# Mitigating the Effects of Unmodelled Time-Varying Systematics

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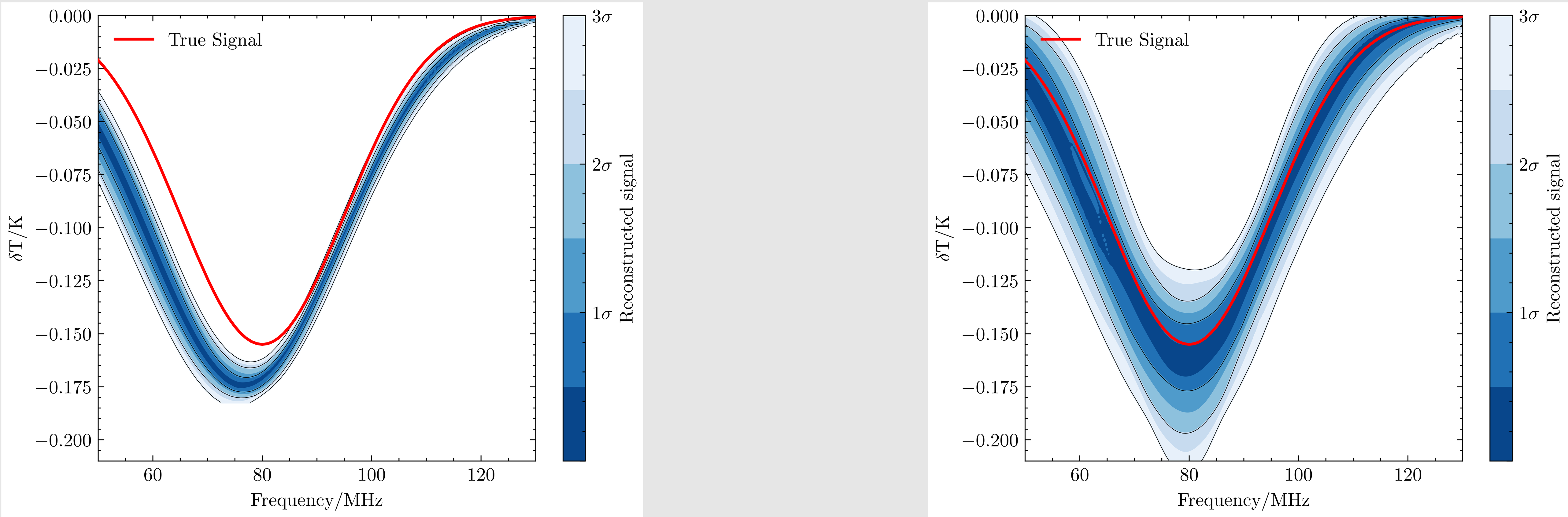
## Posterior Comparison




(a) Standard Pipeline (b) GP Pipeline

Figure 1. Comparison of the recovered signal posteriors plotted with FGIVENX for the standard pipeline and the Gaussian process pipeline. In red is plotted the 'true' signal which was added into the simulated data. There is a foreground modulated systematic with an initial amplitude of $A_{\text{sys}} = A_{21} = 0.155$ K, period of $P_{\text{sys}} = 0.5\sigma_{21} = 7.5$ MHz and phase of $\phi_{\text{sys}} = \pi$ present in the data.

