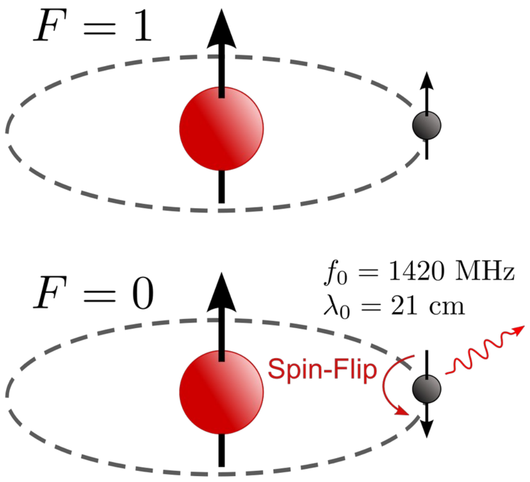
An Update on the REACH experiment and its Bayesian Data Analysis Pipeline

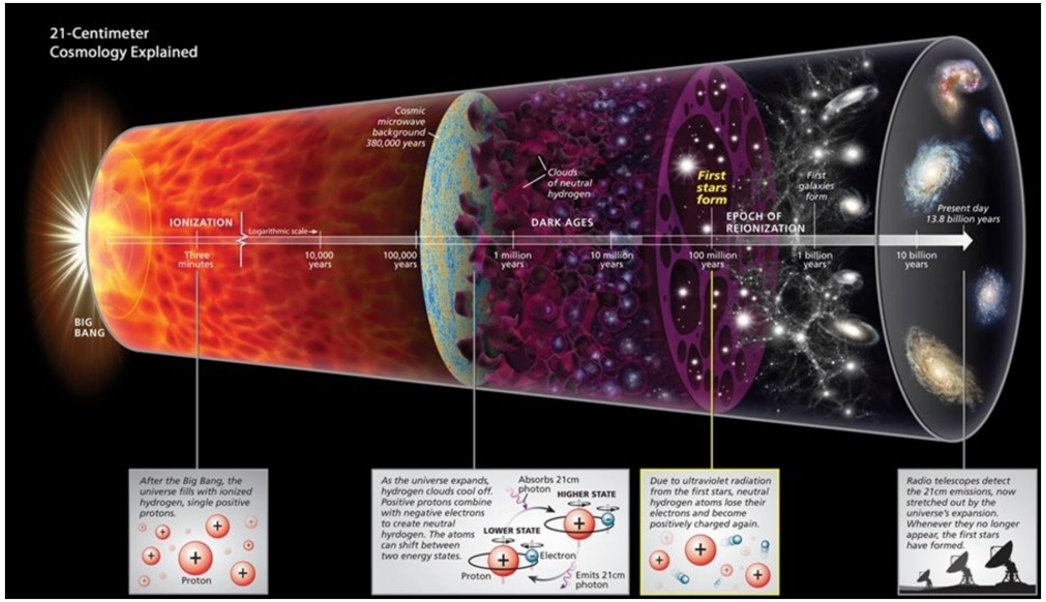
Dominic Anstey

On behalf of the REACH collaboration

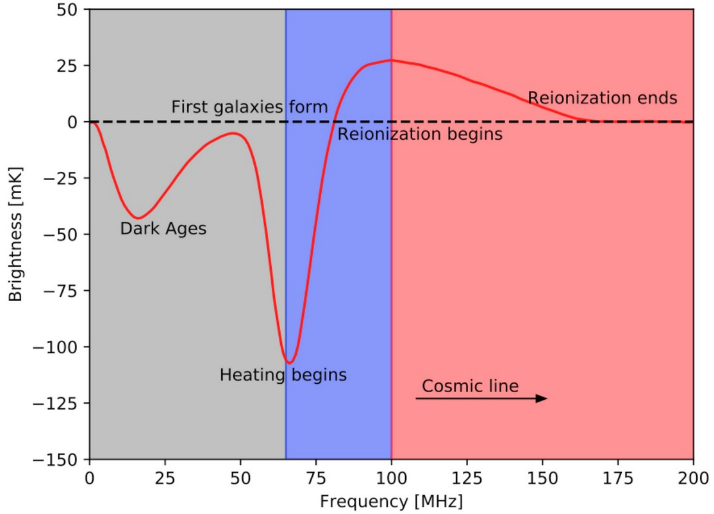
Global 21cm Experiments



https://en.wikipedia.org/wiki/Hydrogen_line



Roen Kelly, Discover Magazine



https://www.astro.phy.cam.ac.uk/research/research-projects/reach/overview

REACH

Cambridge University

Kavli Institute for Cosmology in Cambridge

The Kavli Foundation

Cavendish Astrophysics

Stellenbosch University

