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

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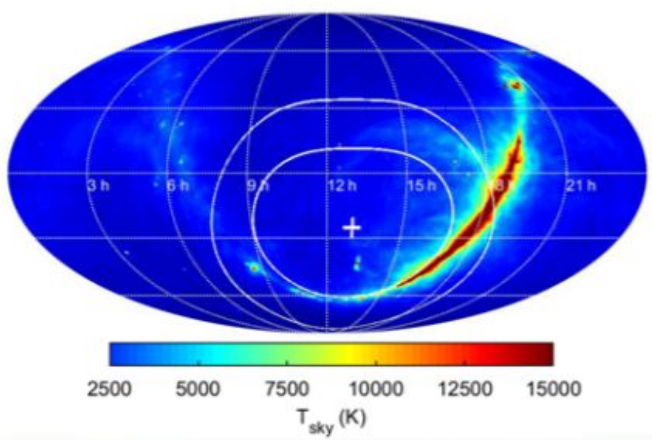
MNRAS, Issue-4, Vol-483, March 2019

National Radio Science Meeting 2019

EDGES Instrument

- **Location:** Murchison Radio Observatory (-26.7^{o} 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)

Data Processing- Modelling

- 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

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

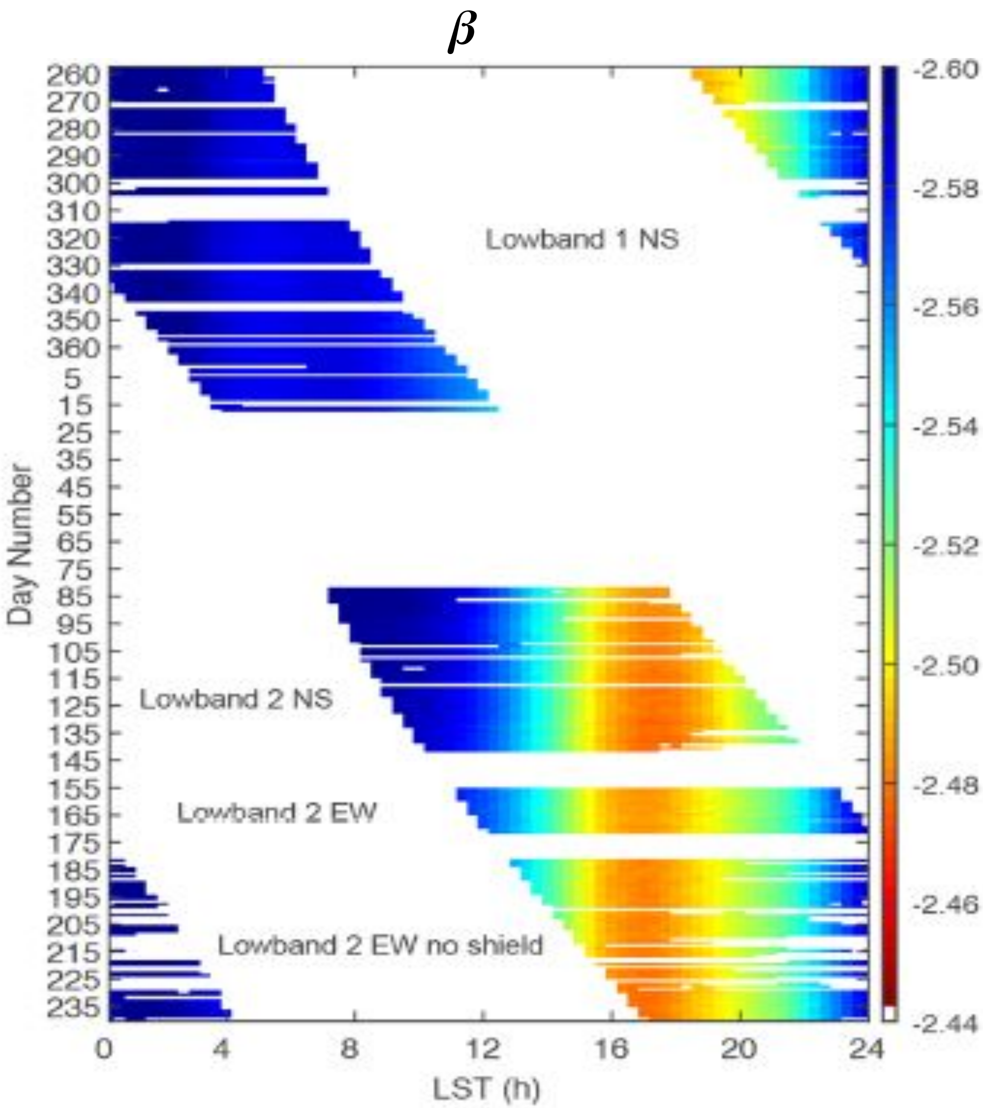
$$T_{\text{ant}} = T_{75}\left(\frac{\nu}{\nu_{75}}\right)^{\beta+\gamma\ln(\frac{\nu}{\nu_{75}})} + T_{\text{CMB}},$$

- β - Spectra index
- ɣ - Curvature to the spectral index
- T_{CMB} - Background temperature (2.723K)

