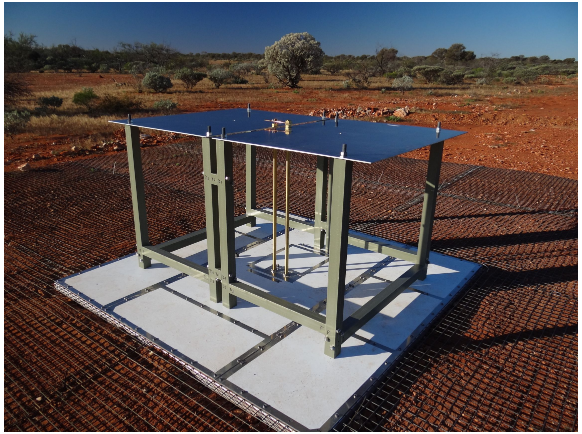
EDGES Calibration Pipeline

Steven Murray + EDGES Collaboration
21cm Global Workshop, Cambridge, 2020

Outline



1. Intro to EDGES calibration
2. A more informative calibration
3. Effects on Nature Paper results
4. Plans for the future

1.
Introduction to EDGES calibration

The Three-Position Switch

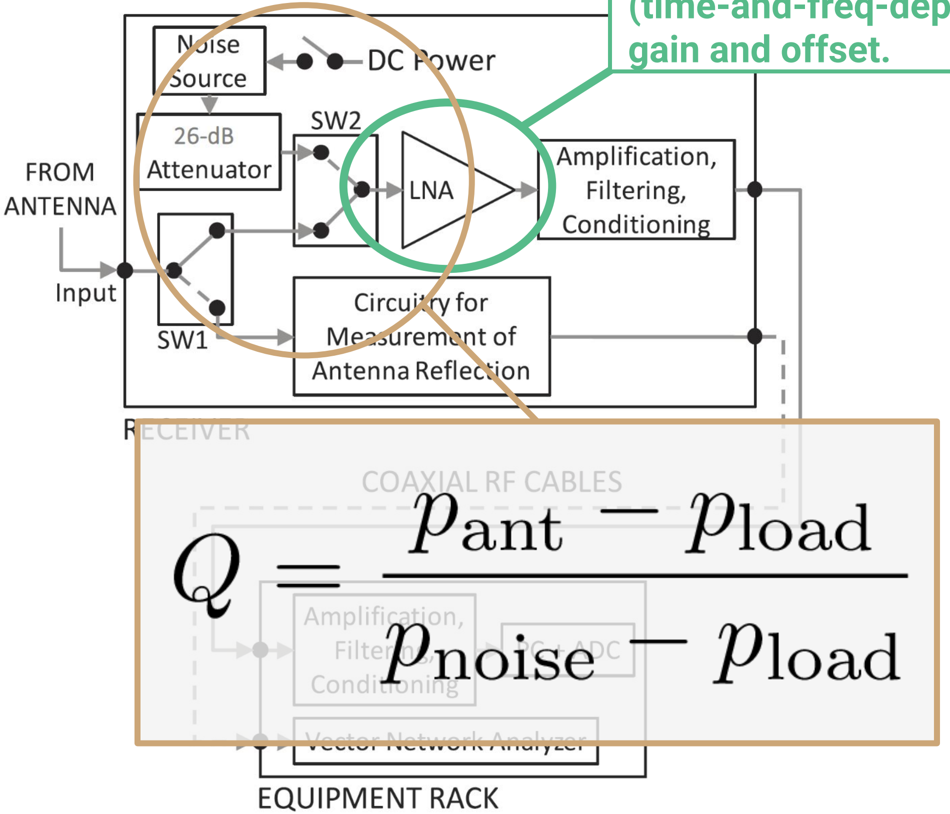
"Q" removes gain.

Residual structure due to differing paths.

Get switch spectral structure *in the lab*. Assumed *time-independent*.

$$\hat{T} = A_\nu Q + B_\nu$$

Arbitrary (time-and-freq-dep.) gain and offset.



$$Q = \frac{p_{\mathrm{ant}} - p_{\mathrm{load}}}{p_{\mathrm{noise}} - p_{\mathrm{load}}}$$

Lab Calibration

- **Monsalve (2017)** gives details for modelling A and B, dependent on S_{11} of sources.

$$K_0 A_\nu = 400 C_1$$

$$K_0 B_\nu = (300 - C_2) + K_1 T_{unc} + K_2 T_{cos} + K_3 T_{sin}$$

- **Measured** | **Fit (Polynomial)**
- Use four **known** input sources in place of antenna.
- **Iteratively** solve for the unknowns.

