Developments in calibration of the global 21-cm experiment REACH

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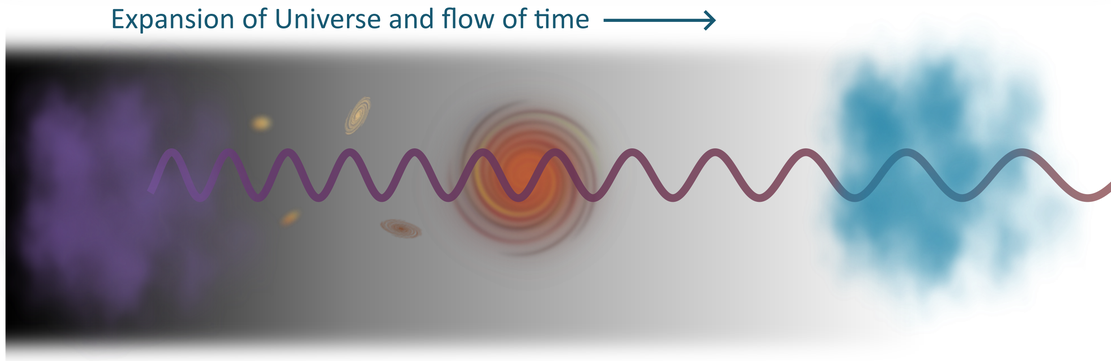
REACH and the 21-cm signal

Radio Experiment for the Analysis of Cosmic Hydrogen (REACH) is a radiometer aiming to detect the redshifted global 21-cm signal from **Cosmic Dawn** and the **Epoch of Reionisation**. With a brightness **~ 100 mK**, this signal is an important probe of the formation of the **first stars and galaxies**.

The systematics forest

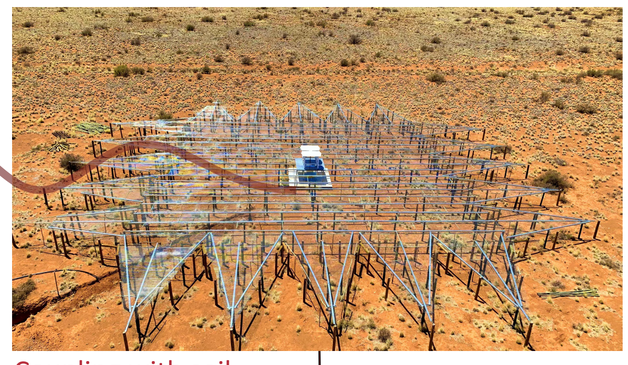


Spin-flip signal emitted from neutral Hydrogen from CD and EoR
z ~ 6-35

Extra-galactic and galactic foregrounds with brightness close to 10^4K

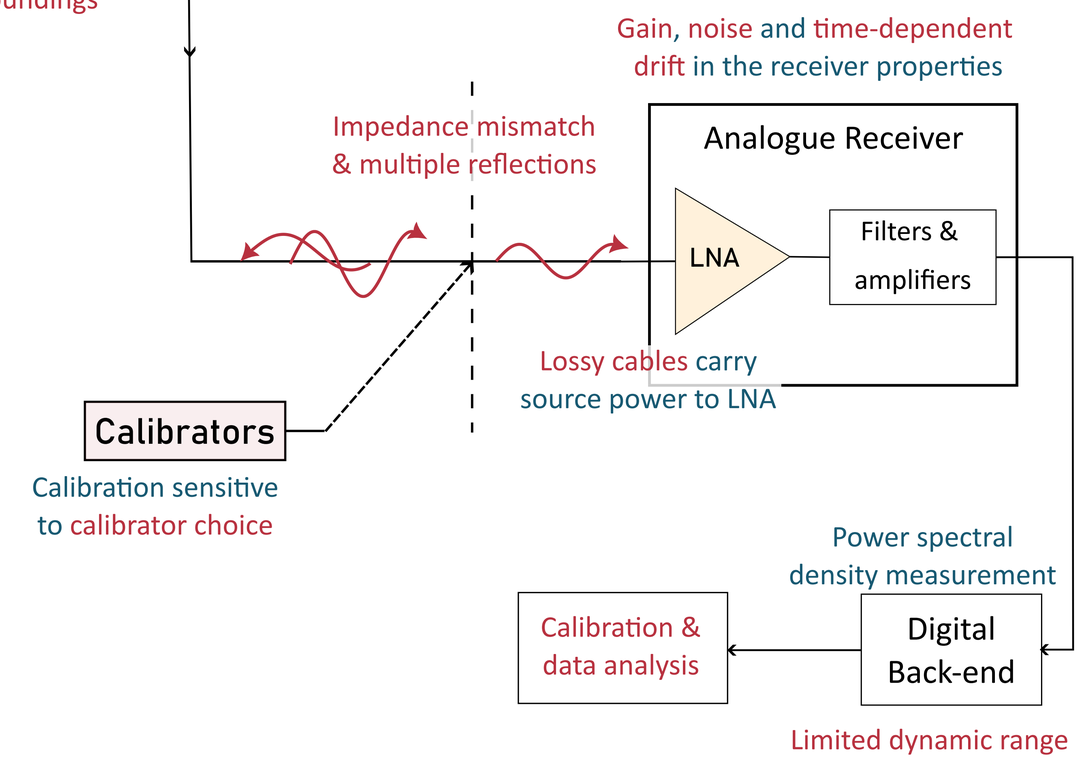
Ionospheric effects

T_{sky} coupled with chromatic antenna radiation pattern to give T_{ant}



Coupling with soil and surroundings

Radio Frequency Interference from terrestrial sources



Receiver Calibration

Corrects the instrument **noise**, **reflections** and **gain** to get the true temperature of a source, using known sources (calibrators)[1].