Results - Two parameter Fitting

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

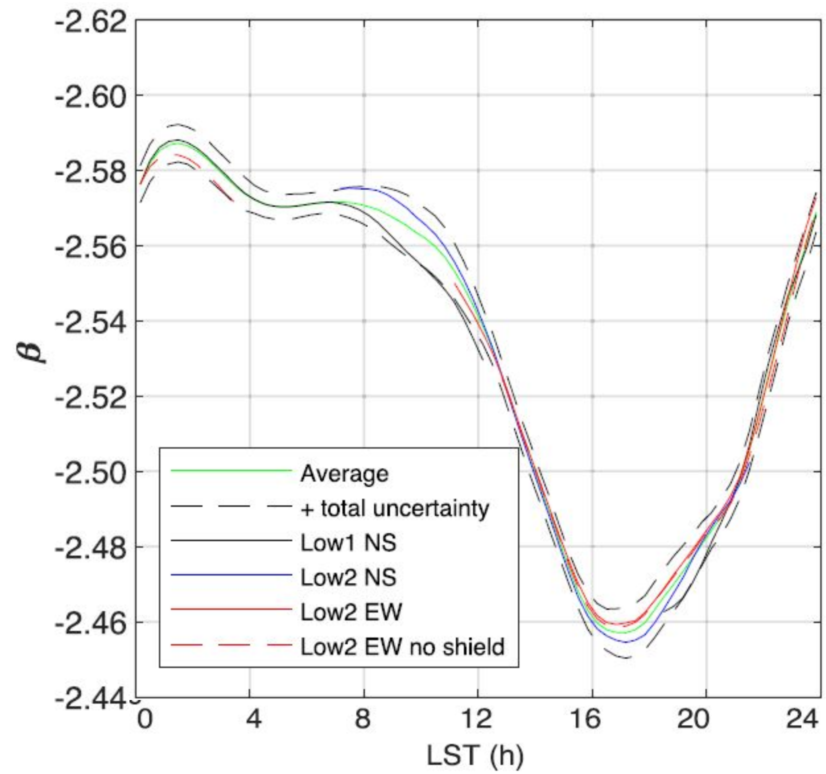
- **Estimated Parameters:** β & T_{75}
- Range: -2.46 to -2.60
- Galaxy up: -2.46
- Galaxy down: -2.58
- Stable over time



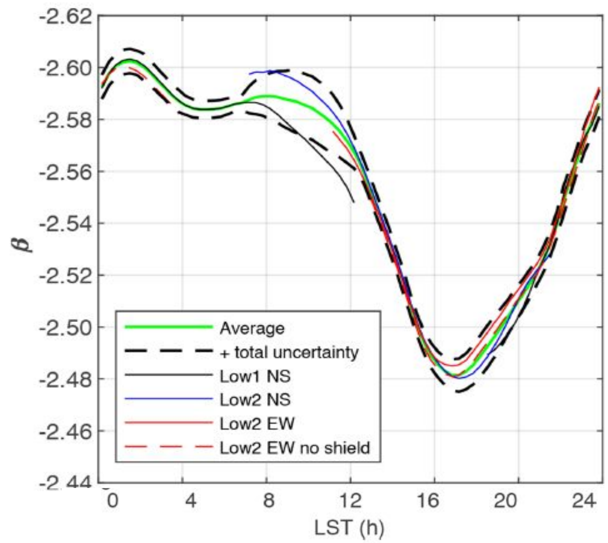
Results - Two parameter Fitting

Averaging the results:

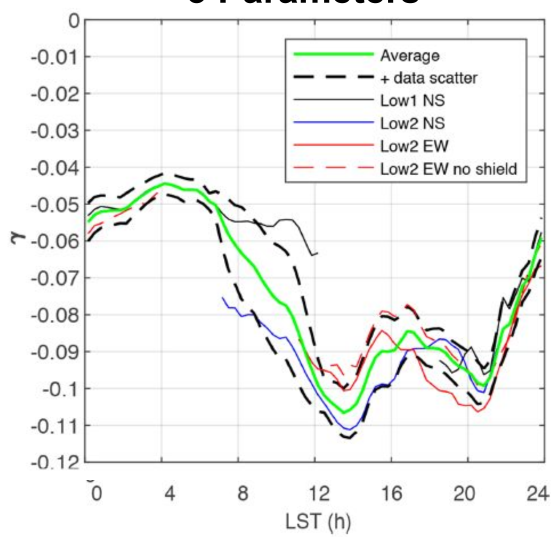
- Averaged the parameters over days
- Added uncertainty
- Results from all configurations are within the systematic uncertainties

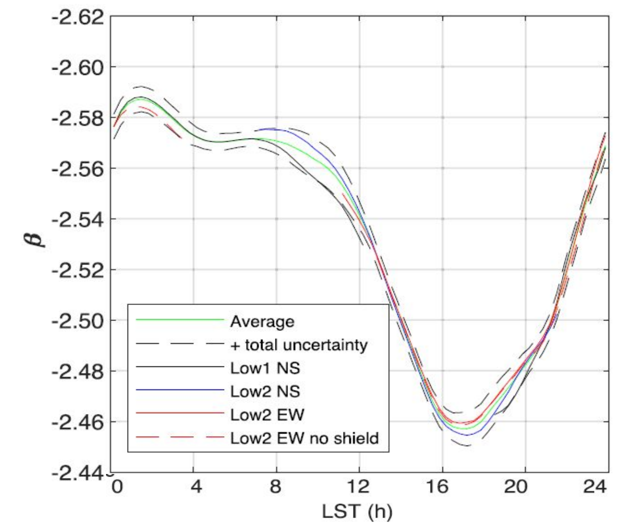


Results - 2 & 3 parameter fitting



3 Parameters





2 Parameters

Results - Accounting for Uncertainties

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

⇒ $\Delta_\beta = 0.004$

⇒ $\Delta_\beta = 0.01$

Adding all the errors in quadrature:

