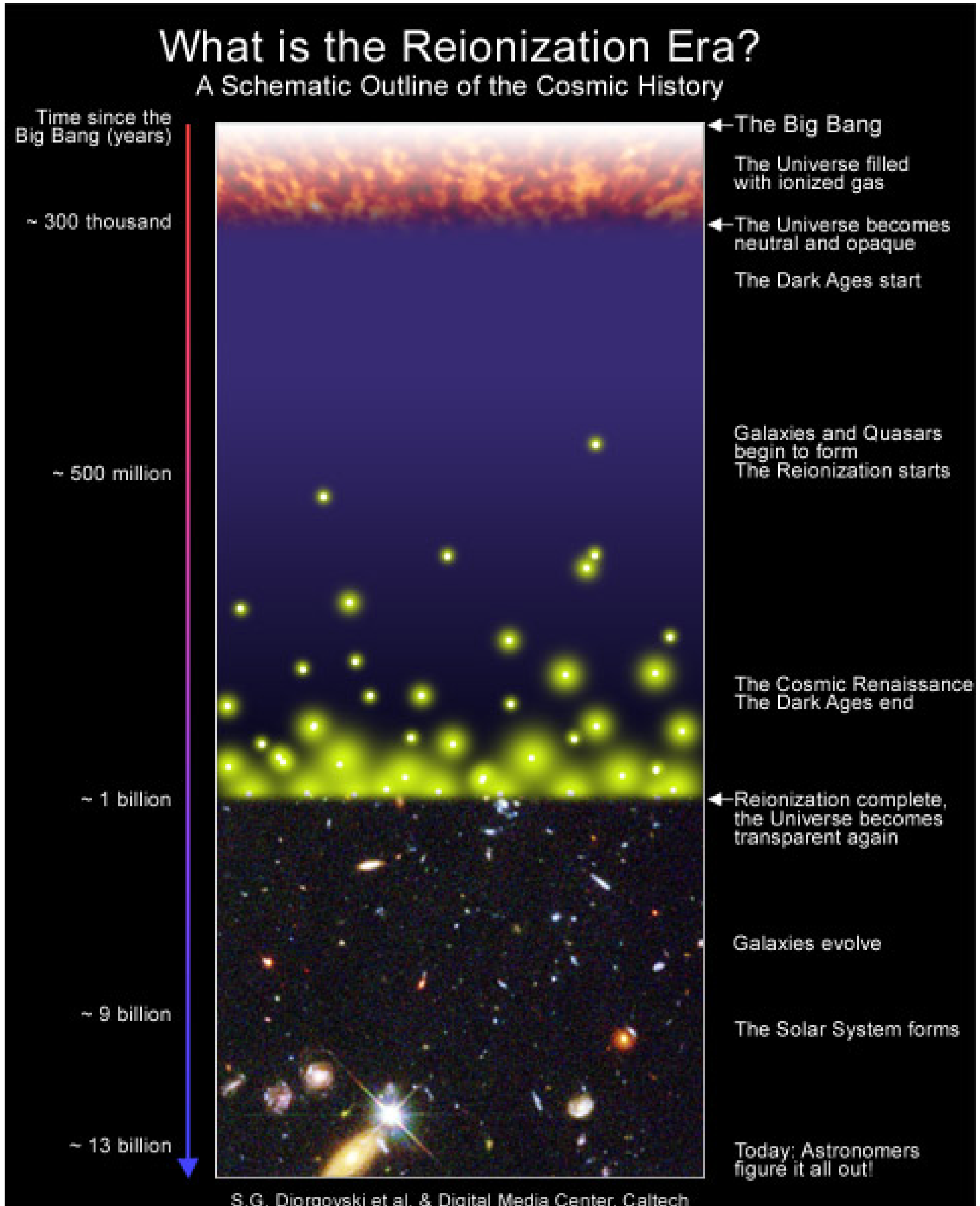
Instruments for studying the Epoch of Reionization (EOR)