National Research Foundatio South African Radio Astronomy Observatory

The ALBORADA Trust

Leibniz-Institut für Astrophysik Potsdam

REACH

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Sussex University

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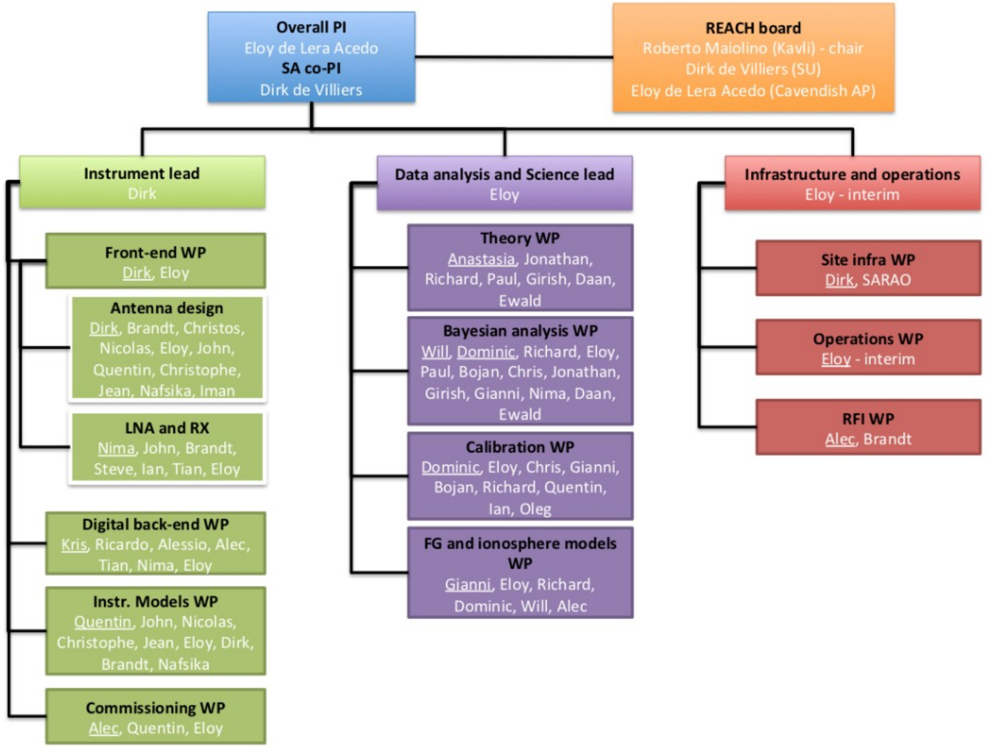
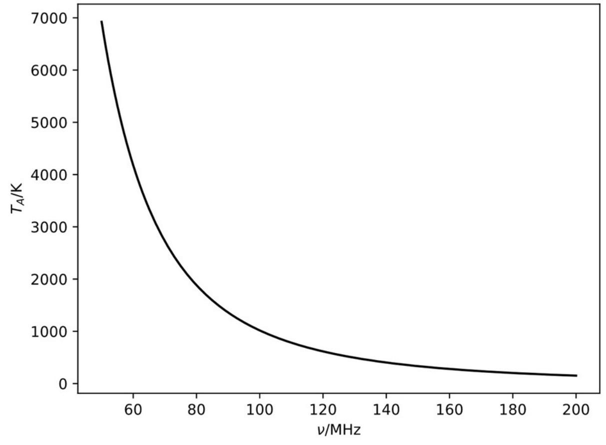


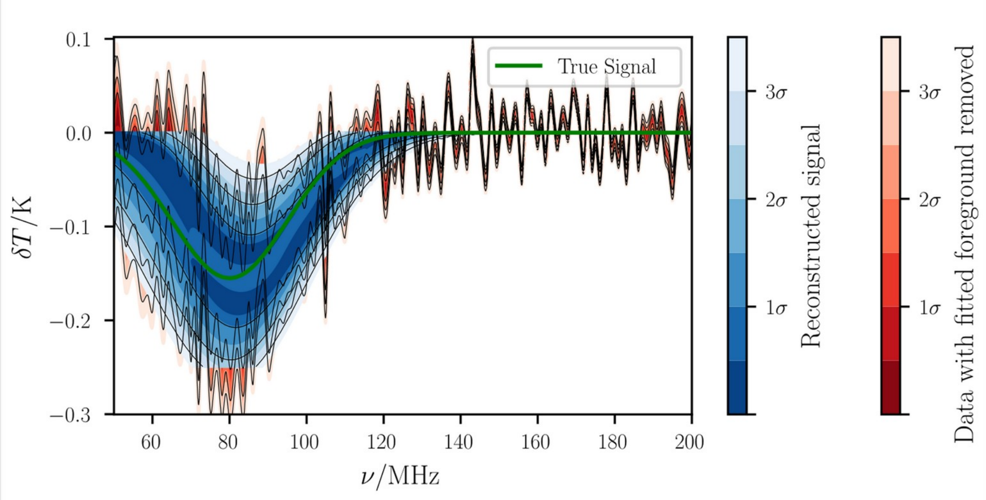
REACH Summary

- Designed with Bayesian calibration and data analysis in mind
- Use physics-rooted, physically interpretable models to understand and account for systematics
- Simultaneous observations with two different antennae