## Systematics in the REACH System

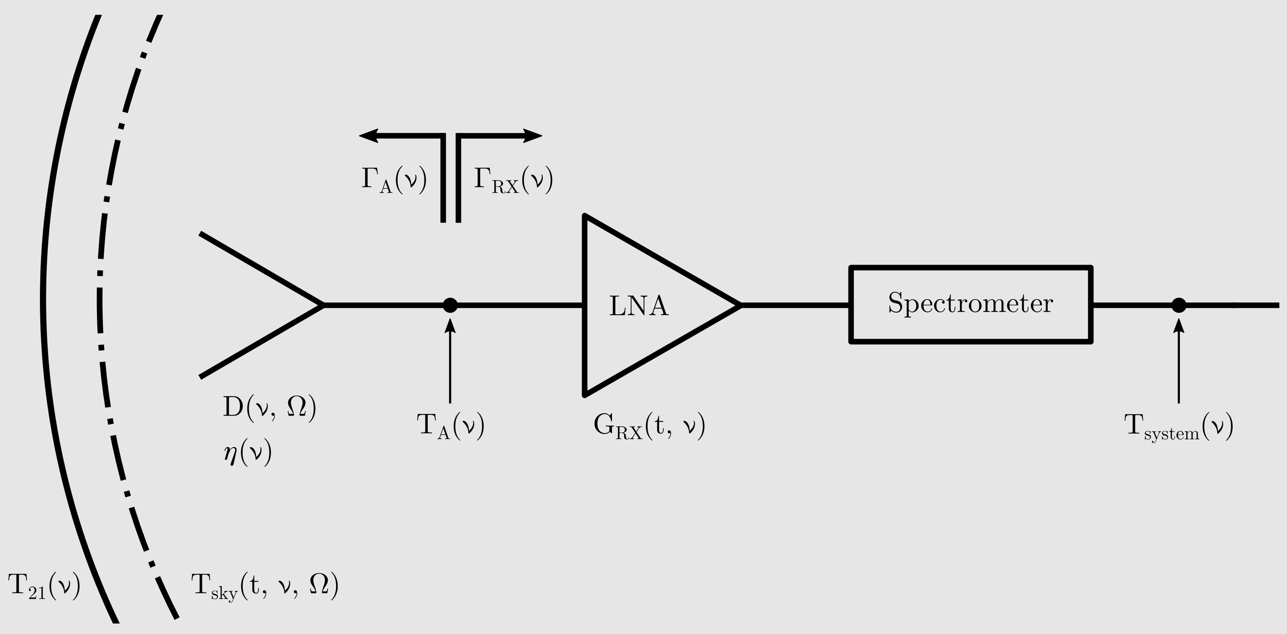



Figure 2. Schematic diagram of the REACH antenna and receiver.

- Some systematics are expected to be static, others **vary with time**
- Reflections from the soil **vary with rainfall** [Bevins et al. 2021]
- Impedences in the system are **temperature dependent**
- Improperly modelled beams can cause systematics which **vary with the galactic foreground power**