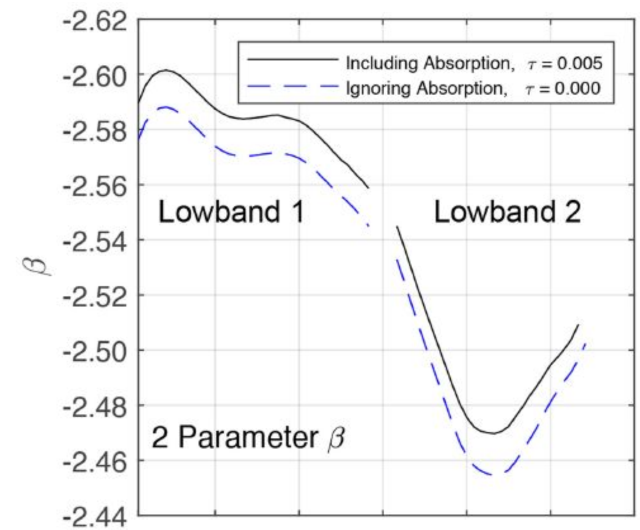
⇒ $\sigma_\beta = 0.006$ + data scatter

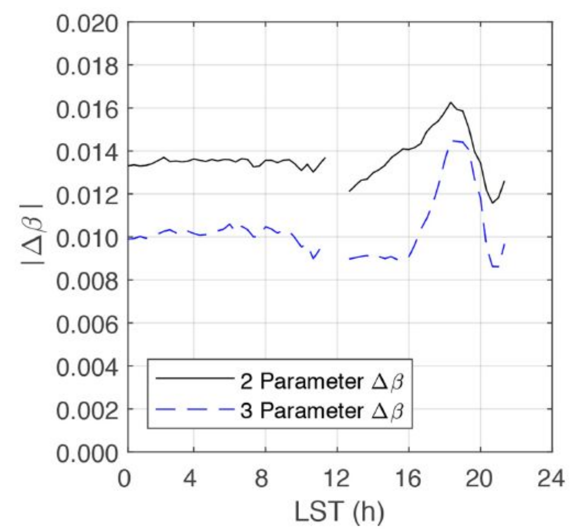
Results - Ionosphere Impact

$$T_{\rm sky} = T_{75}\overbrace{\left(\frac{\nu}{\nu_{75}}\right)^{\beta}}^{\textbf{2 param}} \times \underbrace{\left[e^{-\tau\left(\frac{\nu}{\nu_{75}}\right)^{-2}}\right]}_{\textbf{Absorption; } \boldsymbol{\tau} \textbf{ = 0.005}} + \overbrace{T_e\left[1 - e^{-\tau\left(\frac{\nu}{\nu_{75}}\right)^{-2}}\right]}^{\mathbf{T_e = 1000K \Rightarrow Emission = 1K}} + T_{\rm CMB},$$

- Correcting for the ionosphere made β ***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