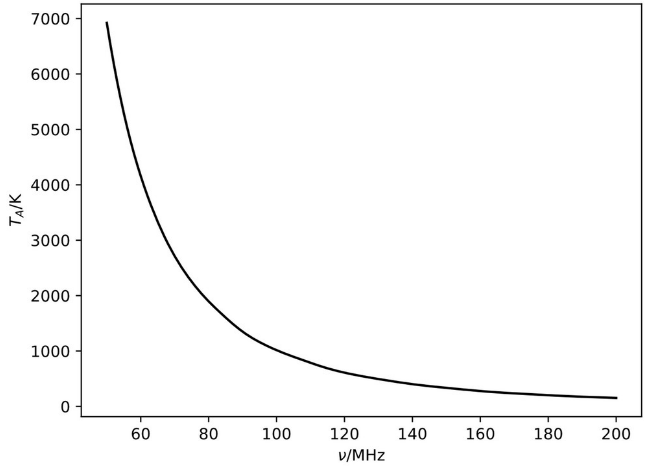
Radio Foregrounds and Chromaticity

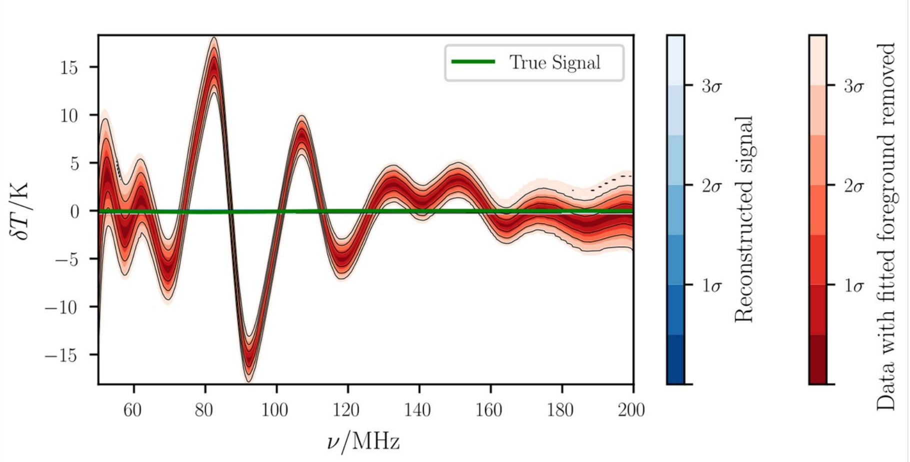
Achromatic antenna



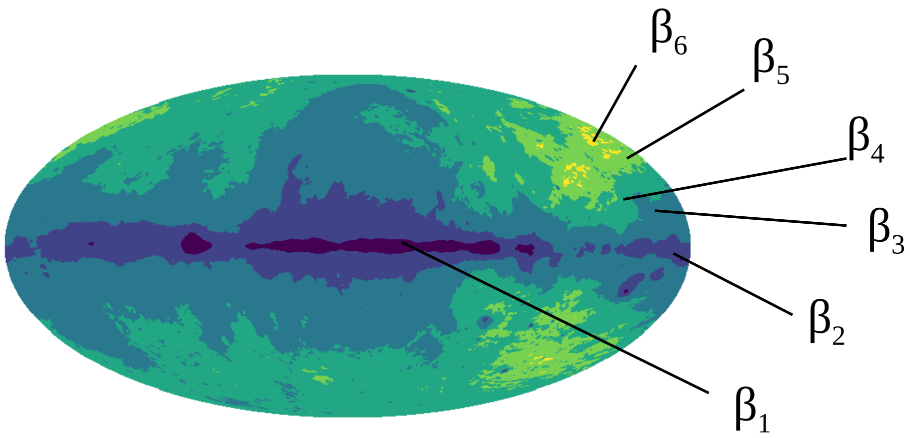


Chromatic antenna





Summary of REACH Pipeline

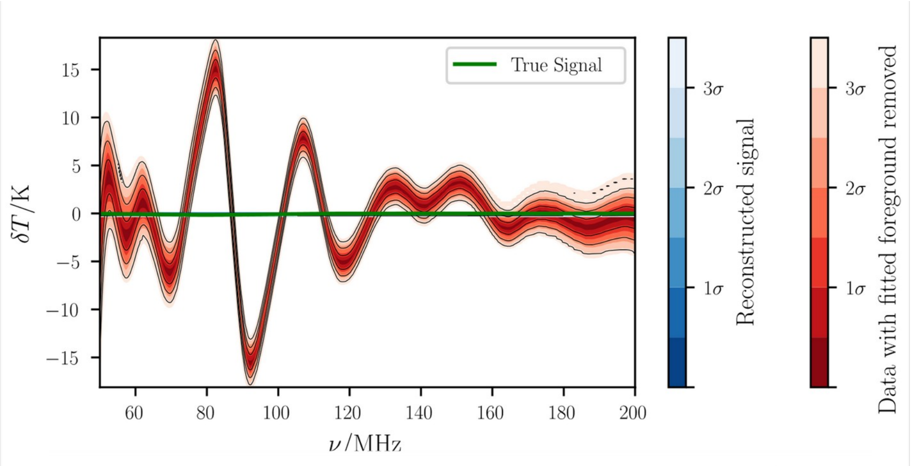


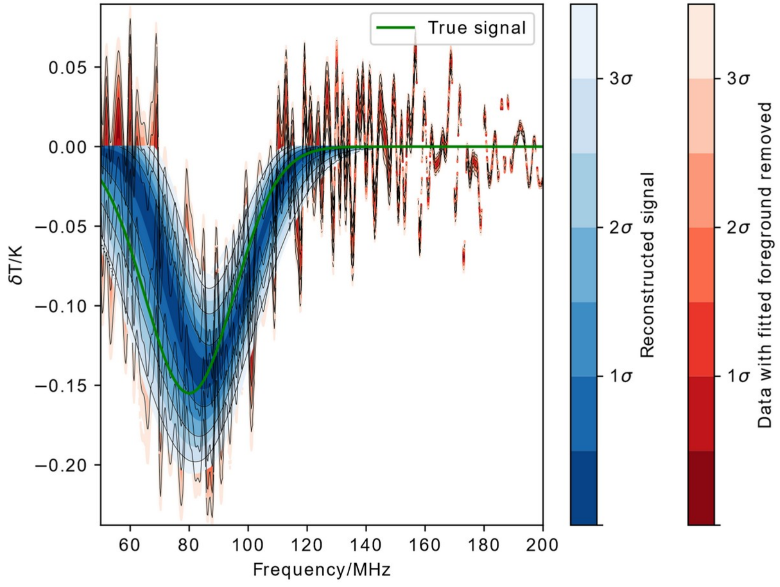
$$T_{\mathrm{F}}\left(\nu,\theta_{\mathrm{F}}\right)=\frac{1}{4\pi}\int_{0}^{4\pi} D\left(\theta,\phi,\nu\right)\times\int_{t_{\mathrm{start}}}^{t_{\mathrm{end}}}\sum_{i=1}^{N