Presentation to CORF

by Alan Rogers 19 Nov 08


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 emmision

CMB > Tspin H1 in absorption

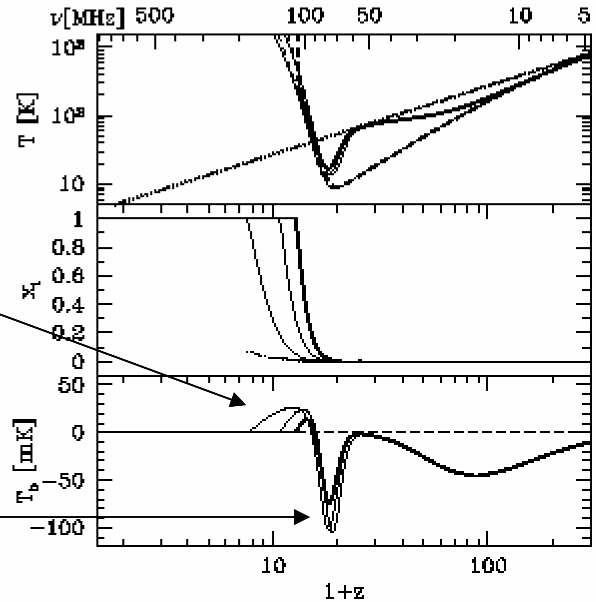


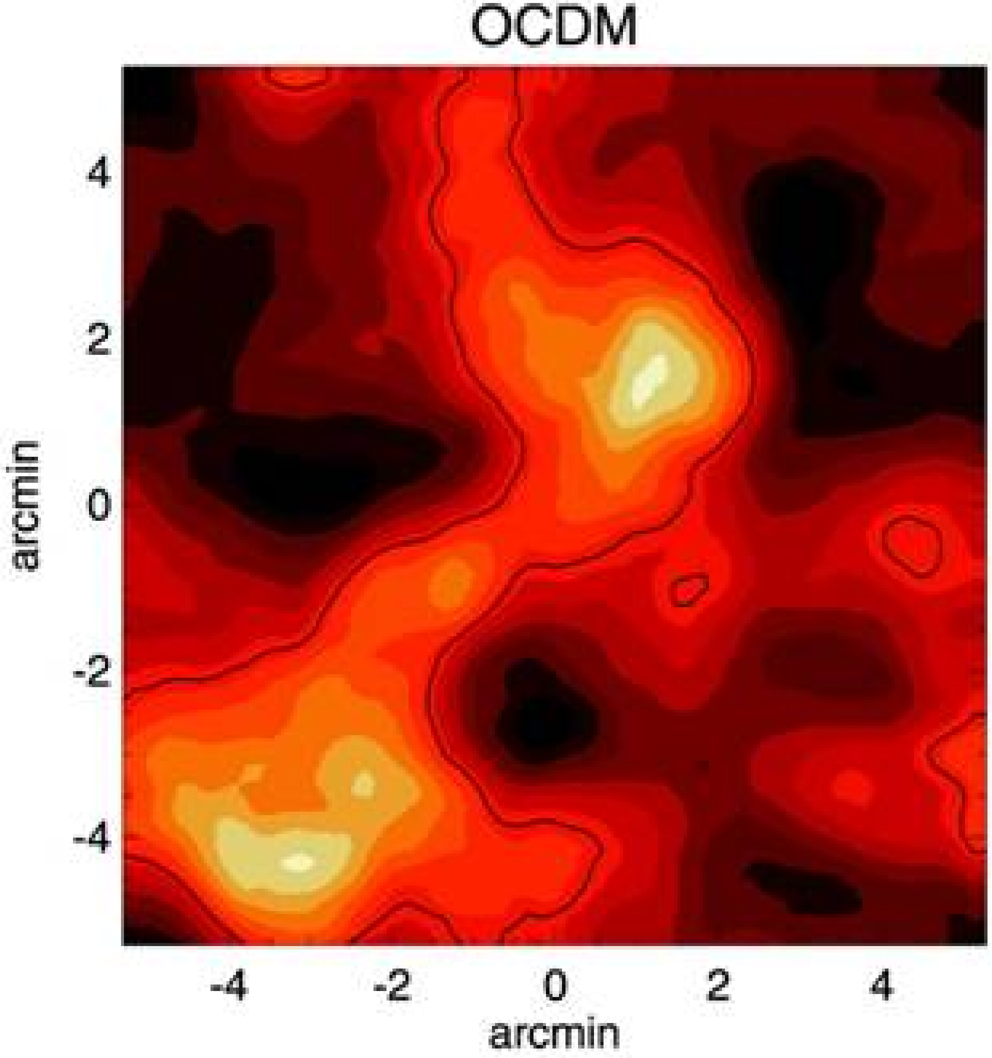
FIG. 1: *Top panel:* Evolution of the CMB temperature T_{CMB} (dotted curve), the gas kinetic temperature T_K (dashed curve), and the spin temperature T_S (solid curve). *Middle panel:* Evolution of the gas fraction in ionized regions x_i (solid curve) and the ionized fraction outside these regions (due 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 ($z < z_{\rm reion}$) where the 21cm fluctuations from residual hydrogen follow the matter power spectrum, an intermediate redshift regime ($z_{\rm reion} < z < z_{\rm trans}$) where Lyα 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 ($z > z_{\rm trans} \approx 23$). For pedagogical purposes, let us describe the evolution on a single comoving scale (say, $k = 0.1\ {\rm Mpc}^{-1}$) 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 $T_{\rm CMB}$. 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

The Orbcomm satellite downlink 137-138 MHz

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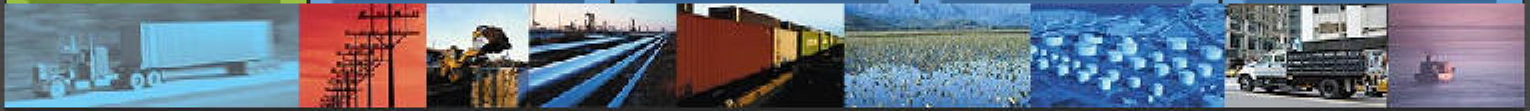

Our Technology

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- User Equipment
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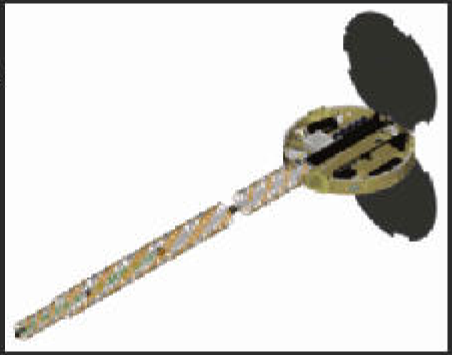
Space Segment



ORBCOMM operates a network of low Earth orbit (LEO) satellites that provide worldwide coverage. These satellites are relatively small in size, weighing less than one hundred pounds and measuring only forty-two inches in diameter and six inches in height before deployment. The relatively small size of our satellites is made possible by the fact that they do not require a propulsion system to maintain the satellites in the appropriate orbit and have significantly lower power requirements as compared to geostationary satellites.