2.
A More Informative Calibration

Motivation

Model number	Global signal model, δT_b	Log-polynomial order, $\bar{T}_{Fg}$	Damped sinusoid, T_{cal}	Noise model, N	log(evidence)	Residual RMS [mK]
1	-	3	-	white	-4289.96 ± 0.36	255.7
2	-	4	-	white	-4121.56 ± 0.35	237.9
3	ARES	3	-	white	-3429.35 ± 0.25	224.4
4	ARES	4	-	white	-3402.66 ± 0.25	217.2
5	-	3	Equation 19	white	-2876.04 ± 0.29	223.4
6	-	4	Equation 19	white	-2185.80 ± 0.29	179.2
7	ARES	3	Equation 19	white	-2074.01 ± 0.24	189.0

Sims & Pober 2020

Systematics may reduce necessity of absorption feature in data (Singh 2019, Sims 2020).

*What are the **physical** priors on such effects?*

The Problem With Iterative Fits

You don’t know the **uncertainties**.

Each fitted parameter (there are ~50) has uncertainties that **should** propagate to the final spectrum as a **covariance**.

This information is **lost**.

A Bayesian Model

Set up a simple □^{2} likelihood:

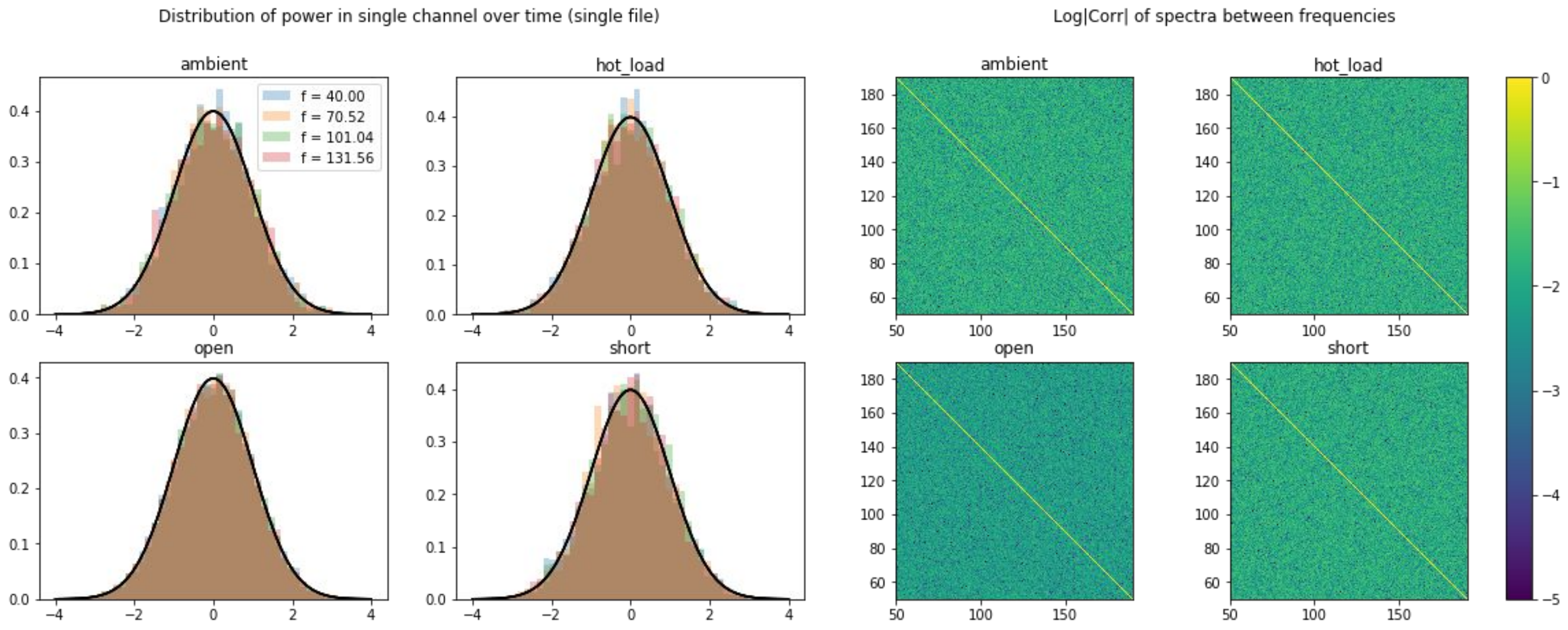
$$\ln \mathcal{L}(\mathbf{Q}_\nu|\vec{\theta}) = -\sum_{\rm src}\sum_{\nu} \ln \sigma_Q(\nu|\vec{\theta}, \mathrm{src}) + \frac{\left[\mathbf{Q}_\nu^{\rm src} - Q(\nu|\vec{\theta}, \mathrm{src})\right]^2}{2\sigma_Q^2(\nu|\vec{\theta}, \mathrm{src})},$$