} M_i\left(\theta,\phi\right)\left(T_{230}\left(\theta,\phi\right)-T_{\mathrm{CMB}}\right)\left(\frac{\nu}{230}\right)^{-\beta_i} dt d\Omega + T_{\mathrm{CMB}}$$

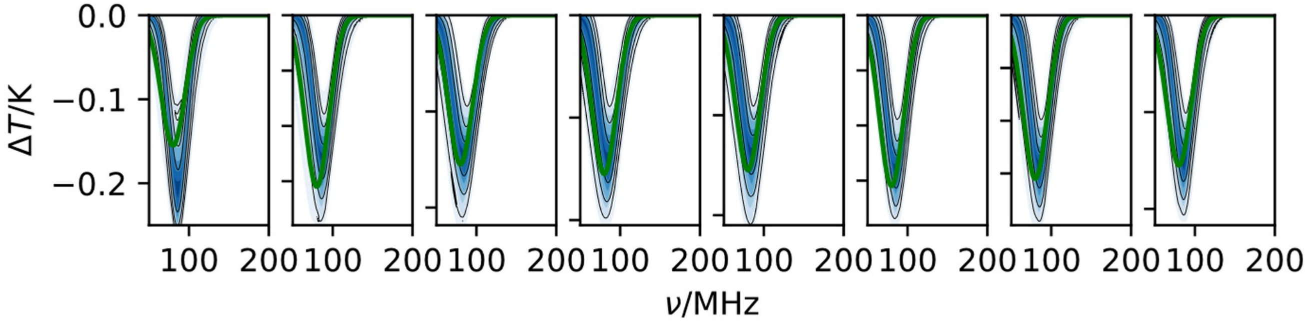
$$\log\mathcal{L}=\sum_{i}-\frac{1}{2}\log\left(2\pi\sigma_{\mathrm{n}}^{2}\right)-\frac{1}{2}\left(\frac{T_{\mathrm{data}}\left(\nu_i\right)-\left(T_{\mathrm{F}}\left(\nu_i,\theta_{\mathrm{F}}\right)+T_{S}\left(\nu_i,\theta_{\mathrm{S}}\right)\right)}{\sigma_{\mathrm{n}}}\right)^{2}$$