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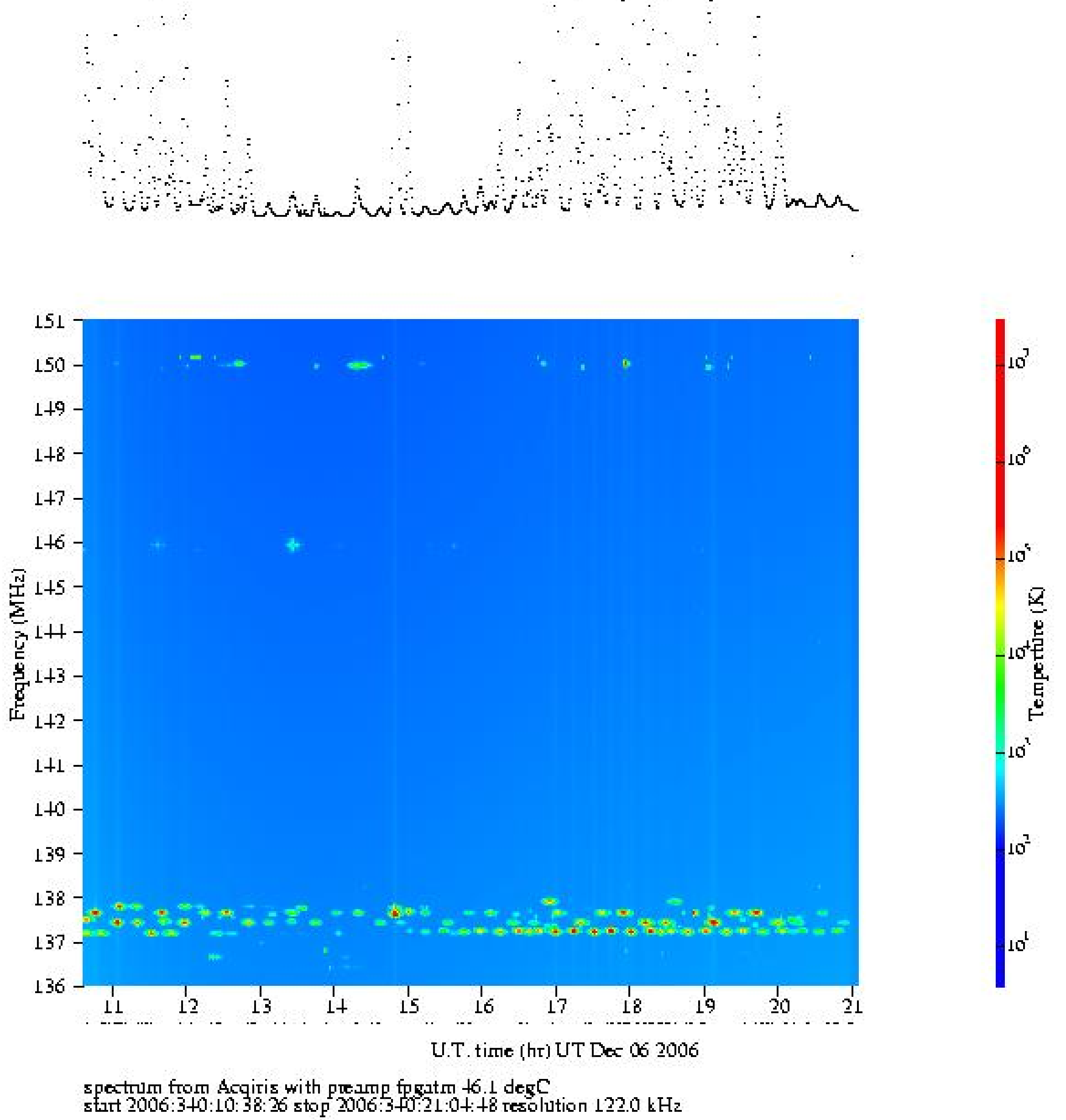


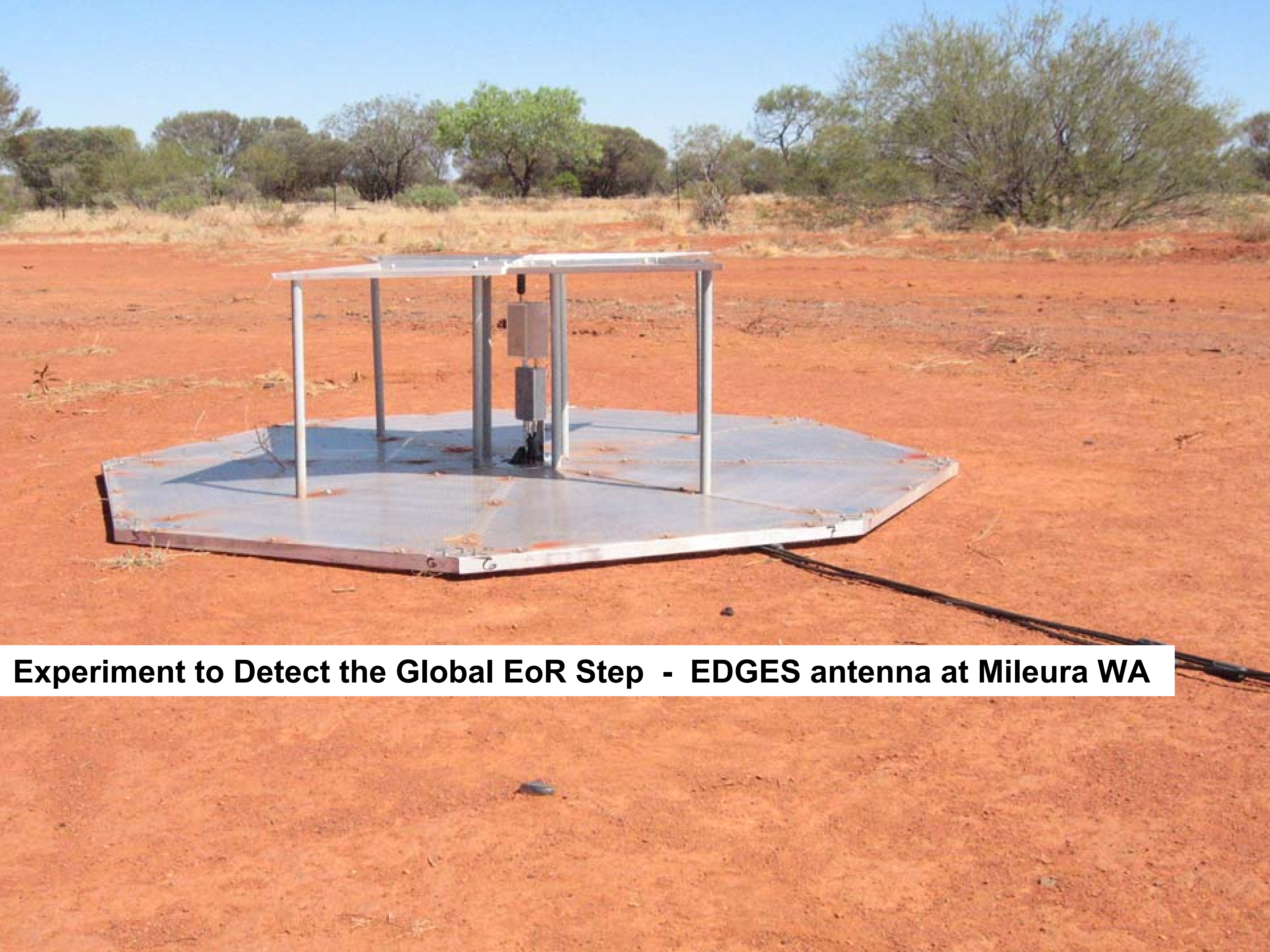
Signals from the Orbcomm 137-138 MHz along with 150 MHz beacons plus some unkown sources of RFI at Mileura WA