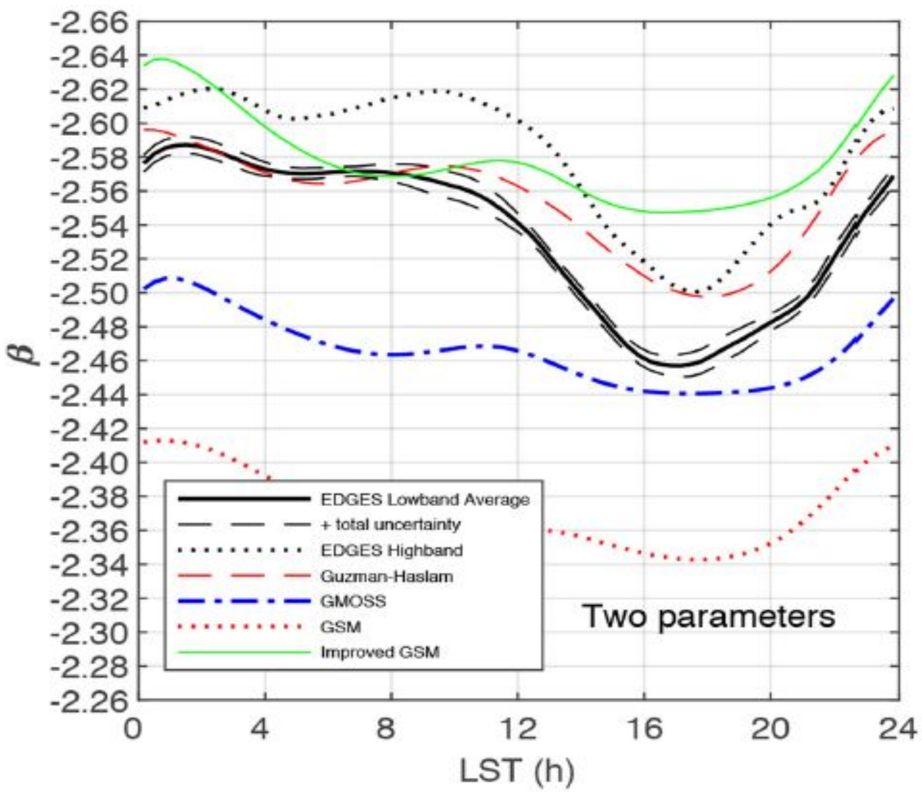


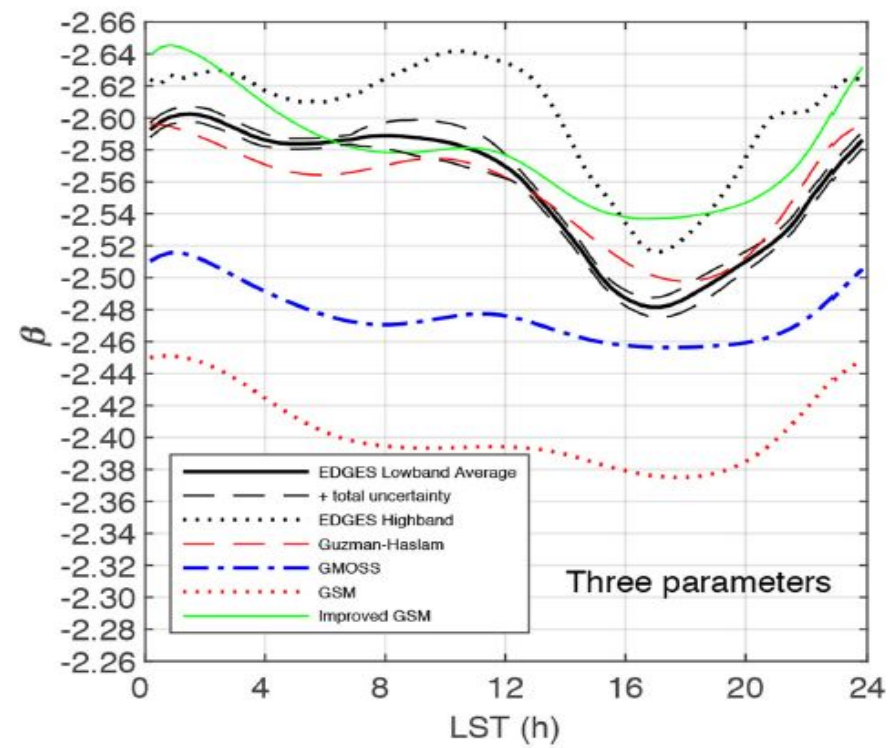


Results - Standard sky models

- **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

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





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 β
  - two-parameter and
  - three-parameter equations
- Three-parameter β 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 β

