Constraining the Astrophysics of the Early Universe using the SARAS Instrumentation

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SARAS2 Analysis and Results

The SARAS2 Data

Singh et al 2017, 2018
What are we doing differently?

Previously:
Polynomial Foregrounds

This Work:
Maximally Smooth Foregrounds (maxsmooth)
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Foreground Modelling

\[ T^*_f = T_f \eta_t \]

\[ \frac{d^m T^*_f}{d \nu^m} \leq 0 \quad \text{or} \quad \frac{d^m T^*_f}{d \nu^m} \geq 0 \]

\[ T^*_f = \sum_{k=0}^{N-1} a_k (\nu - \nu_0)^k \]

![Graph showing the relationship between \( T_A \) and \( \nu \)]

![Graph showing the difference between \( T_A \) and \( T_f \)]
Systematic Modelling

\[ T_A = (T_{21} + T_{fg})\eta_t + T_{NS} \]

\[ T_{NS,2}(\nu) = \eta_t \left( \frac{\nu}{v_0} \right)^{\alpha_{sys}} A \sin \left( \frac{2\pi\nu}{P} + \phi \right) \]

\[ T_{NS,1}(\nu) = \left( \frac{\nu}{v_0} \right)^{\alpha_{sys}} A \sin \left( \frac{2\pi\nu}{P} + \phi \right) \]
Noise Modelling

\[ \log \mathcal{L} = \sum_i \left( -\frac{1}{2} \log(2\pi\sigma^2) - \frac{1}{2} \left( \frac{T_A(v_i) - T_M(v_i)}{\sigma} \right)^2 \right) \]

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<th>Noise Model</th>
<th>( \sigma )</th>
<th>Prior</th>
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<tr>
<td>Constant</td>
<td>( A_{\sigma} )</td>
<td>( A_{\sigma} = 10^{-3} - 10^{-1} ) mK</td>
<td>Log Uniform</td>
</tr>
<tr>
<td>Frequency</td>
<td>( A_{\sigma} )</td>
<td>( \nu^\beta_{\sigma} )</td>
<td>( A_{\sigma} = 10^{-4} - 10^{-1} ) mK</td>
</tr>
<tr>
<td>Damped</td>
<td>( A_{\sigma} )</td>
<td>( \left( \frac{\nu}{\nu_0} \right)^{-\beta_{\sigma}} )</td>
<td>( \beta_{\sigma} = 0 - 5 )</td>
</tr>
<tr>
<td>Relative Weights</td>
<td>( A_{\sigma} )</td>
<td>( W(v) )</td>
<td>( A_{\sigma} = 10^{-2} - 10^{-1} ) mK</td>
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Table 2. The tested frequency dependent and independent standard deviation models for the assumed Gaussian noise in the SARAS2 data. In the frequency damped noise model \( \nu_0 \) is the central frequency in the band. The origin of the relative weights, \( W(v) \), is discussed in section 3.1.
Signal Modelling

Models from Reis et al. 2020 and 2021
Results

Systematic Noise Signal

Fit Number

Efficiency - Constant
Damped - Constant
Efficiency - Freq. Damped
Damped - Freq. Damped
Efficiency - Relative Weight
Damped - Relative Weight

log(\(Z\))
\[ P_{\text{combined}}(\theta|D, M) = \sum_i w_i P_i(\theta|D, M) \quad w_i = \frac{Z_i}{\sum_j Z_j} \]
Results – Radio Galaxy Excess Background

![Graph showing distribution of radio galaxy excess background with axes labeled as follows: log(f_c), log(V_c), log(f_X), \tau, log(f_{radio}).]
Conclusions

- SARAS2 has provided constraints on the magnitude of any excess radio background from high redshift radio galaxies above the CMB.

- We have identified a systematic in the SARAS2 data (probably ground emission).

- The workflow used here could be applied to REACH data...
SARAS2 Foreground Modelling

![Graph showing the RMS values at different redshifts and frequencies.]

- **RMS = 197.54 mK**
- **RMS = 19.76 mK**
- **RMS = 24.90 mK**
- **RMS = 11.71 mK**
“Standard” Signals

\[
\begin{align*}
\log(V_c) &\ -2.5 \quad 0.0 \quad 2.5 \\
\log(f_X) &\ -2.5 \quad 0.0 \quad 2.5 \\
\tau &\ -2 \quad -1 \\
E_{\text{min}} &\ 1 \quad 2
\end{align*}
\]
Results – In the Context of HERA

\[
\begin{align*}
\log(V_c) & \approx -2.5 ^{0.0} \quad 2.5 \\
\log(f_X) & \approx 0.04 ^{0.06} \quad 0.050 ^{0.075} \\
\tau & \approx 0.0 ^{2.5} \quad 5.0 \\
\log(f_{\text{radio}}) & \approx 1.0 ^{1.5} \quad 4.0
\end{align*}
\]

*The HERA Collaboration 2022