Spectral Index of the Diffuse Radio Background between 50-100 MHz

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EDGES Instrument

- **Location:** Murchison Radio Observatory (-26.7° deg)
- **System:** Blade Dipole zenith pointing, Ground plane and temperature controlled receiver
- **Band:** Two low-band instruments (50-100MHz)
- **Beamwidth:** @ 75MHz -
  - 71.6 deg (parallel)
  - 108 deg (perp)
Data Collection

- **Data collection:**
  - 244 nights/348 days
  - Different configurations
  - Only night time data (minimize solar and ionospheric disturbances)

| Instrument configuration | Year | Day Numbers   | Span |
|--------------------------|------|---------------|------|
| Lowband 1 NS             | 2016 | 258 to 366    | 109  |
| Lowband 1 NS             | 2017 | 001 to 017    | 17   |
| Lowband 2 NS             | 2017 | 082 to 142    | 61   |
| Lowband 2 EW             | 2017 | 155 to 171    | 17   |
| Lowband 2 EW, no shield  | 2017 | 181 to 239    | 58   |
Data Processing

● **Absolute Calibration:**
  ○ Coefficients estimated from the standard loads in the lab & S11 from the field

● **Beam correction:**
  ○ Scaled Haslam sky map
  ○ Simulated beam solution
    ■ FEKO model
    ■ Dielectric Ground

● **Time Binning:** Raw resolution ⇒ 20 min averages

● **Freq Binning:** Raw resolution ⇒ 400KHz (125 bins)
The calibrated data is modelled as a power law. (primary components are synchrotron and free-free emission)

Worked with two 2 and 3 term fits

\[ T_{\text{ant}} = T_{75} \left( \frac{\nu}{\nu_{75}} \right)^\beta + T_{\text{CMB}}, \]

\[ T_{\text{ant}} = T_{75} \left( \frac{\nu}{\nu_{75}} \right)^\beta + \gamma \ln\left( \frac{\nu}{\nu_{75}} \right) + T_{\text{CMB}}, \]

- \( \beta \) - Spectra index
- \( \gamma \) - Curvature to the spectral index
- \( T_{\text{CMB}} \) - Background temperature (2.723K)
The fitting was carried out for every LST bin each day.

- **Estimated Parameters:** $\beta$ & $T_{75}$
- **Range:** -2.46 to -2.60
- **Galaxy up:** -2.46
- **Galaxy down:** -2.58
- **Stable over time**
Results - Two parameter Fitting

**Averaging the results:**

- Averaged the parameters over days
- Added uncertainty
- Results from all configurations are within the systematic uncertainties
Results - 2 & 3 parameter fitting

**2 Parameters**

**3 Parameters**

**2 Parameters**
1. **Ground Loss:**
   a. Finite ground plane ⇒ part of the beam is going to look into the ground
   b. Taking the higher limit of 0.5 per constant loss sin
      \[ \Delta \beta = 0.002 \]

2. **Antenna & Balun Loss:**
   a. Balun that connects
   b. Antenna panel resistances
      \[ \Delta \beta = 0.005 \]
      \[ \Delta \beta = 0.001 \]

3. **Beam Chromaticity:**
   a. Calculated beta from two models finite ground and infinite
   b. Effect of uncertainty in the spatial structure of foreground at 75MHz
      i. Used different scaling indices: -2.65 to -2.45
      \[ \Delta \beta = 0.004 \]
      \[ \Delta \beta = 0.01 \]
      \[ \sigma_\beta = 0.006 + \text{data scatter} \]

Adding all the errors in quadrature:
Results - Ionosphere Impact

\[ T_{sky} = T_{75} \left( \frac{v}{v_{75}} \right)^{\beta} \times \left[ e^{-\tau \left( \frac{v}{v_{75}} \right)^{-2}} \right] + T_e \left[ 1 - e^{-\tau \left( \frac{v}{v_{75}} \right)^{-2}} \right] + T_{CMB}, \]

Absorption; \( \tau = 0.005 \)

- Correcting for the ionosphere made \( \beta \) more negative for both 2 & 3 parameter fits

| Fits  | Points      | No Ionosphere | With Ionosphere |
|-------|-------------|---------------|-----------------|
| 2 - Param | Galaxy Down | -2.58         | -2.594          |
| 3 - param | Galaxy Down | -2.60         | -2.61           |
Results - Standard sky models

- **Comparison**: Spectral index results to simulated observations.
  - **Use**: EDGES beam (NS orientation) and sky maps:
    - de Oliveira-Costa GSM
    - Improved GSM
    - GMOSS
    - Haslam 408MHz & Guzman 45MHz

\[
T_{\text{ant}}(\nu) = \int_{\Omega} T'_{\text{sky-model}}(\nu, \Omega) B(\nu_{75}, \Omega)d\Omega + T_{\text{CMB}},
\]
Discussions

- Used EDGES lowband data (50 - 100 MHz)
- Instrument calibration, including corrections for ground loss, antenna losses, and beam chromaticity - Results stable over time.
- Derived the $\beta$
  - two-parameter and
  - three-parameter equations
- Three-parameter $\beta$ are more negative than two-parameter by approximately 0.02.
- Looked at effects of ionosphere
- Compared results to values from sky models.