EXTRA SLIDES

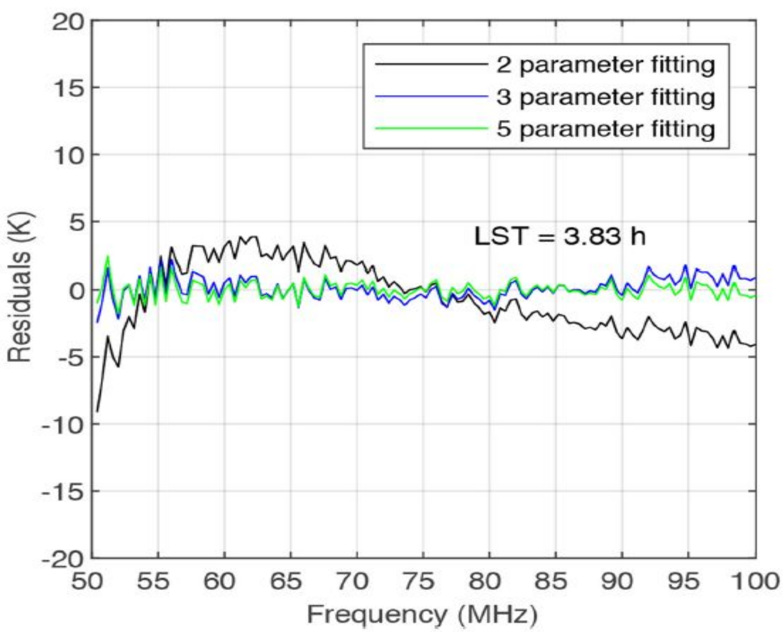
Results - Extended Model

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

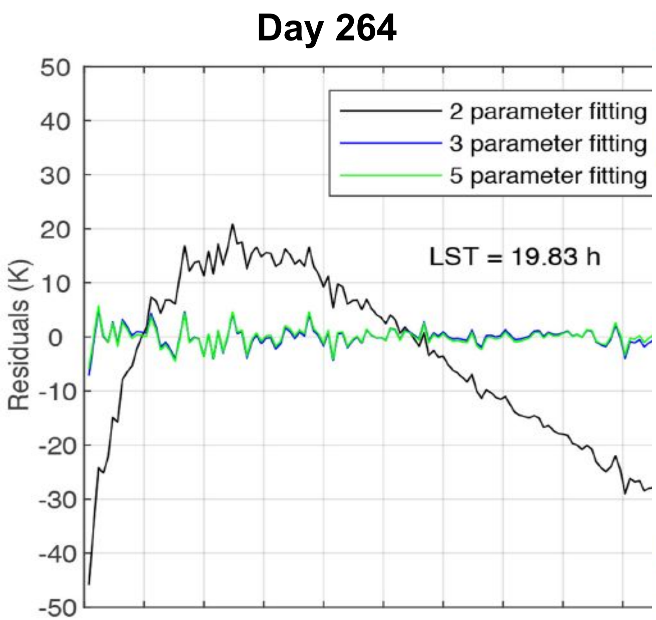
$$T_{\mathrm{ant}} = T_{75}\left(\frac{\nu}{\nu_{75}}\right)^{\beta+\gamma\ln(\frac{\nu}{\nu_{75}})+\underbrace{a_4[\ln(\frac{\nu}{\nu_{75}})]^2+a_5[\ln(\frac{\nu}{\nu_{75}})]^3}} + T_{\mathrm{CMB}},$$

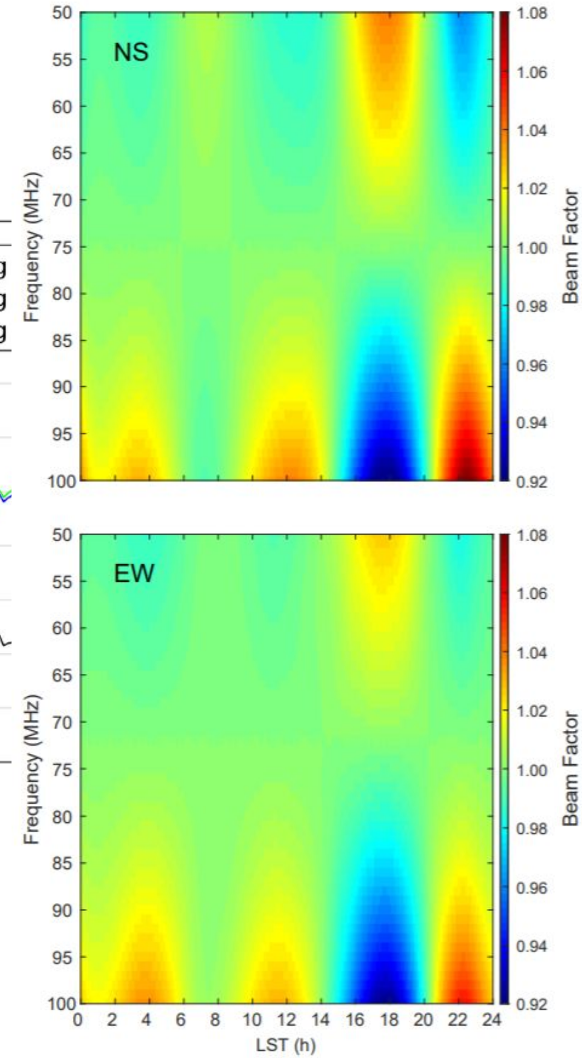
- Minimal change when compared to 3 term fits