Recall:

$$Q_{\rm src} = \frac{T_{\rm src}^{\rm meas} - B_{\rm src}}{A_{\rm src}}$$

Use **MCMC/Nested-Sampling** to fit.

Justification of uncorrelated Gaussian Likelihood



What about the model variance?

- Assuming Gaussianity and hot noise-source (and perfect impedance matching…):

$$\sigma^2_{Q_t} = \alpha \left(\frac{T_A - T_L}{T_{NS}} \right)^2 \left[\frac{T_A^2 + 2T_{LNA}^2 + T_L^2}{(T_A - T_L)^2} - 2\frac{T_L^2 + T_{LNA}^2}{(T_A - T_L)T_{NS}} + \frac{2T_L^2 + T_{NS}^2 + 2T_{LNA}^2}{T_{NS}^2} \right]$$

- Non-matched solution being worked on.
- α requires a model of the spectrometer efficiency.
- For now… just **measure** the variance from data.

3.
Effects on Nature Paper Results

The Idea

Recalibrate & Refit B18

How much extra uncertainty is there on the Bowman et al. (2018) parameters, if calibration uncertainty is accounted for?

Re-Calibration of Bowman (2018) Data

The initial process:

1. Generate full posterior on calibration parameters.

2. De-calibrate B18 data using best-fit.

3. Re-calibrate from posterior to generate data covariance.

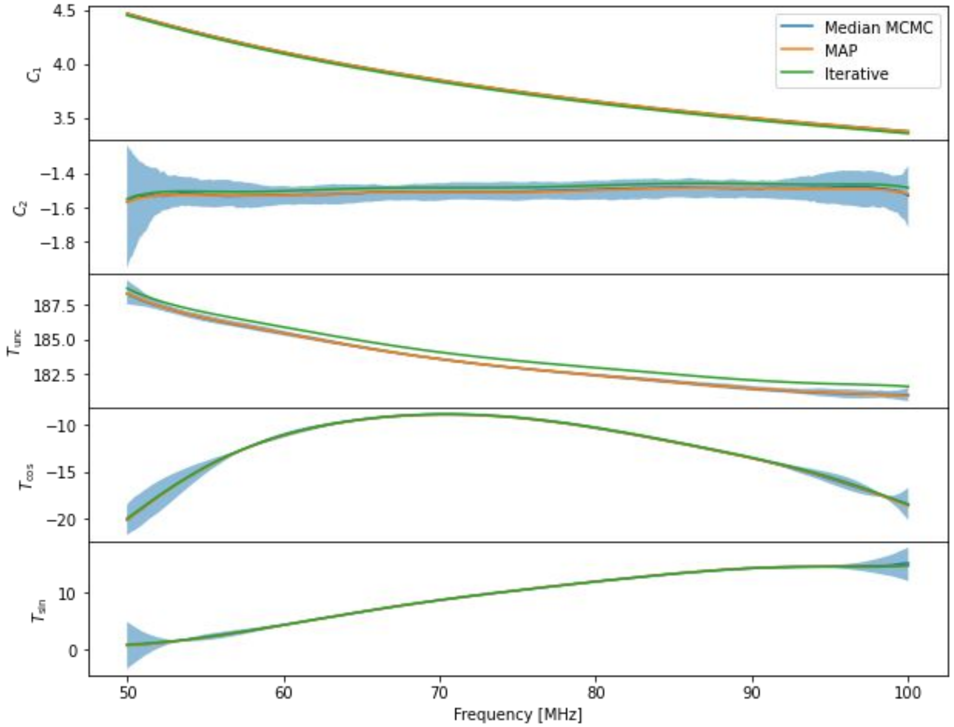
4. Re-fit absorption+foregrounds with new covariance

Uncertainties on Calibration Parameters

Bayesian fits mostly comparable to iterative fit (except T_{unc}).