## Time Varying Systematic Model

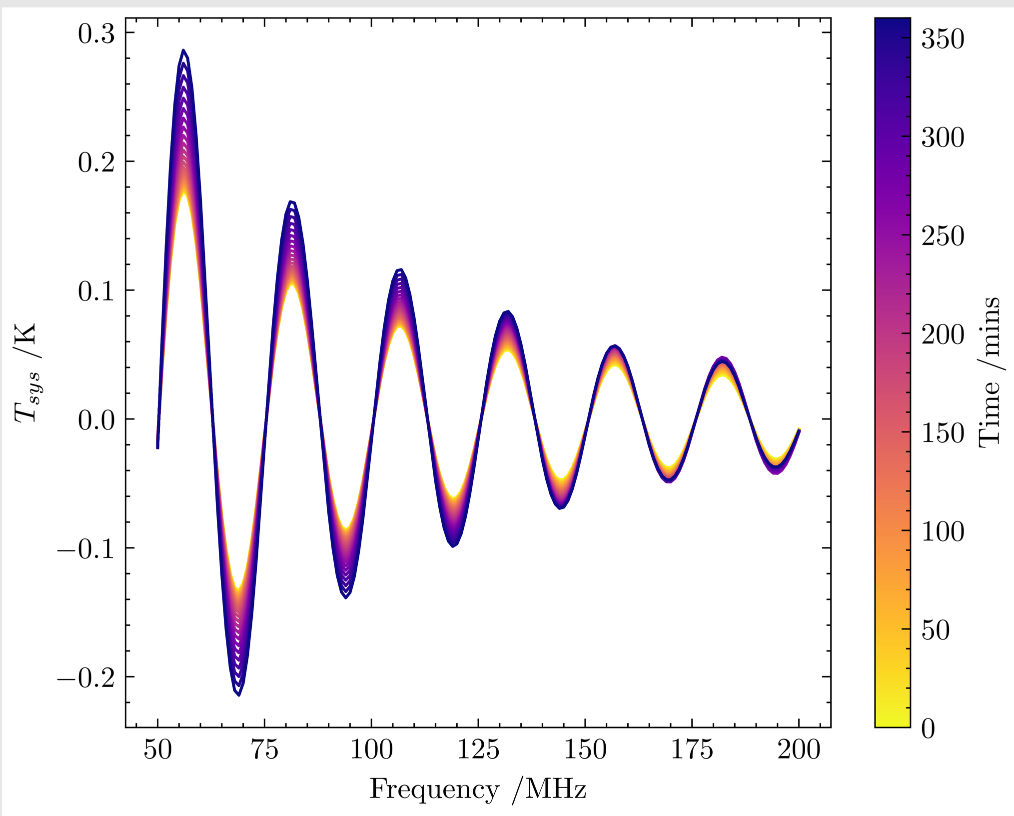



Figure 3. Example of a damped sinusoidal systematic which is modulated by the incoming power from the galactic foreground over 24 time bins of length 15 minutes. The initial amplitude of the systematic was set to $A_{\text{sys}} = 0.209$ K.

- Model systematic as a **damped sinusoid** whose amplitude is **modulated by the power of the galactic foreground**

## Standard REACH Pipeline

- Fully Bayesian **forward model** of beam model, galactic foregrounds and global signal [Anstey et al. 2021]

$$\log \mathcal{L}_{\text{std}} = \sum_i -\frac{1}{2}\log(2\pi\sigma_0^2) - \frac{1}{2}\left(\frac{T_{\text{data}}(\nu_i) - (T_{\text{fg}}(\nu_i) + T_{21}(\nu_i) + T_{\text{CMB}})}{\sigma_0}\right)^2 \qquad (1)$$

## Gaussian Process Pipeline

- Uses **Squared Exponential kernel** to fit for time covariance [Kirkham et al. 2024]

$$\log \mathcal{L}_{\text{GP}} = -\frac{1}{2}\log\left[(2\pi)^n|\mathbf{C}|\right] - \frac{1}{2}(\mathbf{D} - \mathbf{M}(\theta))^T \boldsymbol{C}^{-1}(\mathbf{D} - \mathbf{M}(\theta)) \qquad (2)$$

$$\mathbf{C}_{ij} = \sigma_{0,\text{GP}}^2 + \sigma_{\text{SE}}^2 \exp\left(-\frac{|t_i - t_j|^2}{2\ell^2}\right) \qquad (3)$$