EDGES expt. antenna at Mileura Dec 06

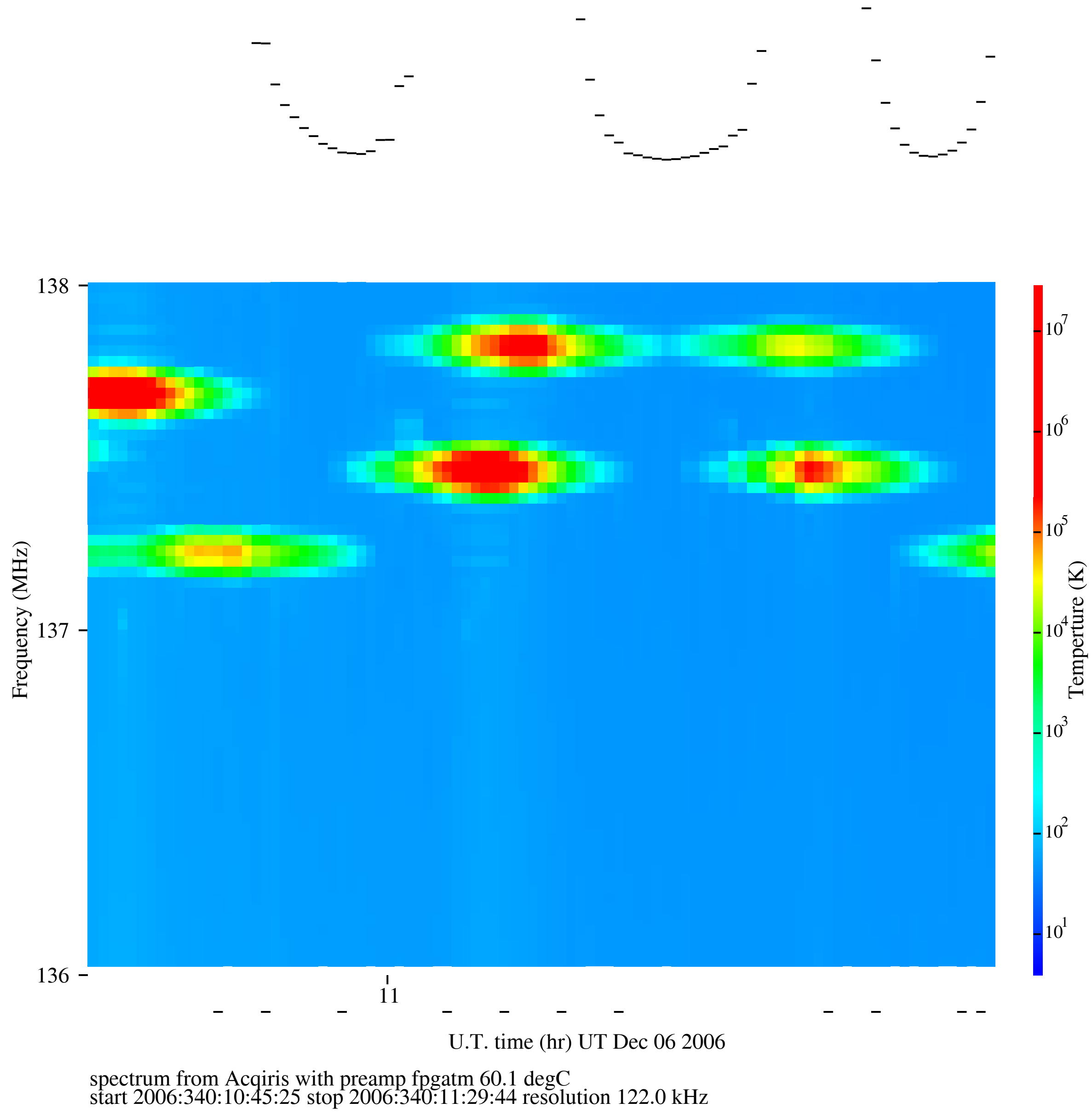
Typical scene at a “Station”