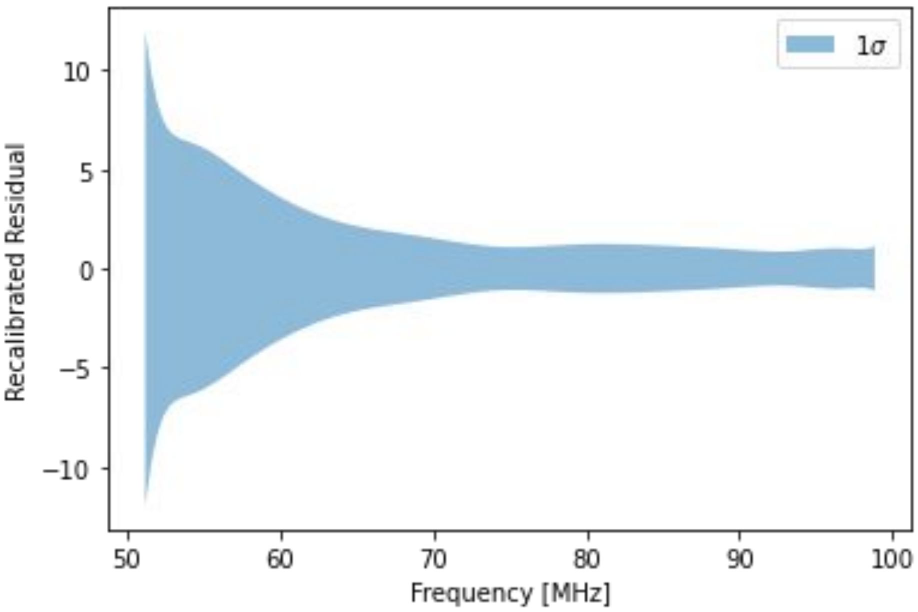
Higher uncertainty at band edges (expected).

100-150mK overall amplitude uncertainty.