FUTURE WORK:

- Combine Lowband, Midband & Highband data and estimate $\beta$
EXTRA SLIDES
Results - Extended Model

- To investigate the possibility of bias added two more terms:

\[ T_{\text{ant}} = T_{75} \left( \frac{\nu}{\nu_{75}} \right)^{\beta + \gamma \ln\left( \frac{\nu}{\nu_{75}} \right)} + a_4 \left[ \ln\left( \frac{\nu}{\nu_{75}} \right) \right]^2 + a_5 \left[ \ln\left( \frac{\nu}{\nu_{75}} \right) \right]^3 + T_{\text{CMB}}, \]

- Minimal change when compared to 3 term fits

| Terms | RMS(K) |
|-------|--------|
| 2     | 2.7    |
| 3     | 0.85   |
| 5     | 0.66   |

Day 264

LST = 3.83 h
Day 264

Residuals (K)

LST = 19.83 h

Beam Factor

Frequency (MHz)

NS

EW
| Parameter | LST (h) | No ionospheric corrections (fitting terms) | With ionospheric corrections (fitting terms) | Exp–log (terms) |
|-----------|---------|------------------------------------------|---------------------------------------------|-----------------|
|           |         | 2 | 3 | 2 | 3 | 5 |
| $T_{75}$ (K) | 0       | 1806 | 1807 | 1815 | 1816 | 1807 |
|           | 6       | 1673 | 1673 | 1681 | 1682 | 1673 |
|           | 12      | 2566 | 2568 | 2579 | 2580 | 2568 |
|           | 18      | 4749 | 4752 | 4773 | 4776 | 4751 |
| $\beta$   | 0       | -2.576 | -2.592 | -2.590 | -2.603 | -2.591 |
|           | 6       | -2.571 | -2.585 | -2.585 | -2.595 | -2.585 |
|           | 12      | -2.539 | -2.568 | -2.553 | -2.578 | -2.565 |
|           | 18      | -2.463 | -2.489 | -2.477 | -2.499 | -2.489 |
| $\gamma$  | 0       | - | -0.055 | - | -0.042 | -0.068 |
|           | 6       | - | -0.047 | - | -0.034 | -0.041 |
|           | 12      | - | -0.099 | - | -0.086 | -0.090 |
|           | 18      | - | -0.089 | - | -0.076 | -0.079 |
| $a_4$     | 0       | - | - | - | - | -0.048 |
|           | 6       | - | - | - | - | -0.004 |
|           | 12      | - | - | - | - | -0.053 |
|           | 18      | - | - | - | - | 0.018 |
| $a_5$     | 0       | - | - | - | - | -0.022 |
|           | 6       | - | - | - | - | -0.031 |
|           | 12      | - | - | - | - | -0.158 |
|           | 18      | - | - | - | - | -0.025 |
| RMS       | 0       | 3.7 | 1.2 | 2.9 | 1.2 | 1.0 |
| Resid. (K)| 6       | 2.9 | 0.9 | 2.2 | 0.9 | 0.9 |
|           | 12      | 9.0 | 1.6 | 7.9 | 1.6 | 1.4 |
|           | 18      | 15 | 3.6 | 13 | 3.6 | 2.8 |
Results - Three parameter fitting

- $\beta$, $T_{75}$ & $\gamma$
- Stable over time (within each instrument)
- Averaged the parameters over days
- Added uncertainty
- More between 8 -12h mainly because less data there.
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Results - Two parameter Fitting

The fitting was carried out for every LST bin each day.

- Estimated Parameters: $\beta$ & $T_{75}$
- Range: 1000K to 5000K
- Galaxy up: 4770K
- Galaxy down: 1800K
- Stable over time (within each instrument)
The fitting was carried out for every time bin each day.

- **Estimated Parameters:** $\beta$ & $T_{75}$
- **Range:** 2K to 15K
- **Galaxy up:** 17K
- **Galaxy down:** 3K
- **Stable over time (within each instrument)**
Introduction

**Motivation**

Spectral index useful for:

- To carry out basic ISM science
- To 21cm community for foreground removal

**Our Approach**

- EDGES can help estimate the diffuse radio structure
- It has a wide beam that averages the sky flux
- We have already estimated and reported the spectral index for 100-200 MHz
Results - Standard sky models

- **The GH model:**
  - For 2-param: good agreement at low LST values, around GC spectral index becomes more negative by up to 0.04
  - For 3-param shows more consistent agreement with measurements of spectral index across all LST values, differing by only up to ±0.02 across all LST.
- **The improved GSM** model more negative than the measured values
- **The GMOSS model** yields more positive predictions of the spectral index. (up to +0.10).
- We also include the spectral index as reported in the high-band paper (Mozdzen et al. 2017).
- The low-band spectral index has become less negative by approximately 0.02–0.04 as compared to the high-band results.