Typical terrain at Boolardy

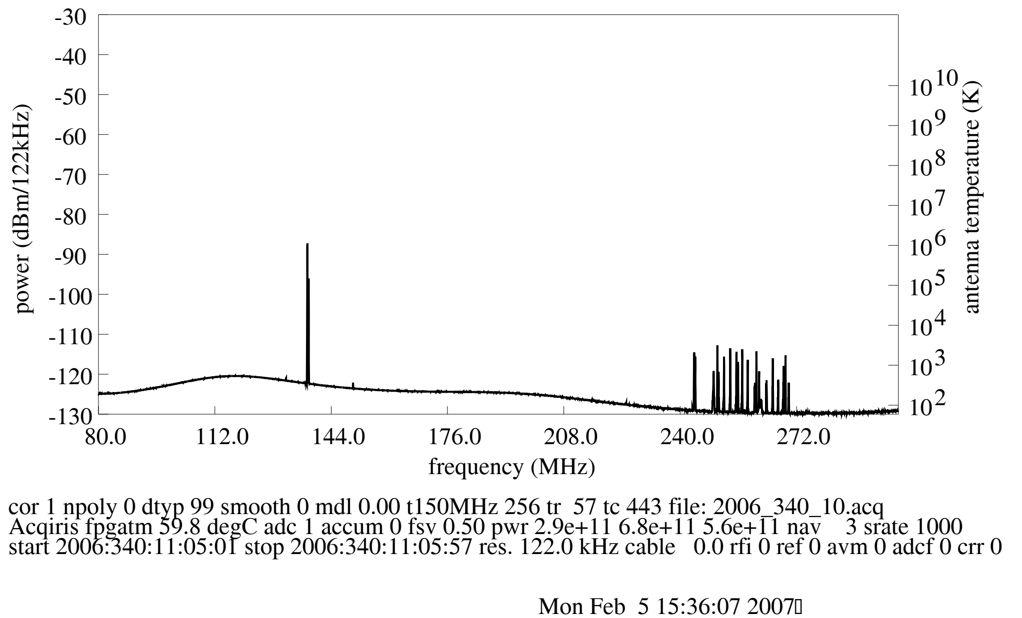
Early prototype of MWA tile



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



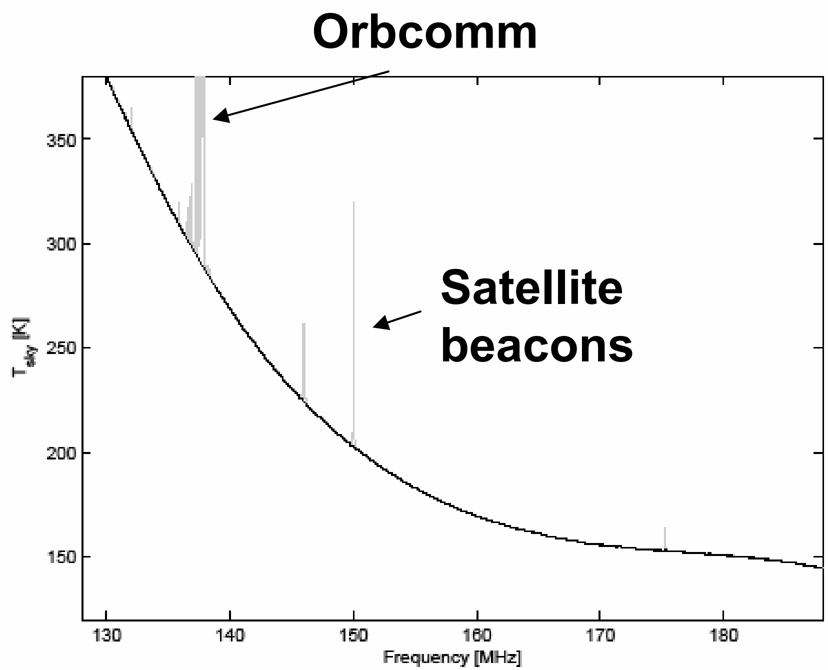
Orbcomm downlink spectra from EDGES spectrometer at Mileura Dec 2006