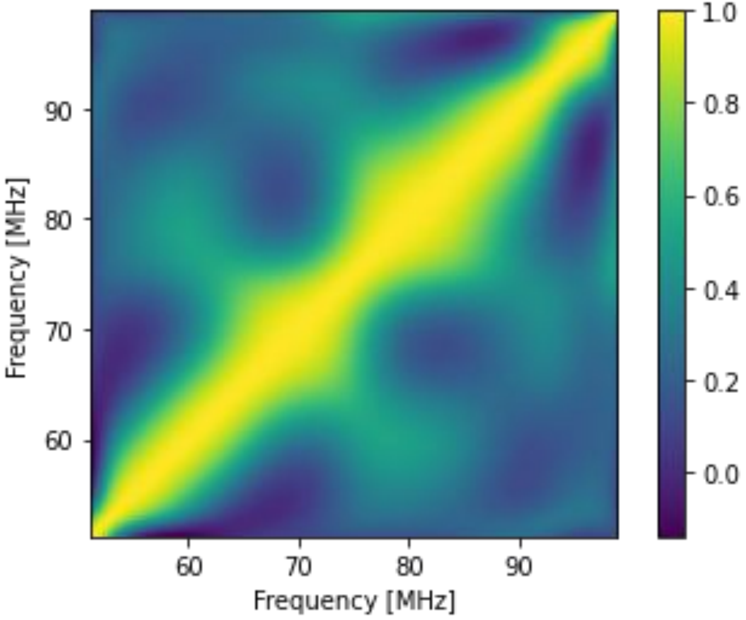


Re-Calibration of Bowman (2018) Data

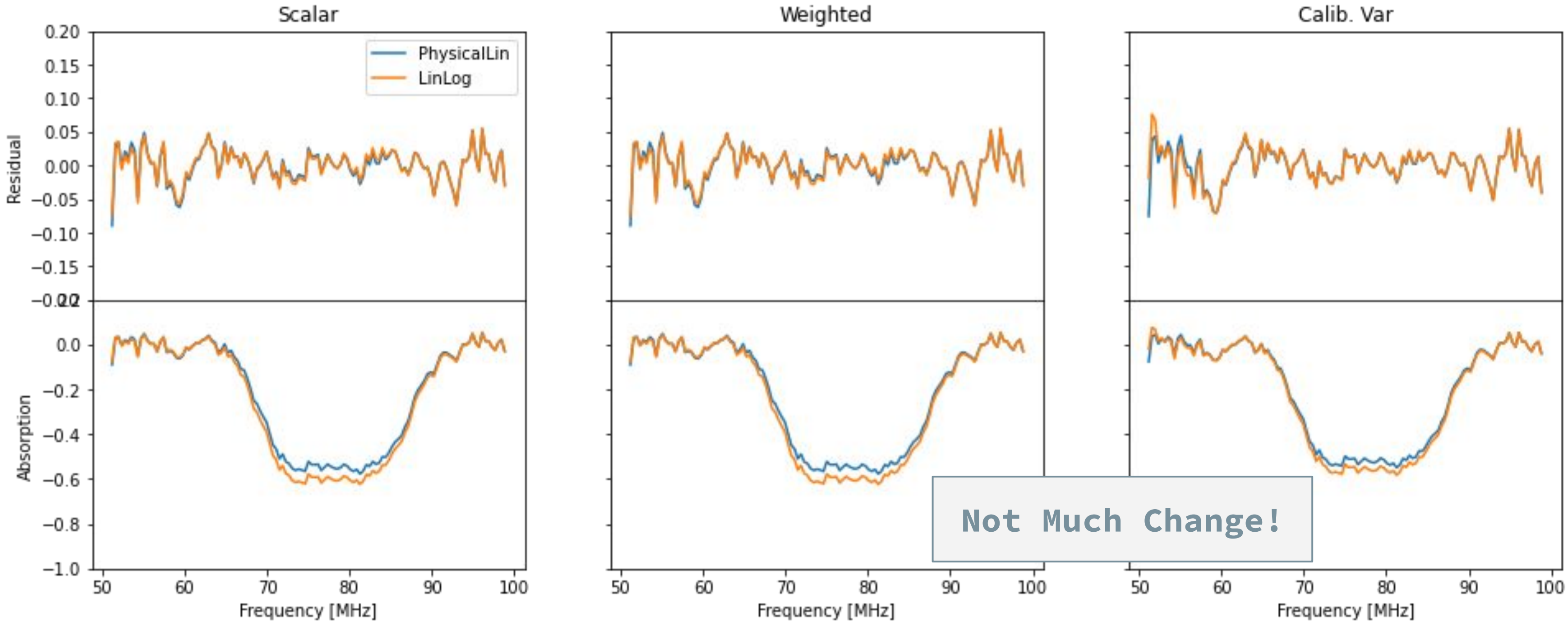
Spectrum Variance from calibration.



Spectrum Correlations



Updated Fit to Bowman (2018) Data



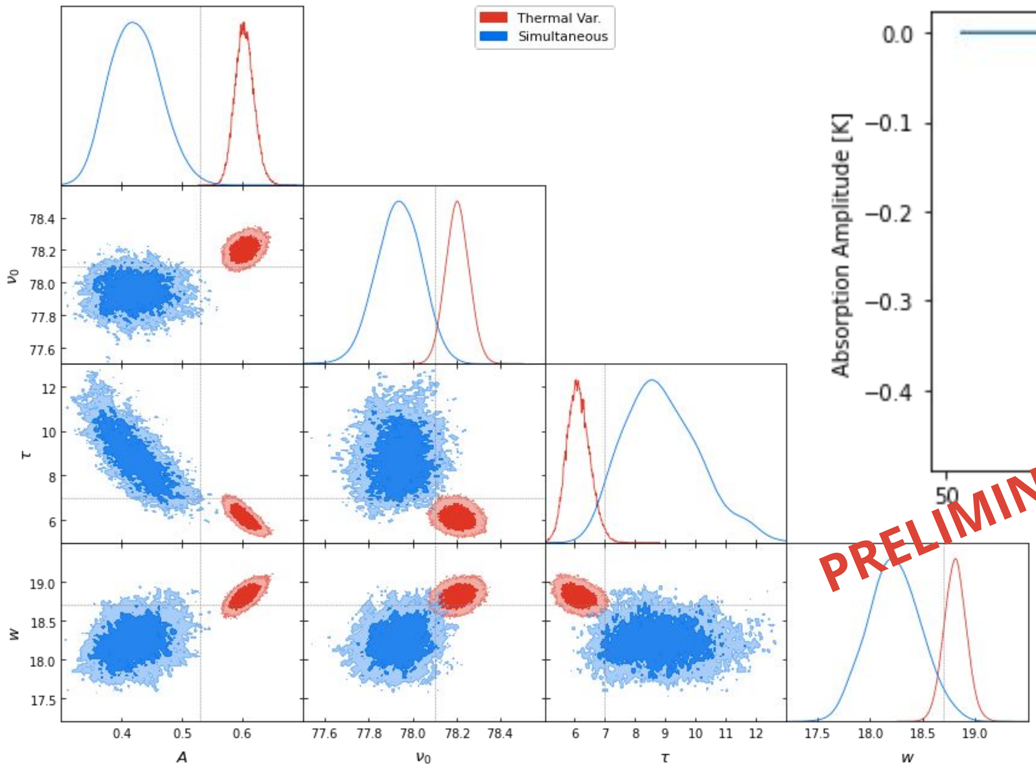
Not Much Change!