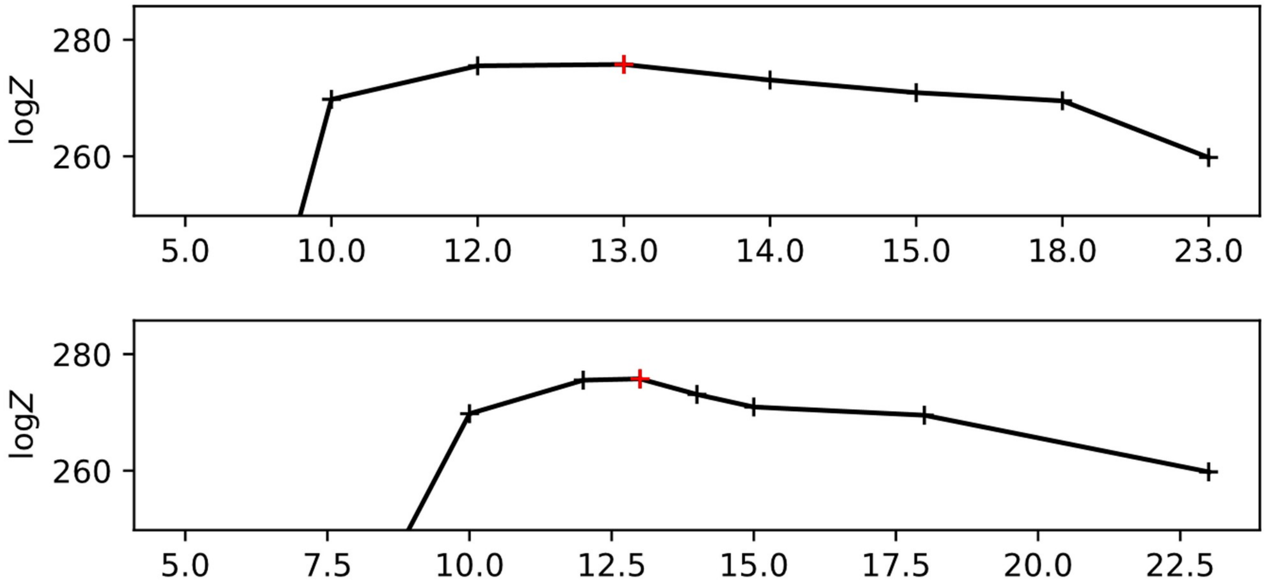
Anstey et al. 2021

Performance



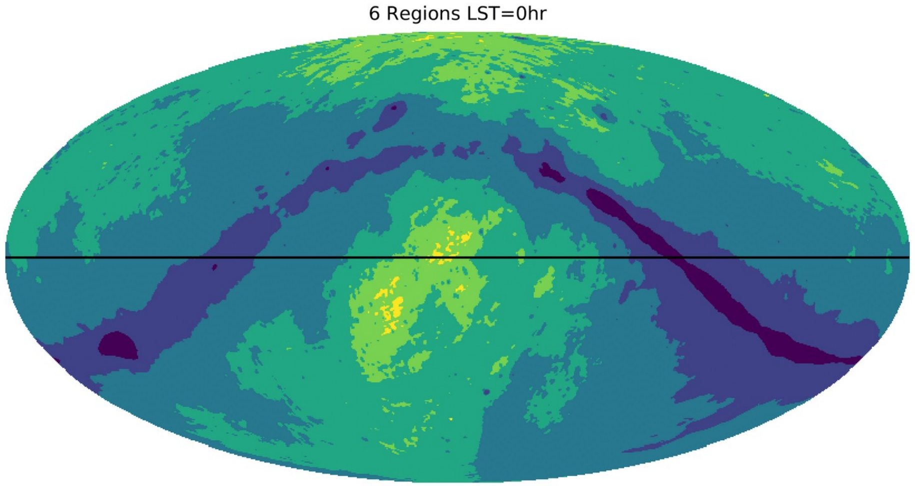


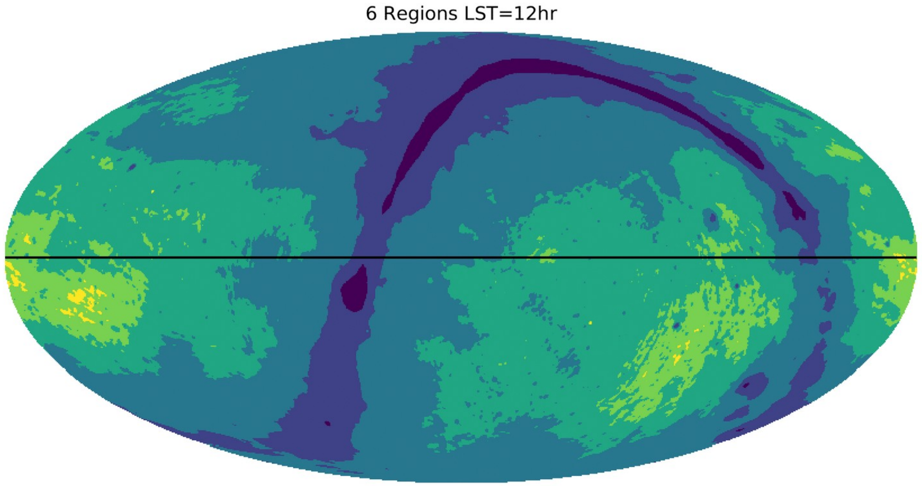




Time-Separated Fitting

$$\log \mathcal{L} = \sum_{i} -\frac{1}{2}\log\left(2\pi\sigma_{\mathrm{n}}^{2}\right) - \frac{1}{2}\left(\frac{\frac{1}{n_j}\sum_j \left[T_{\mathrm{data}}\left(\nu_i, t_j\right)\right] - \left(\frac{1}{n_j}\sum_j \left[T_{\mathrm{F}}\left(\nu_i, t_j, \theta_{\mathrm{F}}\right)\right] + T_{S}\left(\nu_i, \theta_{\mathrm{S}}\right)\right)}{\sigma_{\mathrm{n}}}\right)^{2}$$