Typical spectrum EDGES at Boolardy WA

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

Spectral index β = 2.5 ± 0.1   100-200 MHz

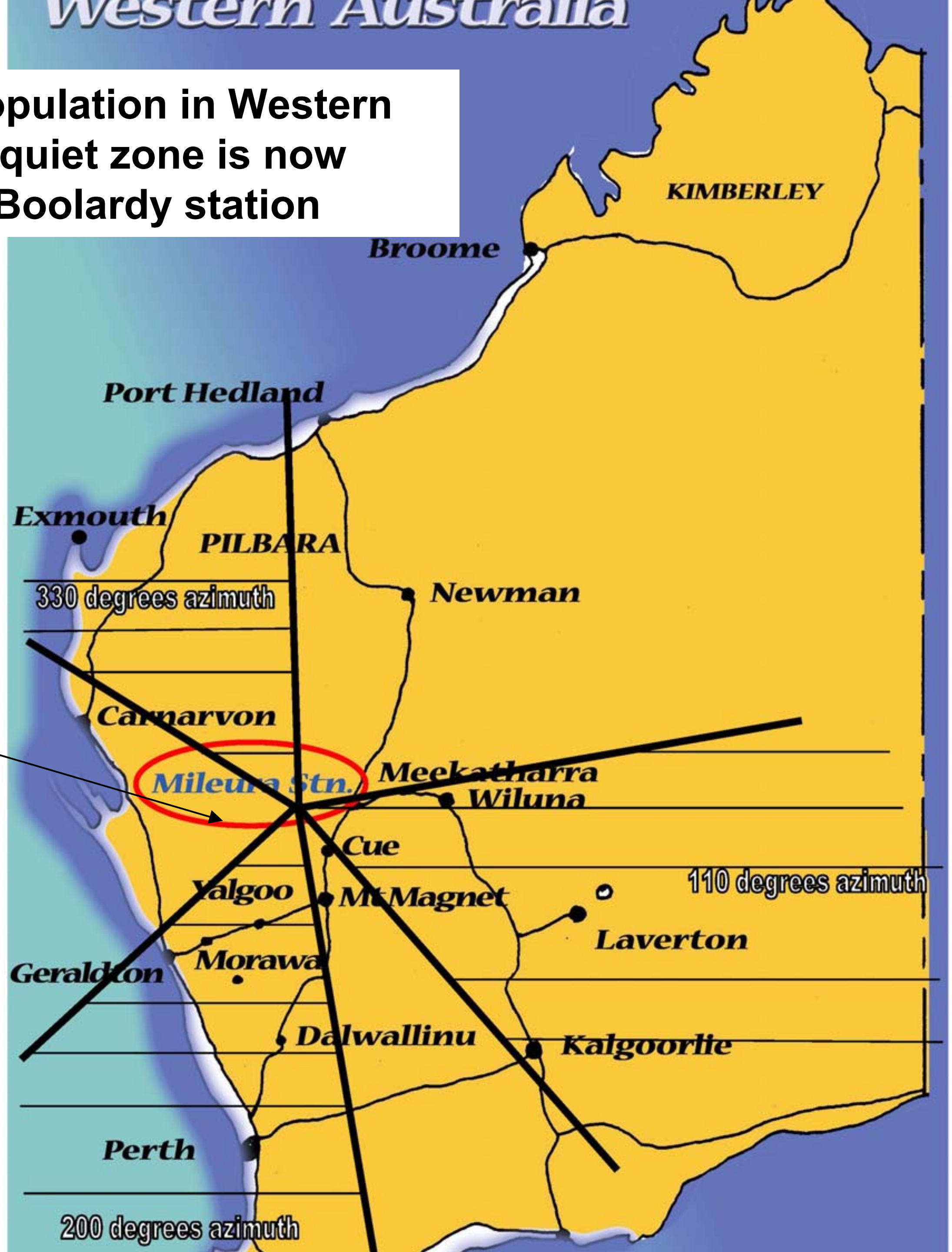


Galactic background spectrum from EDGES

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

EOR "bump" < 450 mK

Region of low population in Western Australia. Radio quiet zone is now centered on the Boolardy station



Boolardy Stn

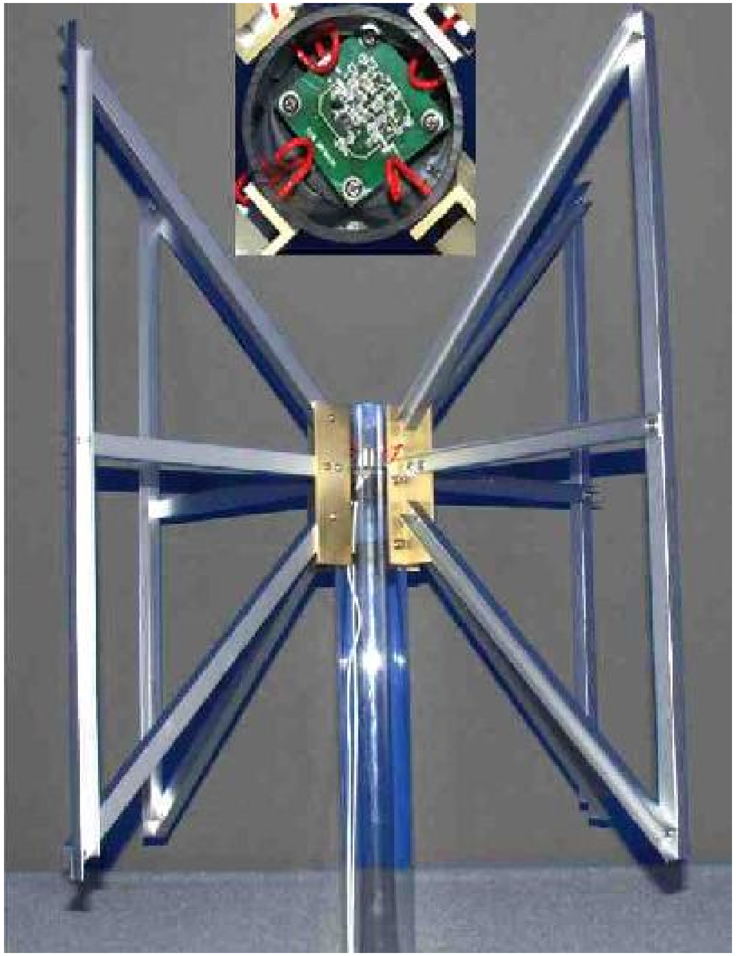
Frequency Range [MHz]	Service	Comments
50 – 94		Low spectrum use
94 – 100	FM broadcast	Geraldton high-power service
100 – 108	FM broadcast	Meekatharra low-power service
108 – 137	Aeronautical	Low use short duration signals (mobile)
137 – 138	Satellite downlink	LEO
138 – 144	TV broadcast	
144 – 149.9		Low spectrum use
149.9 – 150.05	Satellite downlink	LEO
150.1 – 151	DRCS (Telstra phone/fax service)	Note: 150.05-153 MHz is an ITU radio astronomy allocation
151 – 174		Negligible band use
174 – 225	TV broadcast	Geraldton high-power service. Vacant 202 –209 MHz
225 – 243.8		Low spectrum use
243.8 – 250	Satellite downlink	Defence use

Table 1. Qualitative summary of radio activity at Mileura Station. Reconstructed from data in [Thomas, 1999b].