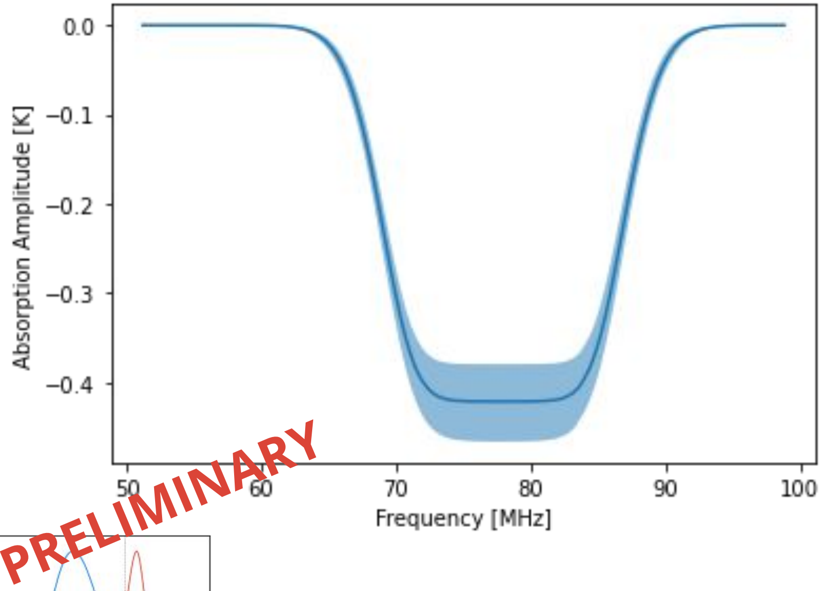
More rigorous fit

Due to data covariance being highly structured:

- Single likelihood for *simultaneous* calibration and absorption/fg fitting.
- Re-calibrate data *within* MCMC.
- Absorption/fg likelihood has no intrinsic covariance.

Updated Fit to Bowman (2018) Data





Summary

Best-fit absorption feature is robust to increased low-frequency variance, and known calibration uncertainties.

Low frequencies significantly more sensitive to calibration errors (as expected).

Uncertainties on absorption parameters inflated by factor of ~3 after accounting for correlated calibration errors.

4.
Plans for the Future

What Other Uncertainties Are There?

- Considered uncertainty of calibration model fitting.

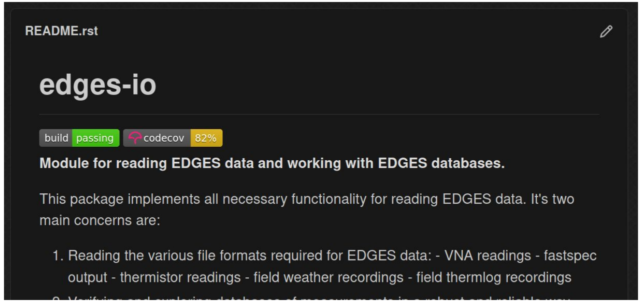
- Other uncertainties:
  - S_{11} measurements (and models!)
  - Beam model/correction
  - Ground-loss model

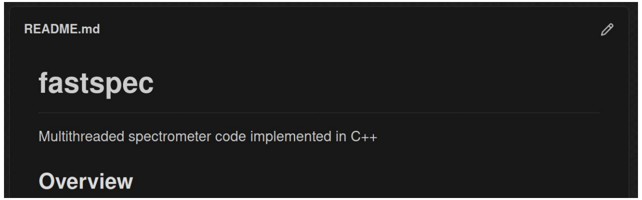
- It’s the **covariance**, in the basis of the data, that is important.