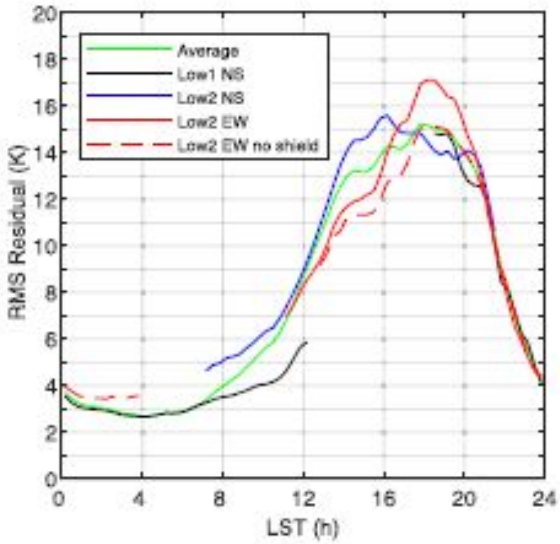
Day 264

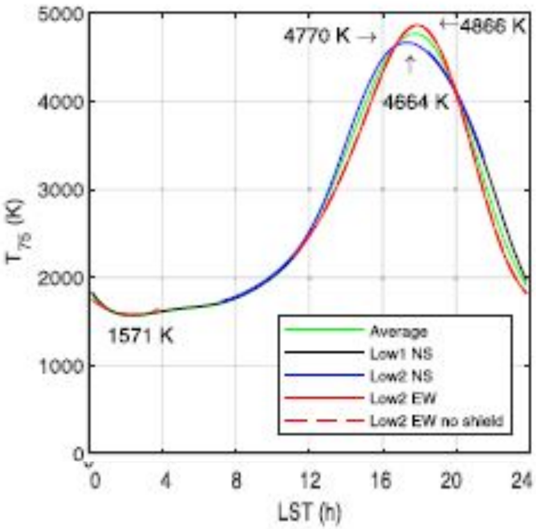


Terms	RMS(K)
2	2.7
3	0.85
5	0.66

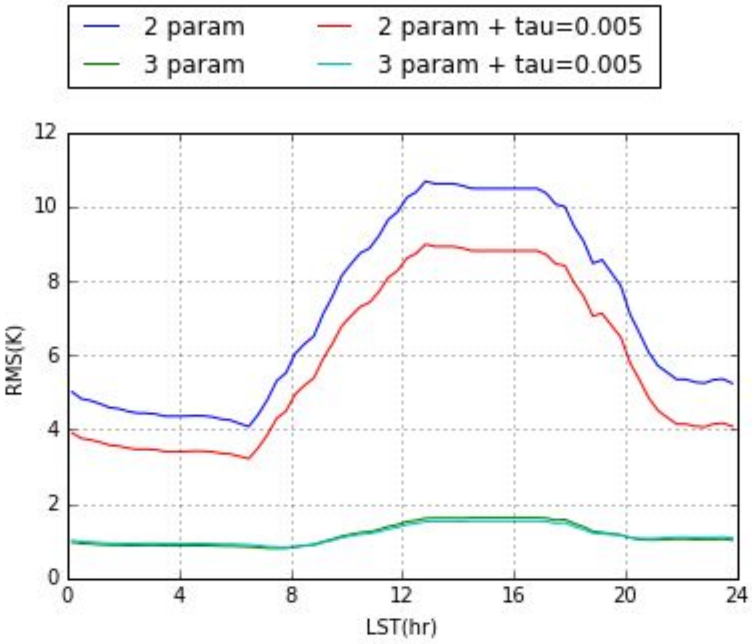

Day 264
2 parameter fitting
3 parameter fitting
5 parameter fitting
LST = 19.83 h
Residuals (K)
50
40
30
20
10
0
-10
-20
-30
-40
-50


NS
EW
Frequency (MHz)
Beam Factor
LST (h)
50
55
60
65
70
75
80
85
90
95
100
1.08
1.06
1.04
1.02
1.00
0.98
0.96
0.94
0.92
0 2 4 6 8 10 12 14 16 18 20 22 24


20
18
16
14
12
10
8
6
4
2
0
0
4
8
12
16
20
24
RMS Residual (K)
LST (h)
Average
Low1 NS
Low2 NS
Low2 EW
Low2 EW no shield

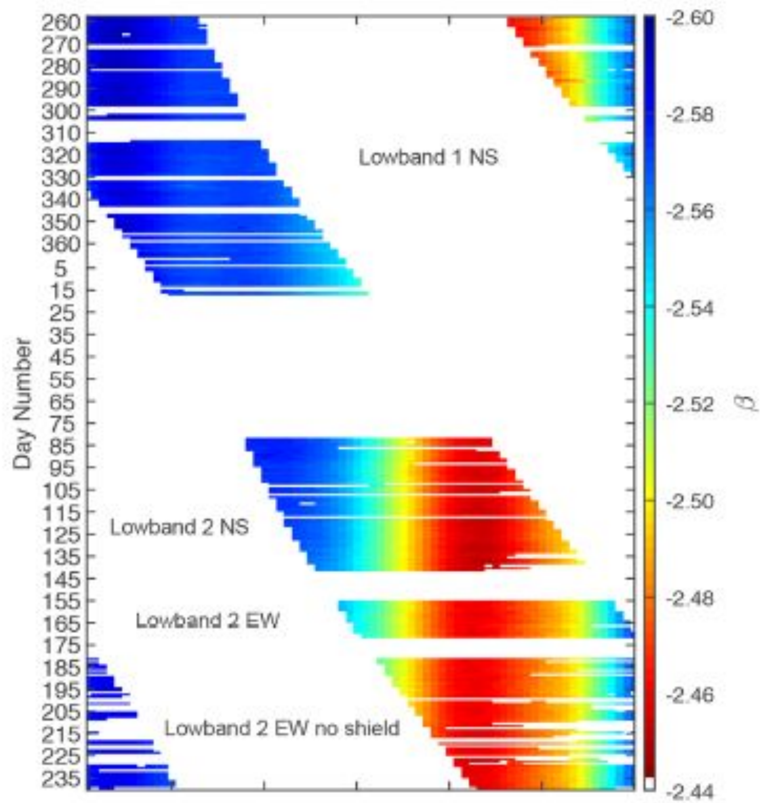

5000
4000
3000
2000
1000
0
0
4
8
12
16
20
24
T_{75} (K)
LST (h)
4770 K →
← 4866 K
↑
4664 K
1571 K
Average
Low1 NS
Low2 NS
Low2 EW
Low2 EW no shield

Parameter	LST (h)	No ionospheric corrections (fitting terms) 2	3	With ionospheric corrections (fitting terms) 2	3	Exp–log (terms) 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
β	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
γ	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 Resid. (K)	0	3.7	1.2	2.9	1.2	1.0
	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


2 param
2 param + tau=0.005
3 param
3 param + tau=0.005
RMS(K)
LST(hr)
0
2
4
6
8
10
12
0
4
8
12
16
20
24

