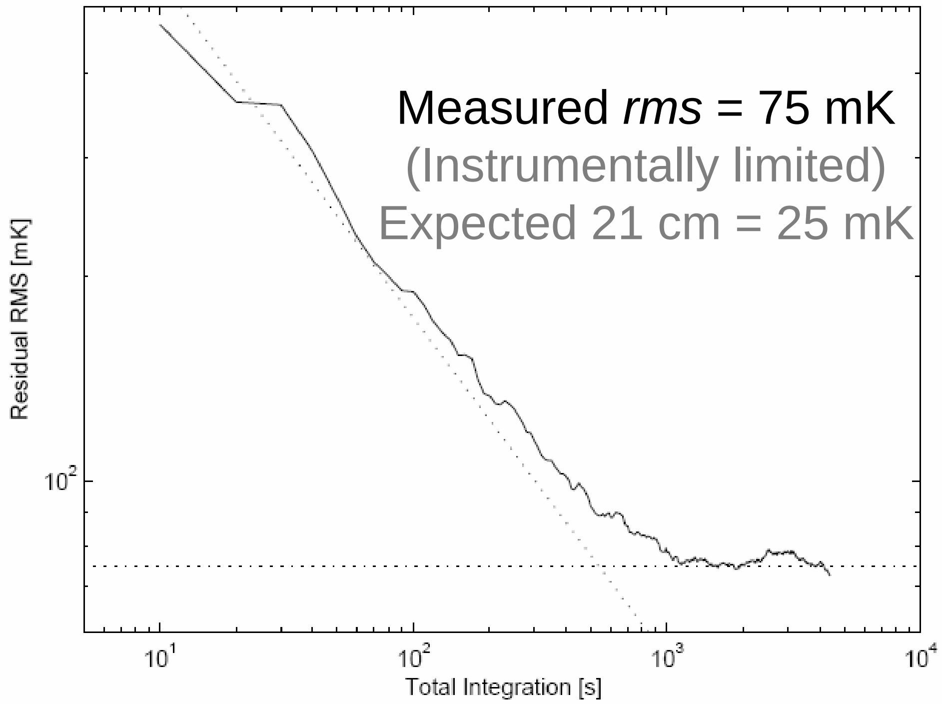
EDGES: Instrumental limit using 8-bit ADC

Residuals after 7th order polynomial fit to spectrum



Black line: smoothed to 2.5 MHz

rms vs. integration time



Bowman, Rogers & Hewitt
Ap.J. 676, pp. 1-9 2008

Instrumental limit using 12-bit ADC

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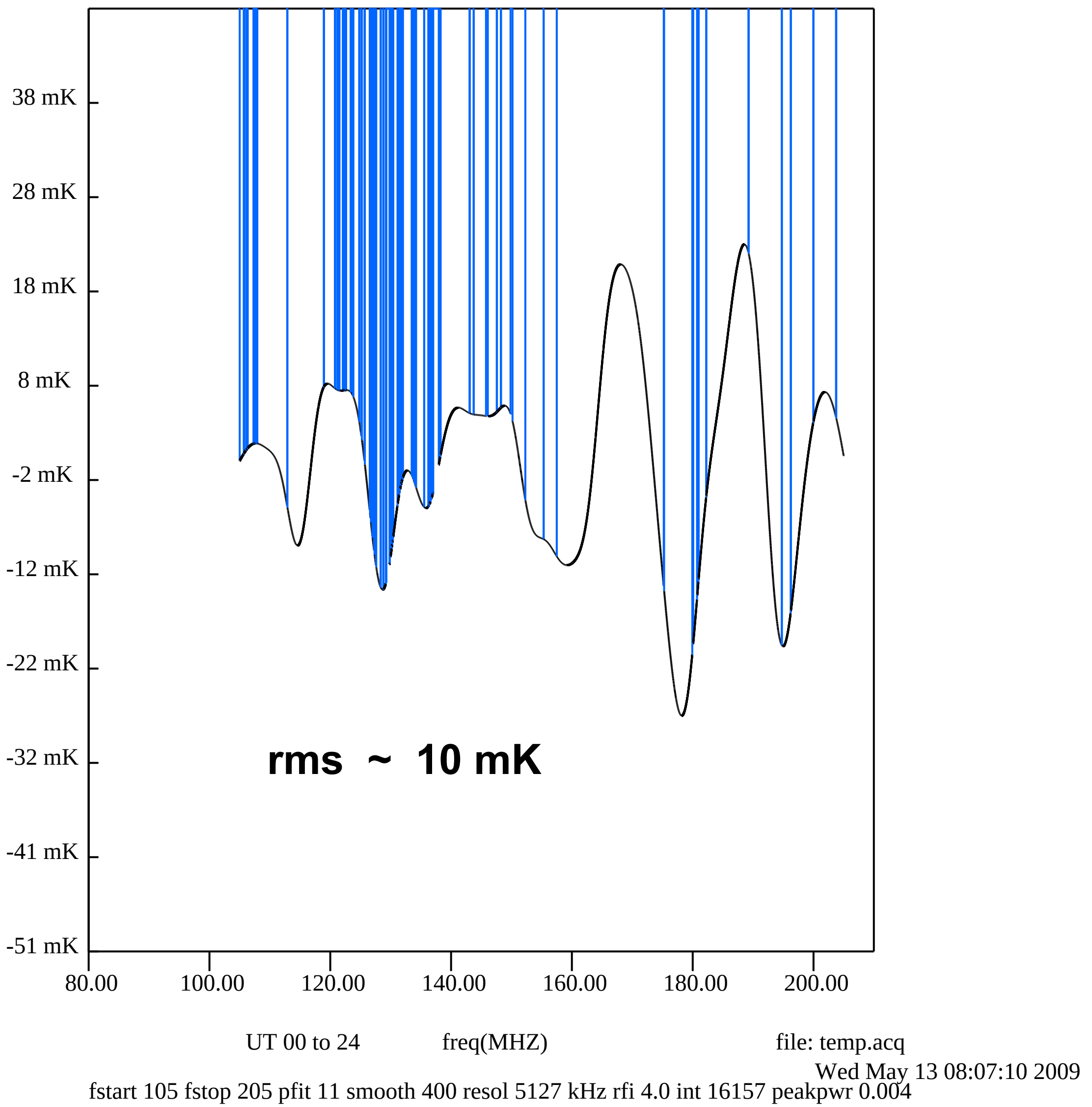

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