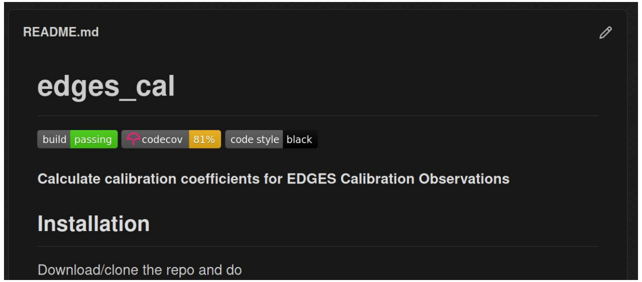
EDGES is Getting an Upgrade

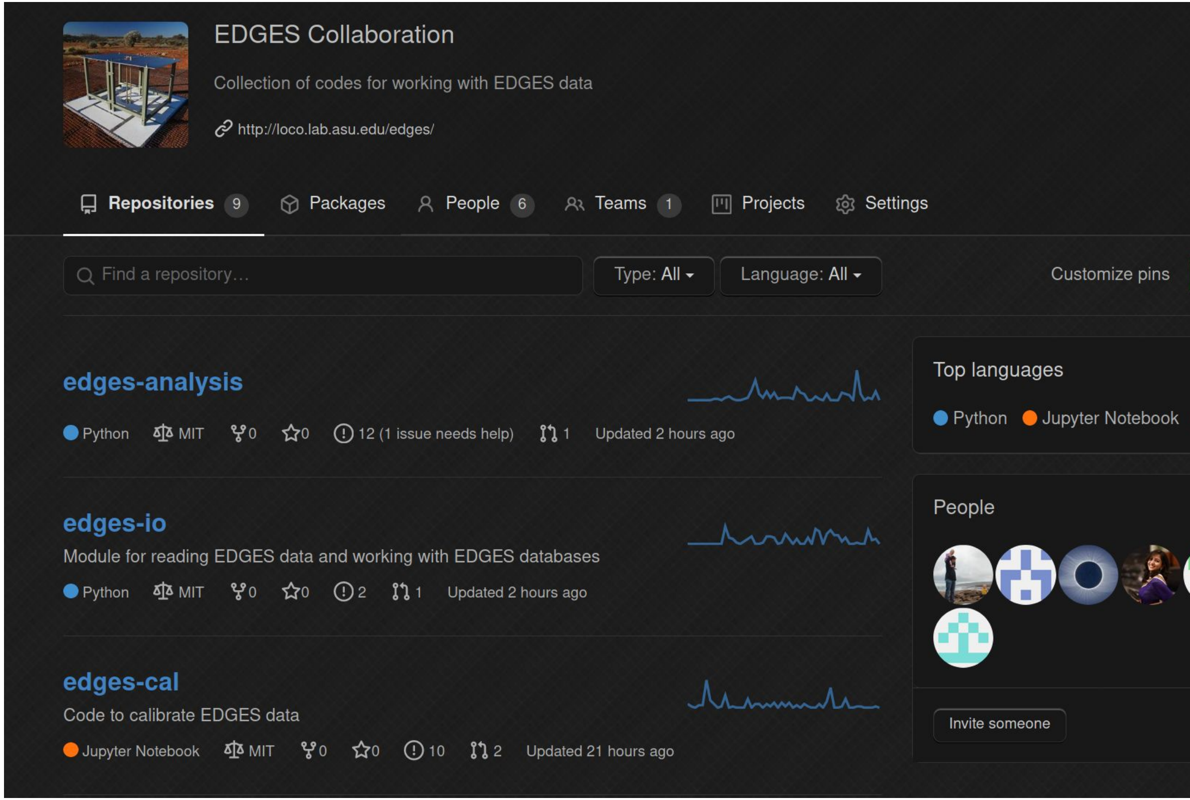
- **EDGES-3** coming in (late) 2021.
- *Raw data* from B18 to be made public, along with a full pipeline spec for reproducing results (~late 2021).
- Data from EDGES-3 to be made public after reasonable period of analysis.
- To do this, need new software...

New Software Pipeline









The Point:

We should (and will!) be accounting for complex modelling uncertainties.

Soon you can too.