Results - Three parameter fitting

- β , T_{75} & ɣ
- 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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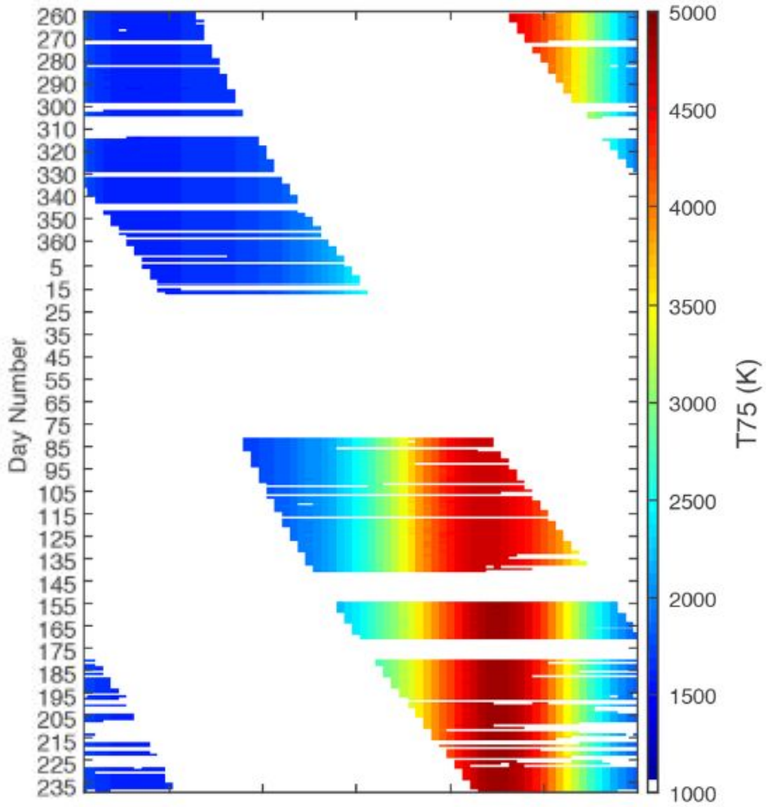

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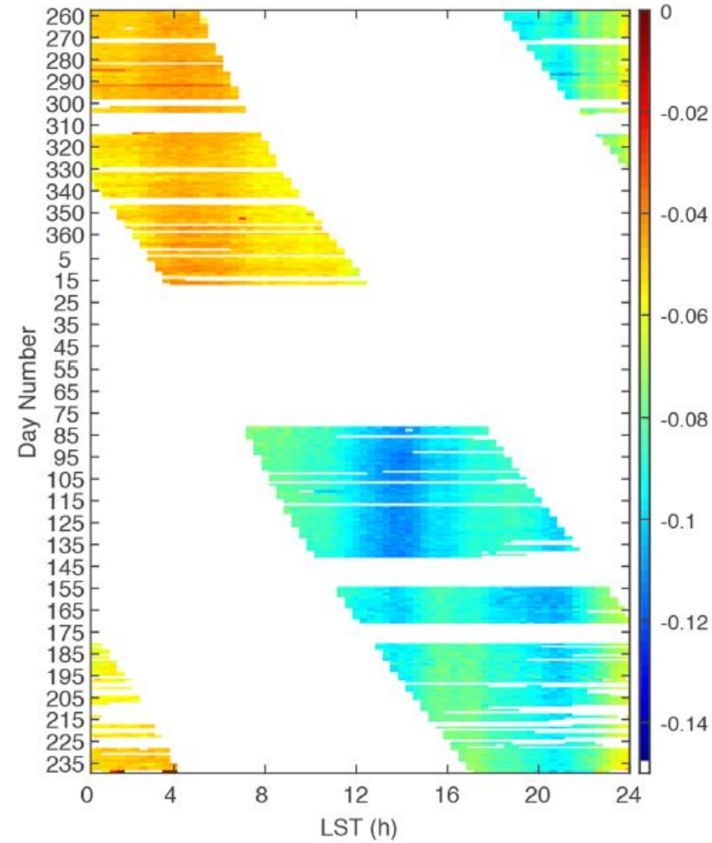

Results - Three parameter fitting

- β , T_{75} & γ
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- Added uncertainty
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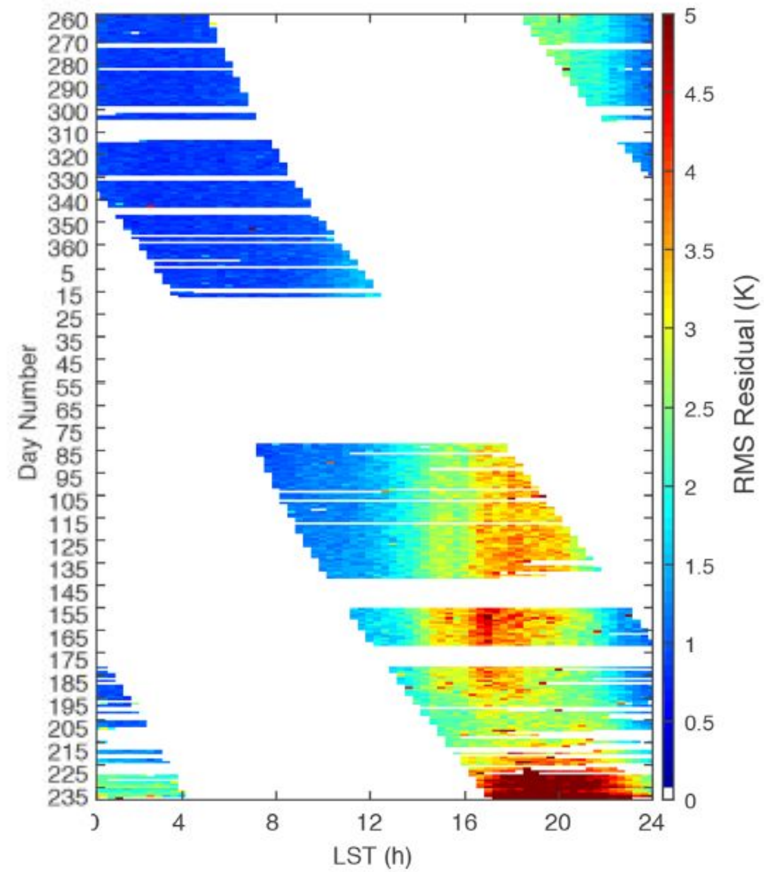