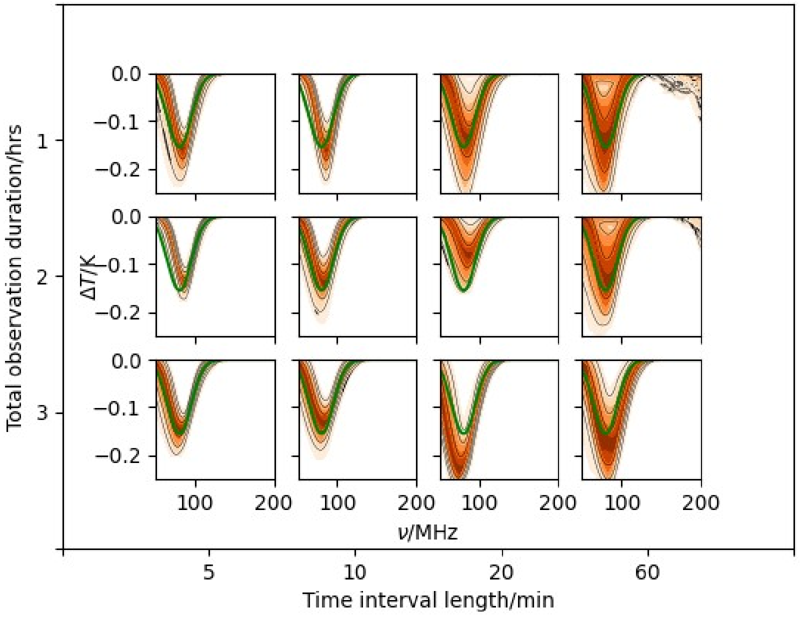




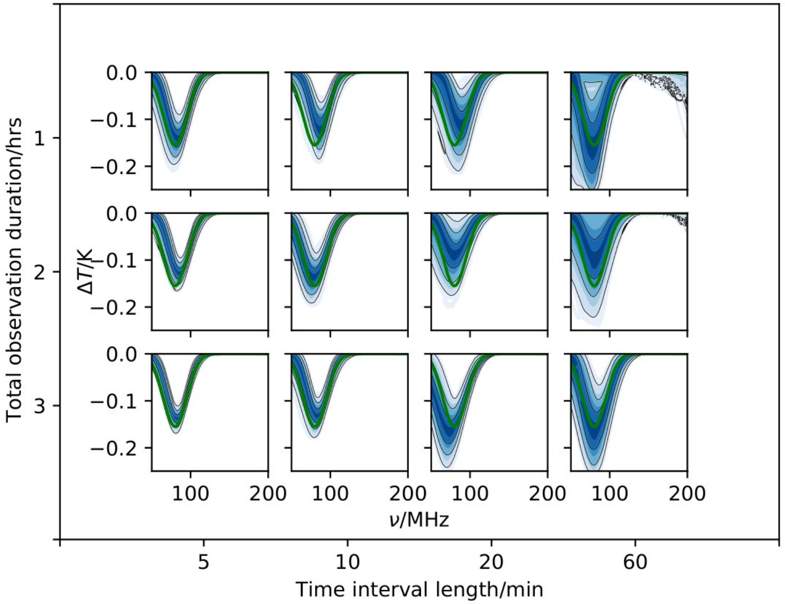
$$\log \mathcal{L} = \sum_{i}\sum_{j} -\frac{1}{2}\log\left(2\pi\sigma_{\mathrm{n}}^{2}\right) = \frac{1}{2}\left(\frac{T_{\mathrm{data}}\left(\nu_i, t_j\right) - \left(T_{\mathrm{F}}\left(\nu_i, t_j, \theta_{\mathrm{F}}\right) + T_{\mathrm{S}}\left(\nu_i, \theta_{\mathrm{S}}\right)\right)}{\sigma_{\mathrm{n}}}\right)^{2}$$