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

The Murchison Widefield Array



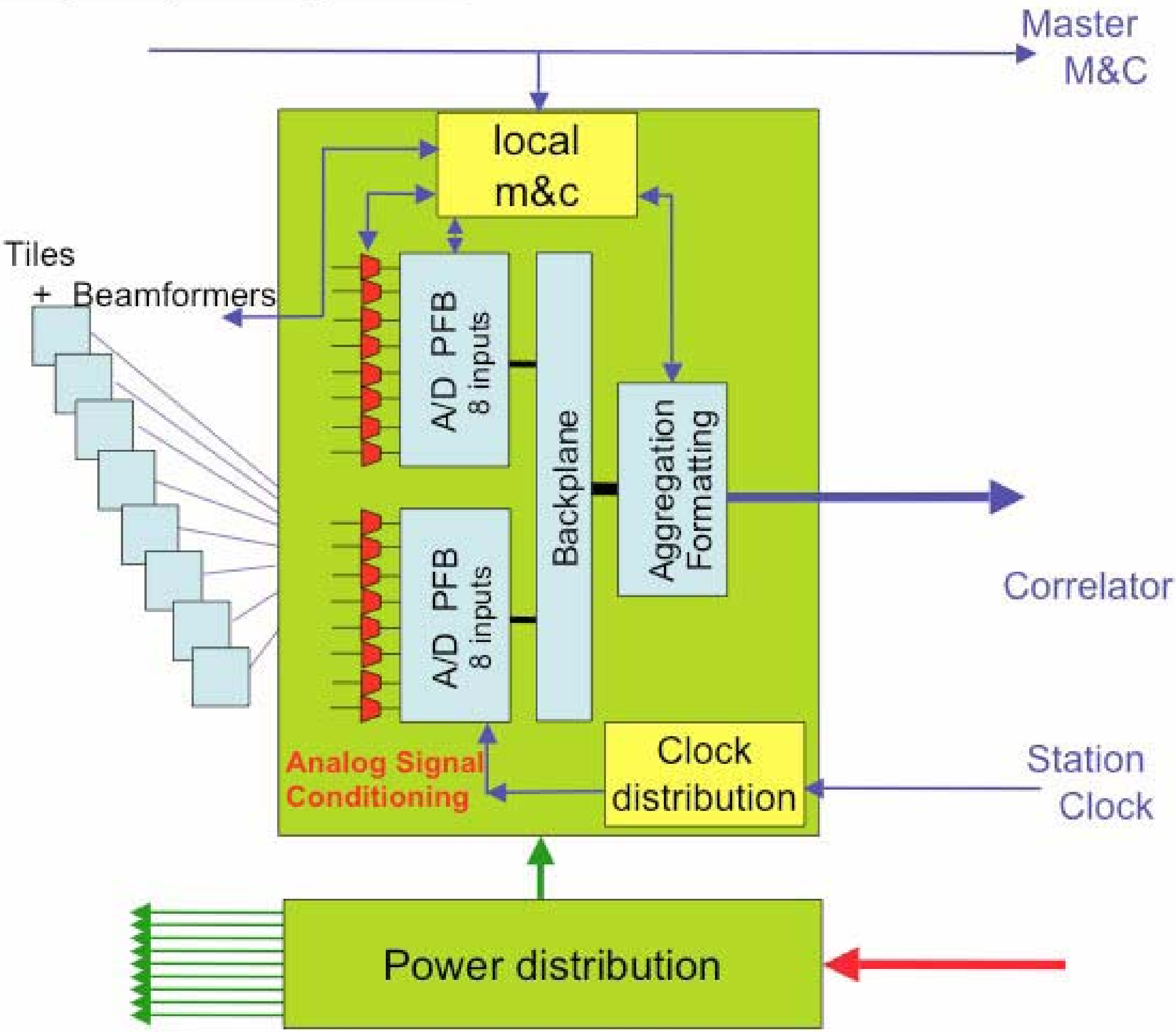
Bowman et al. (2007)