## RMSE

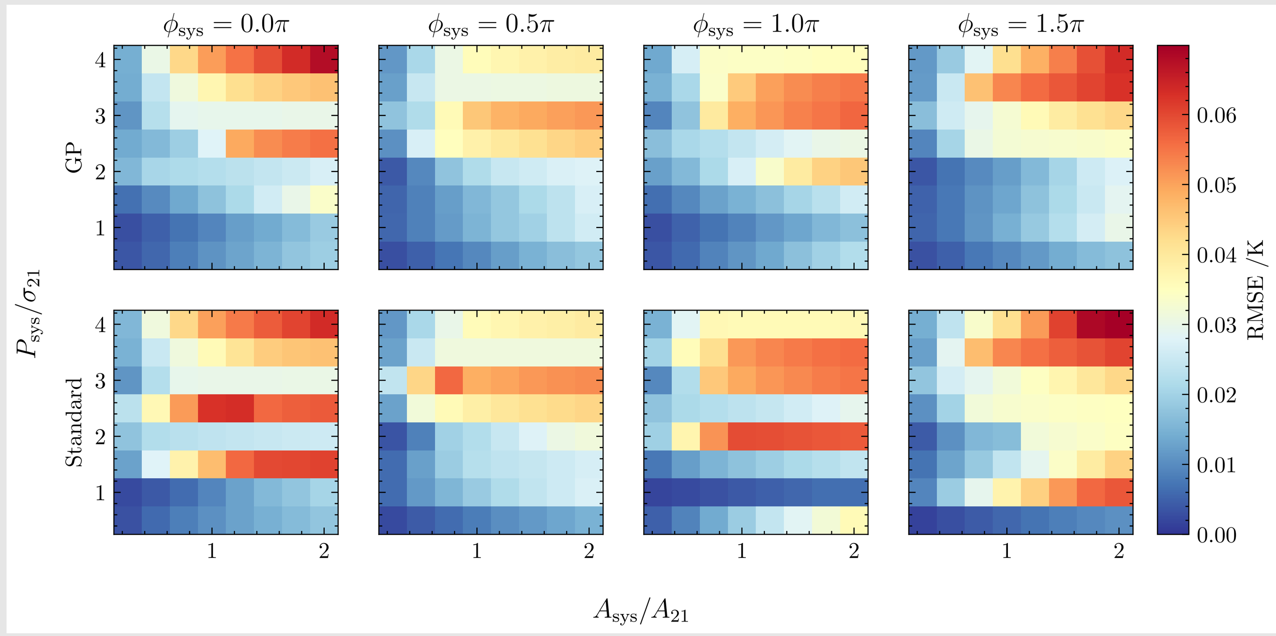



Figure 4. Weighted root mean square error of the pipeline fits for the standard pipeline (lower row) and the Gaussian processes pipeline (upper row) for different systematic parameters.

## Fitted Signal Amplitude error

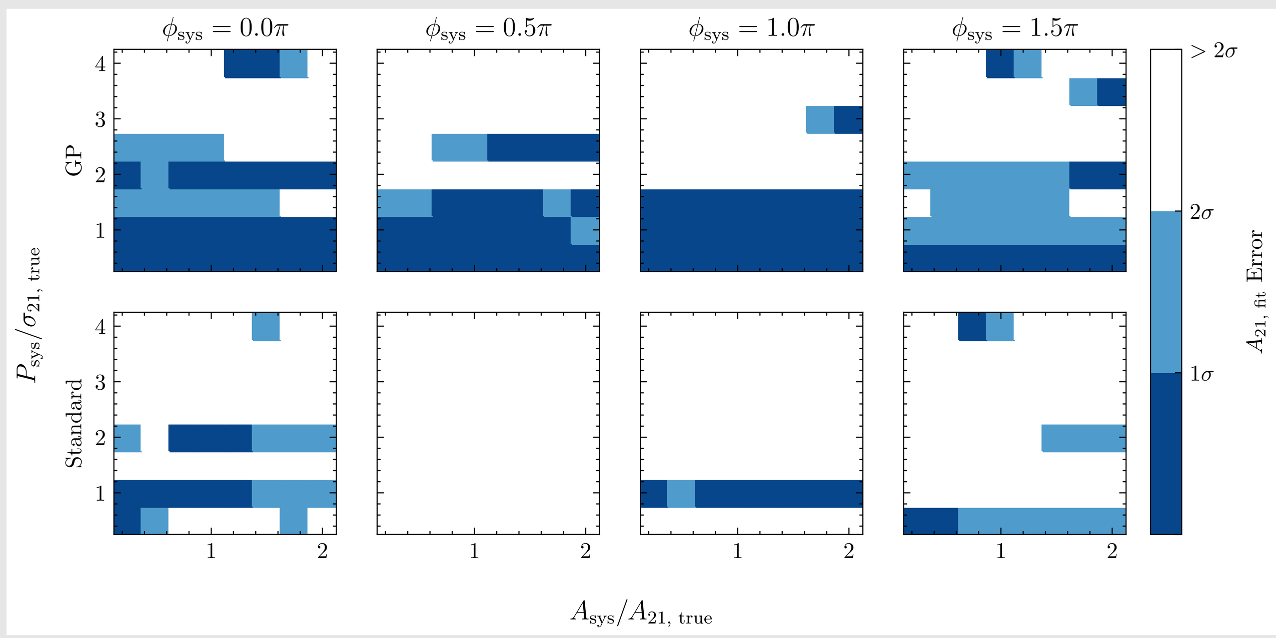



Figure 5. Error in the fitted value of the amplitude of the Gaussian signal model for the standard pipeline (lower row) and the Gaussian processes pipeline (upper row) for different systematic parameters.