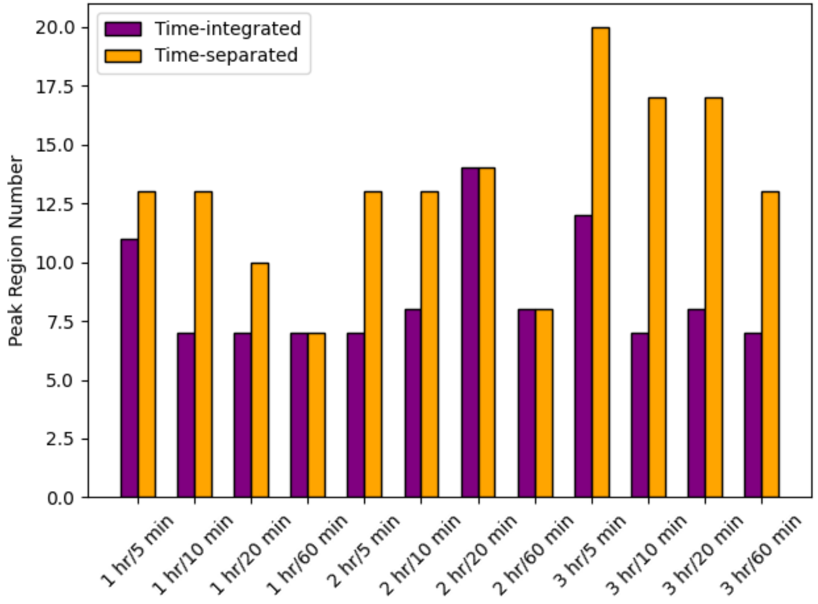
Time-Separated Fitting Results

Time-averaged



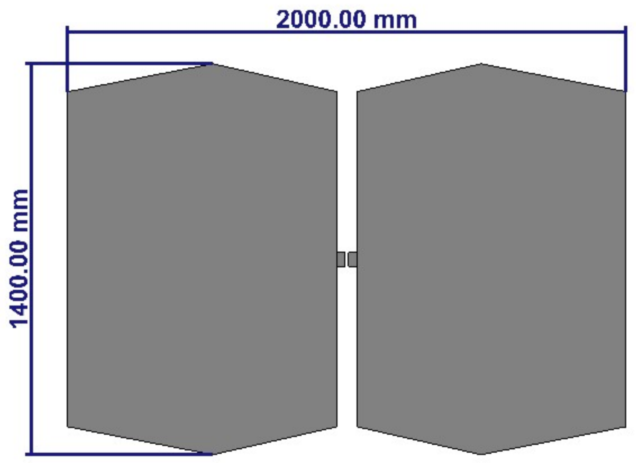
Time-separated

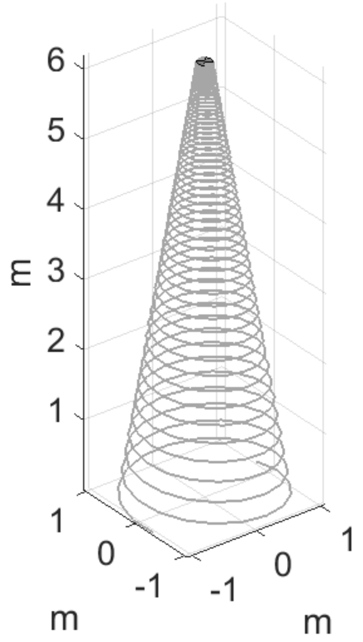




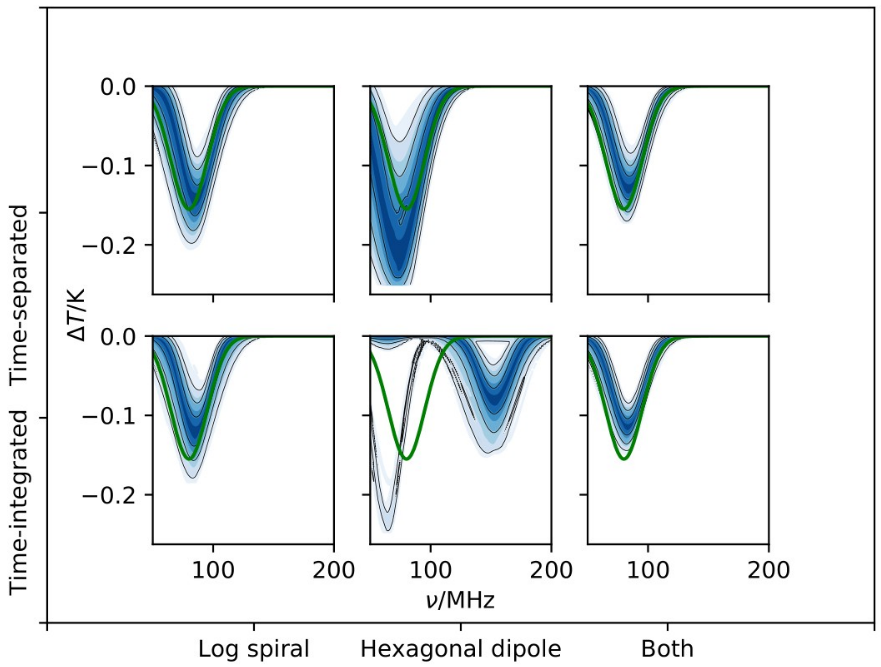
Multiple Antennae

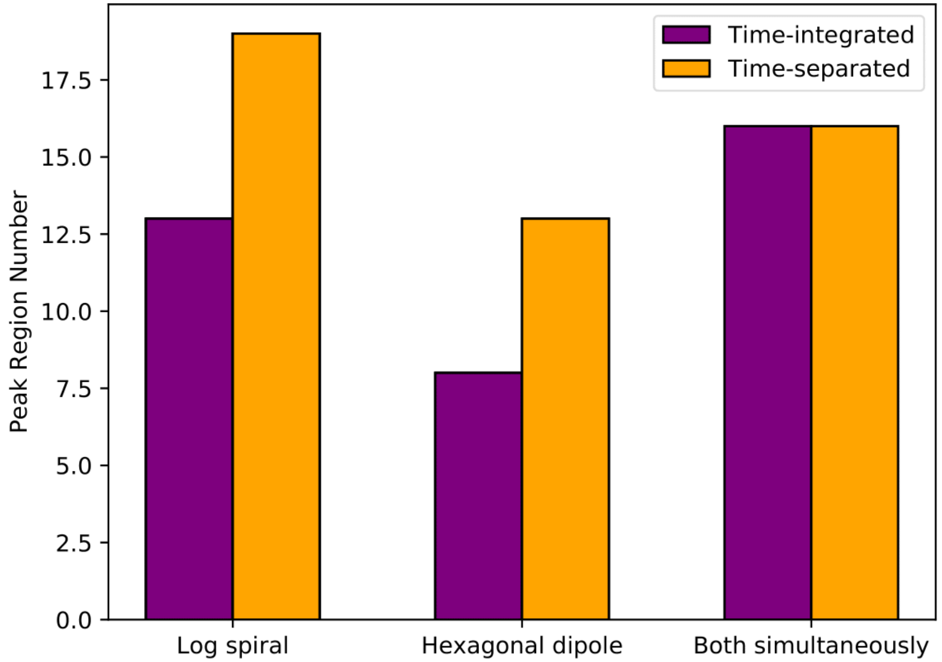
$$\log \mathcal{L} = \sum_i \sum_j \sum_k -\frac{1}{2}\log\left(2\pi\sigma_{\mathrm{n}}^2\right) - \frac{1}{2}\left(\frac{T_{\mathrm{data}\,k}\left(\nu_i, t_j\right) - \left(T_{\mathrm{F}\,k}\left(\nu_i, t_j, \theta_{\mathrm{F}}\right) + T_S\left(\nu_i, \theta_{\mathrm{S}}\right)\right)}{\sigma_{\mathrm{n}}}\right)^2$$





Multiple Antennae Results





Antenna Beam Modelling

The antenna beam pattern may not be known exactly in practice:

