EDGES

Judd D. Bowman, Arizona State University
Alan E. E. Rogers, Haystack Observatory

Kristina Davis, ASU
Sarah Easterbrook, ASU
Hamdi Mani, ASU
Raul Monsalve, ASU
Thomas Mozdzen, ASU
Outline

• Instrument overview
• Contributions to SKA
  + Long-term data archive – a resource for characterizing MRO site
  + Reionization science is possible from MRO site (EDGES-1)
  + Absolute calibration looks feasible to high levels (EDGES-2)
• Summary
EDGES (and DARE) at MRO

26° 42’ 31 S, 116° 38’ 02 E
Simplified block diagram of EDGES
Example data
from ~2 years of nearly continuous measurements

http://loco.lab.asu.edu/edges
EDGES-1 results

Murchison Radio-astronomy Observatory (MRO)

Aug 20 – Oct 20, 2009

1440 wall-clock hours on sky
500 hours after RFI cuts
50 hours eff. integration

+15 dB
EDGES-1 results

$\Delta z_r > 0.06 \text{ for } 6 < z_r < 13$

(95% confidence)

EDGES-2: Absolute Calibration


Goal: Science performance improvement of 10, dual-band (50-100, 100-200 MHz)

In the Field:
• 3-position switched spectra from antenna
• S11 measurement of antenna (during installation)

In the Lab:
• Ancillary 3-position switched spectra from external ambient and hot loads for calibration of internal noise diode
• Ancillary spectrum of an open cable for measurement of LNA noise waves
• Ancillary S11 measurements of ambient and hot loads, LNA input, and open cable used for noise wave measurements
• Measurements done at 2 temperatures for temperature coefficients
• Lab performance verification using “artificial antenna”
Lab testing – work in progress

Use an “artificial antenna” to test accuracy

Assumes:
• A mismatched load at uniform temperatures is precisely equivalent to a lossless antenna observing a uniform sky at the same temperature

Caveat:
• Corrections have to be made for the non-uniform temperature of a hot tungsten filament source (although corrections are small ~ less than 1 K; see EDGES memo 100)
Artificial Antenna

Simulator of antenna looking at sky temperature of 1670K +/- 30K

balun at ambient temperature

Lamp filament of 1670K +/- 30K estimated from 8.26 fold increase in tungsten resistance
Simulated antenna S11

LNA S11

Noise waves

Spectrum of open cable
Lab demonstration of absolute calibration

Estimate absolute calibration of better than 1 part in 3000 currently

Some uncertainty due to corrections for non-uniform temperature of tungsten filament, working on improved modeling

Believe 1 in 10,000 possible with technique in near future

RMS deviation from constant 1666K of <1K

Spectrum from 3-position switch

after correction for balun

after correction for mismatch and LNA noise
Estimates of the sources of error and their magnitude expressed as the residuals to fits with increased numbers of parameters along with the bias in EOR estimation

Parameters of 10 parameter solution:

1] EoR signature (30 mK, 50@145MHz)
2] scale (assumes spectral index of -2.5)
3] constant (ground emission)
4] frequency -2 (ionosphere emission)
5] frequency -4.5 (ionosphere absorption)
6] Magnitude of antenna S11
7] Magnitude of LNA S11
8] S11 phase error
9] S11 delay error
10] temperature scale

<table>
<thead>
<tr>
<th>Error source</th>
<th>Assumed error</th>
<th>Residual mK</th>
<th>EoR mK</th>
<th>Note</th>
</tr>
</thead>
<tbody>
<tr>
<td>Antenna S11</td>
<td>0.01 dB, 0.1°</td>
<td>26 23 16 0 0 0 0</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>LNA S11</td>
<td>0.01 dB, 0.1°</td>
<td>20 18 18 0 0 0 0</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>Antenna loss</td>
<td>0.1%</td>
<td>130 0 0 0 0 0 0</td>
<td>2,4,10</td>
<td></td>
</tr>
<tr>
<td>Antenna beam</td>
<td>Fourpoint</td>
<td>500 300 0 0 5 5 2 7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ionosphere</td>
<td>0.015 dB @ 150 MHz</td>
<td>1500 22 0 0 8 9 2 1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sky spectral index</td>
<td>0.05</td>
<td>2800 200 1 1 6 12 4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Spectral index steepening “gamma”</td>
<td>0.12</td>
<td>9000 2500 1 1 40 60 20 8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Slope in antenna loss</td>
<td>0.1% per 50 MHz</td>
<td>80 74 2 1 30 30 10 3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Slope in antenna S11</td>
<td>0.01 dB per 50 MHz</td>
<td>12 11 10 5 300 25 3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Slope in LNA S11</td>
<td>0.01 dB per 50 MHz</td>
<td>11 10 6 4 300 25 9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temperature</td>
<td>1° K</td>
<td>700 10 10 0 30 10 2 9</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 1A

A Rms residual following removal of scale
B Rms residual following removal of scale and offset
C Rms residual plus removal of $f^{-2}$ and $f^{-4.5}$
D Rms residual plus functions for additional errors listed in table 2
E Bias in EoR for 10 parameter solution
F Bias with 10’ added cable
G Bias with EoR width reduced by factor of 2

Estimate of errors using simulations – for more details see EDGES memo 99
EDGES summary

• EDGES-1 successfully demonstrated viable limits on reionization with only 3-position calibration (no accounting for reflection terms) and polynomial fitting

• Nearly 2-years of RFI (and other event) monitoring at MRO, posted at [http://loco.lab.asu.edu/edges](http://loco.lab.asu.edu/edges), ongoing analysis of RFI correlation with weather, ionosphere, meteors, etc.

• EDGES-2 attempting absolute calibration, 1 part in 10 000 appears within reach, expect first deployment by 2013-Q3. Should constrain reionization duration to dz >1

• Spin-offs include improved calibration and characterization of VNAs at low-frequencies, calibration of noise diodes, “artificial antenna”, real antenna stability (sensitivity to perturbations, temperature, etc.)

• Lessons: Incremental development useful. Keep active memo series