## Fitted Centre Frequency error

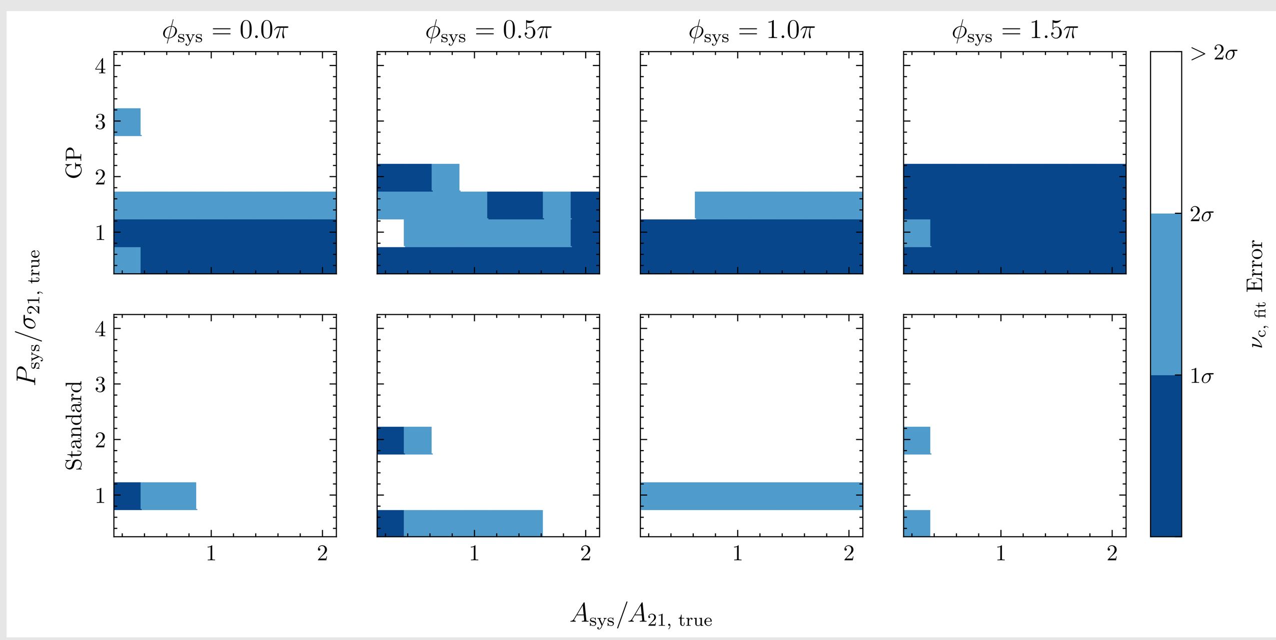



Figure 6. Error in the fitted value of the centre frequency of the Gaussian signal model for the standard pipeline (lower row) and the Gaussian processes pipeline (upper row) for different systematic parameters.

## References

Kirkham, C. J., D. J. Anstey, and E. de Lera Acedo (Jan. 2024). "A Bayesian Method to Mitigate the Effects of Unmodelled Time-Varying Systematics for 21-Cm Cosmology Experiments". In: *Monthly Notices of the Royal Astronomical Society* 527, pp. 8305–8315. ISSN: 0035-8711. DOI: 10.1093/mnras/stad3725. (Visited on 02/09/2024).

Anstey, D., E. de Lera Acedo, and W. Handley (Sept. 2021). "A General Bayesian Framework for Foreground Modelling and Chromaticity Correction for Global 21 Cm Experiments". In: *Monthly Notices of the Royal Astronomical Society* 506.2, pp. 2041–2058. ISSN: 0035-8711. DOI: 10.1093/mnras/stab1765. (Visited on 12/13/2022).

Bevins, H. T. J. et al. (Apr. 2021). "MAXSMOOTH: Rapid Maximally Smooth Function Fitting with Applications in Global 21-Cm Cosmology". In: *Monthly Notices of the Royal Astronomical Society* 502, pp. 4405–4425. ISSN: 0035-8711. DOI: 10.1093/mnras/stab152. (Visited on 10/17/2022).

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