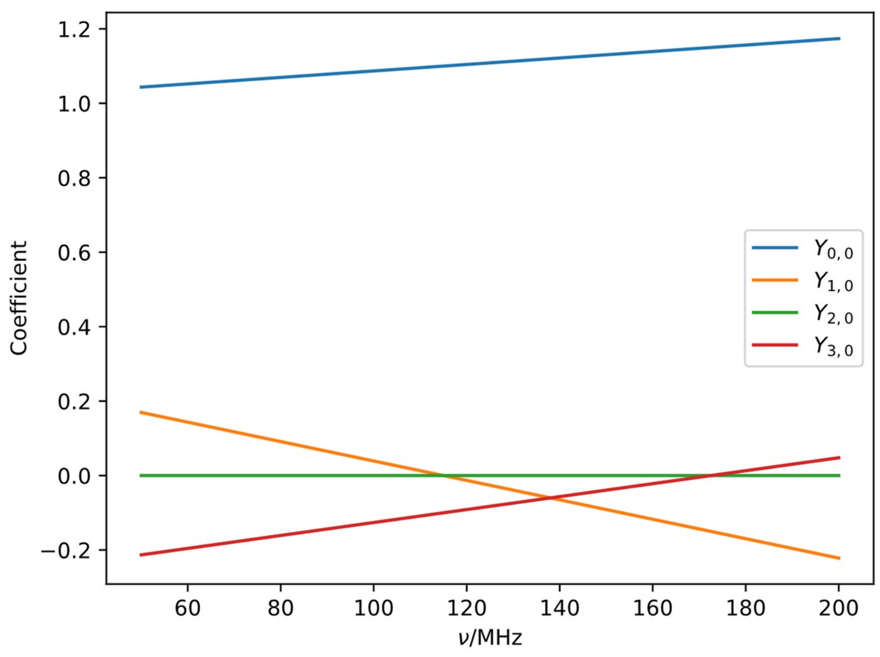
- Soil permittivity
- Horizon effects
- Imperfections in construction
- Etc.

$$D\left(\Omega,\nu,\bar{\theta}\right)=\sum_{j=1}^{M}\theta_j X_j\left(\Omega,\nu\right)$$

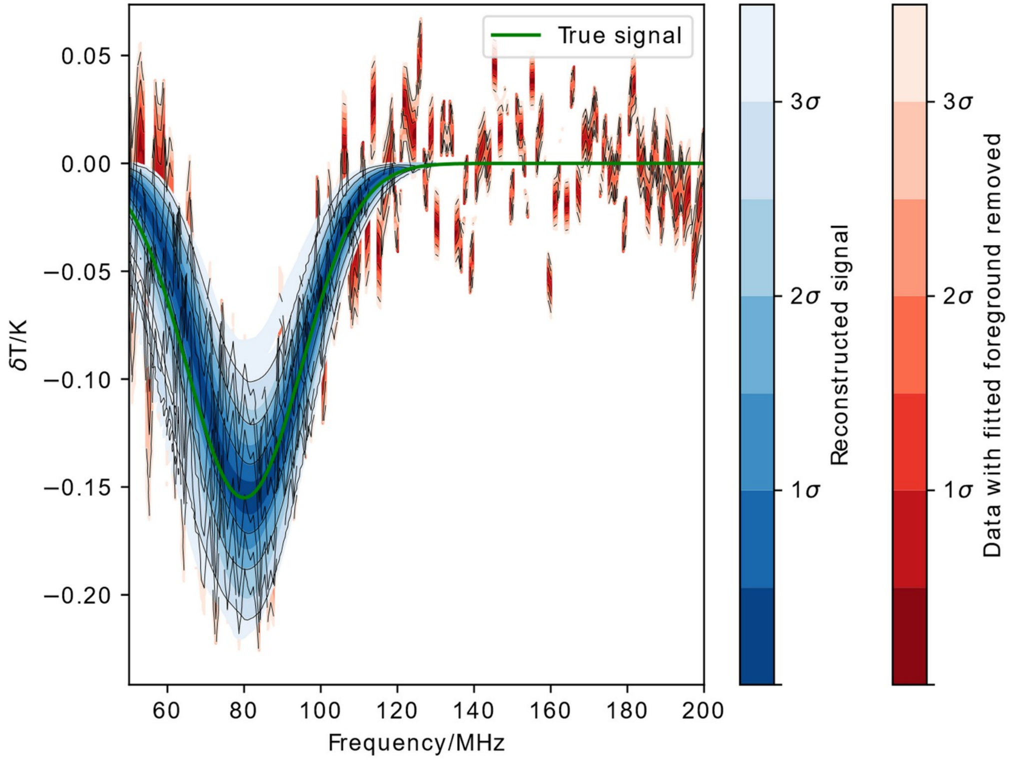
$$D\left(\Omega,\nu,\bar{\theta}\right)=\sum_{j=1}^{M}\Gamma\left(\nu,\bar{\theta}_j\right)Y_j\left(\Omega\right)$$

Fitting for Antenna Beam

Model Beam Coefficients



Fit Results



Conclusions

- REACH is a global 21 cm experiment with a focus on physically-interpretable models, particularly of systematics
- The REACH data analysis pipeline allows modelling of foregrounds and chromaticity based on spectral index
- Using a constant physical property as the parameter allows data from multiple observing times and antennae to be fit simultaneously, giving improvements in signal and particularly foreground reconstruction
- Ongoing work is underway to also model antenna beams

Antenna EM simulations provided by John Cumner and Quentin Gueuning

Plots produced using fgivenx tool: Handley, 2018

REACH