in tiles of 16

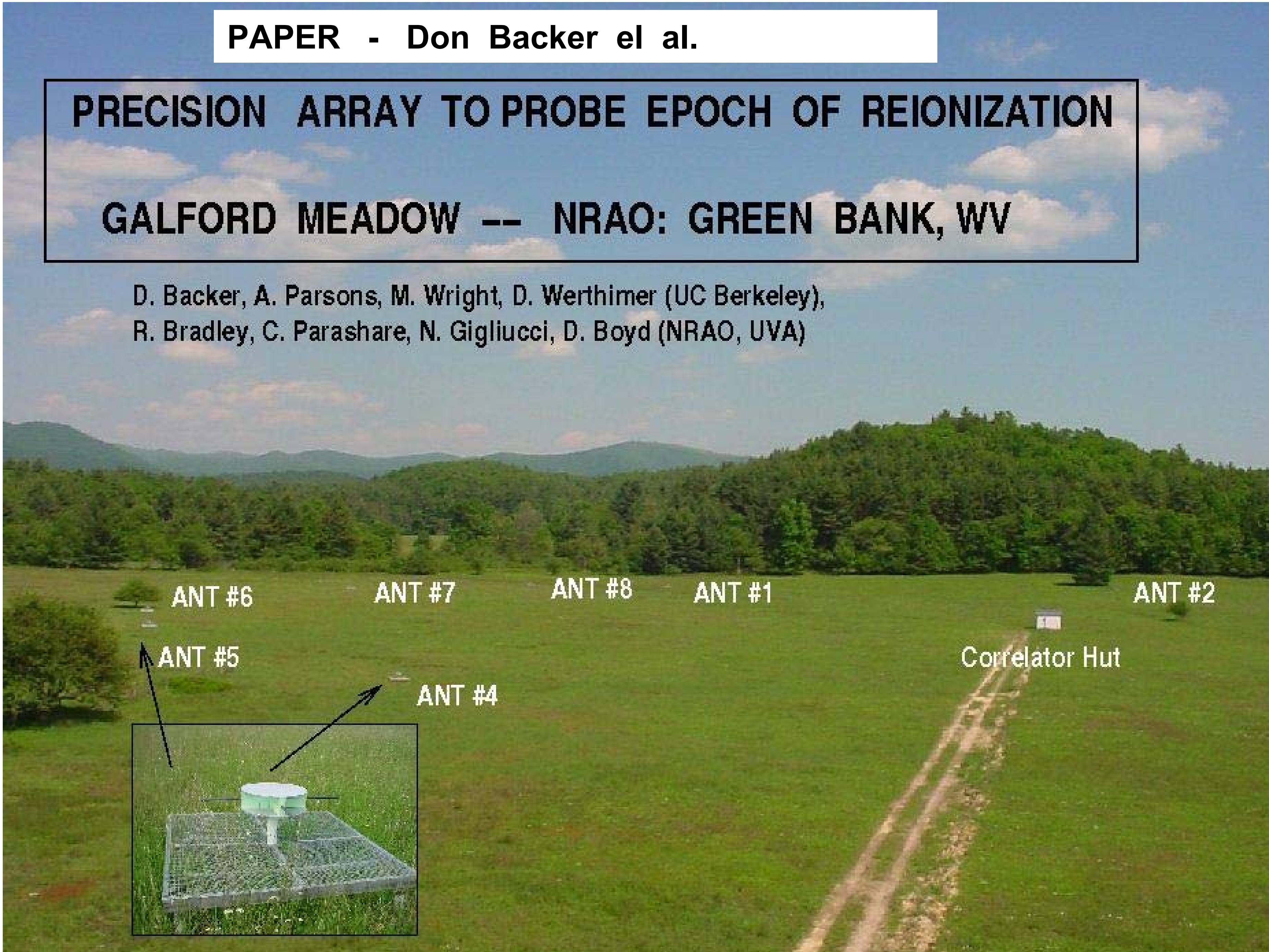
- Broad frequency response
- Large field of view

MWA electronics block diagram

Receiver Node principal components

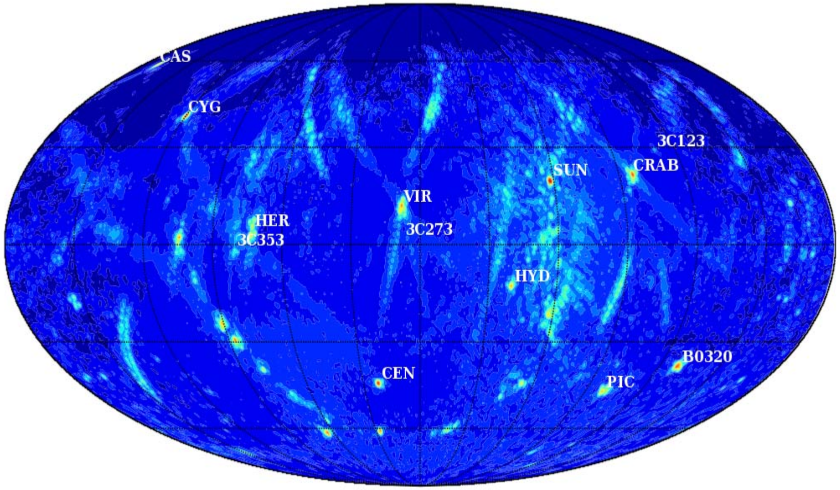


MWA 32 tile deployment at Boolardy WA



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
Correlator Hut
ANT #4

Panoramic view of PAPER at Boolardy

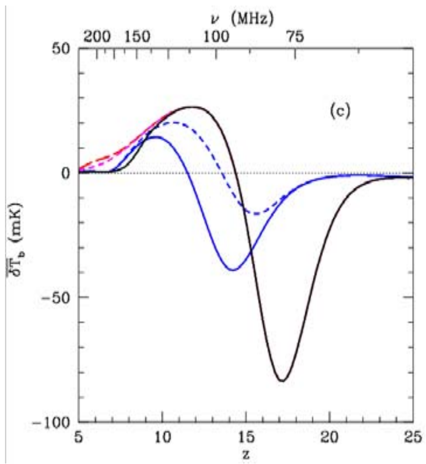


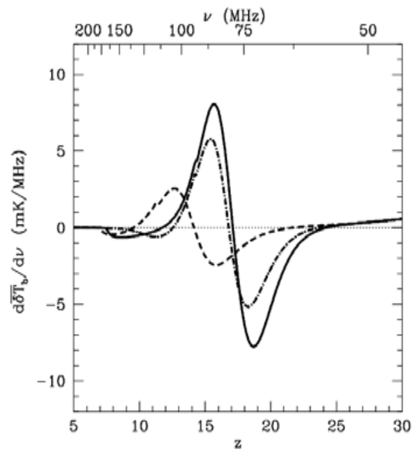
All Sky map by PAPER

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