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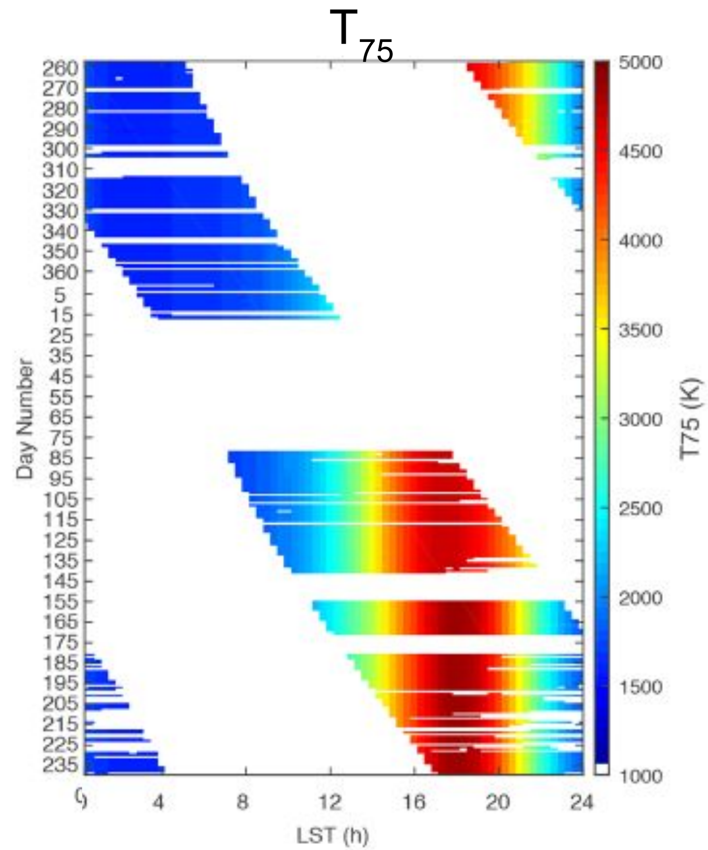
Results - Two parameter Fitting

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

- **Estimated Parameters:** β & T_{75}
- Range: 1000K to 5000K
- Galaxy up: 4770K
- Galaxy down:1800K
- Stable over time (within each instrument)

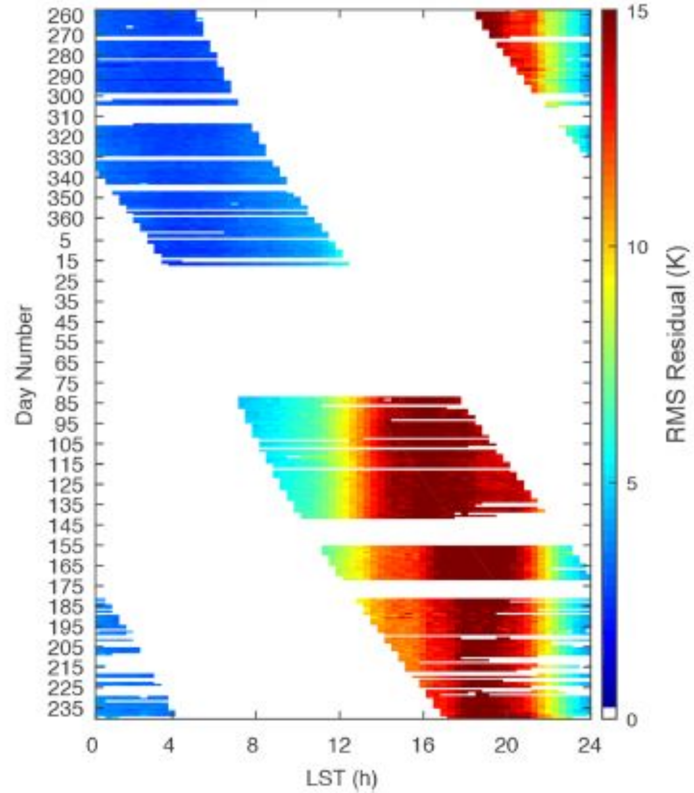


Results - Two parameter Fitting

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

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

RMS



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.