Internal calibrators (resistor+cable) have variable **impedance** and **temperature** and produce a thermal **noise power spectra**.

Receiver response is modelled as a **calibration equation** which is solved from **calibrator measurements** using multiple methods:

Linear least-squares

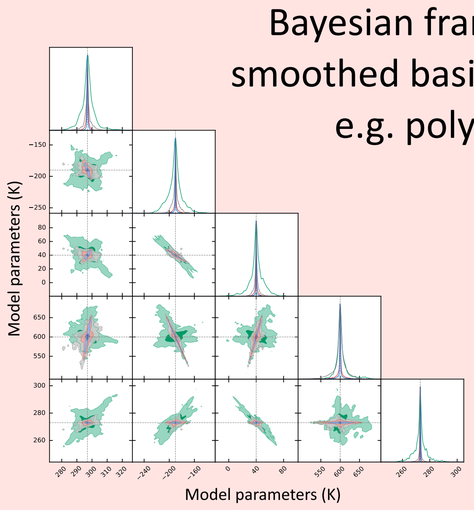
Fits a 5-term calibration equation at each frequency.

No assumption for smoothness over frequency, hence noisy.

Sensitive to calibrator choice and their spectral properties[2].

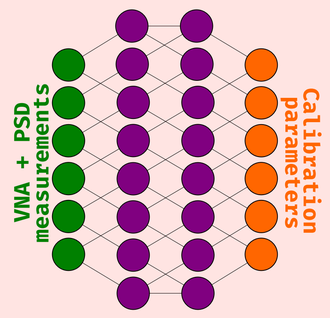
Conjugate priors

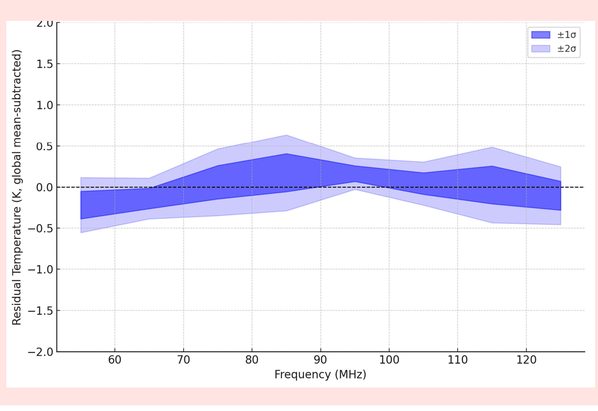
Bayesian framework fits smoothed basis functions, e.g. polynomials[3,4].

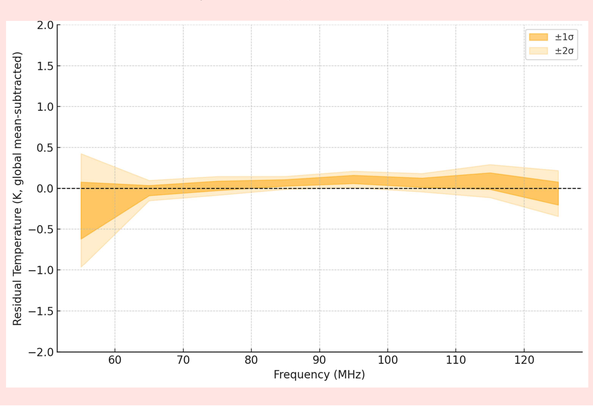


Machine learning

Neural network is trained on calibrators to infer the complex, non-linear behaviour of the receiver that analytical models may fail to capture[5].







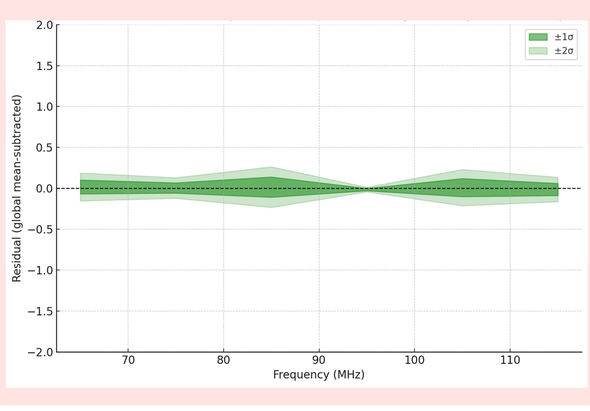


Figure: Calibration methods and the respective calibration residuals for an internal validation source (a 91Ω resistor on a 2m cable) used for REACH.

We are able to achieve sub-Kelvin level residuals on the validation source for all three methods.

Learn more!

References

[1] Roque, I.L.V. et al., Receiver design for the REACH global 21-cm signal experiment. *Exp Astron* **59**, 7 (2025).
[2] Dash, A.K. et al., Optimisation of calibration sources for global 21-cm experiments: the REACH case. *In preparation*.
[3] Roque, I.L.V. et al., Bayesian noise wave calibration for 21-cm global experiments. *MNRAS* **505**, 2638 (2021).
[4] Kirkham, C.J. et al., Capturing system drift with time-series calibration for Global 21-cm cosmology experiments. *MNRAS* **546**, stag232 (2026).
[5] Leeney, S.A.K. et al., Radiometer calibration using machine learning. *Sci Rep* **15**, 34335 (2025).

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