SCUOLA NORMALE SUPERIORE

EDGES-3 AND OTHER UPDATES

Steven Murray + EDGES collaboratoin

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LoCo
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EDGES:
Experiment to Detect the Global
Eor Signal

The EDGES Team

PIs

Alan Rogers

Judd Bowman

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Engineers

Titu Samson

John Barrett

Ken Wilson

Researchers

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Peter Sims

Rigel Capallo

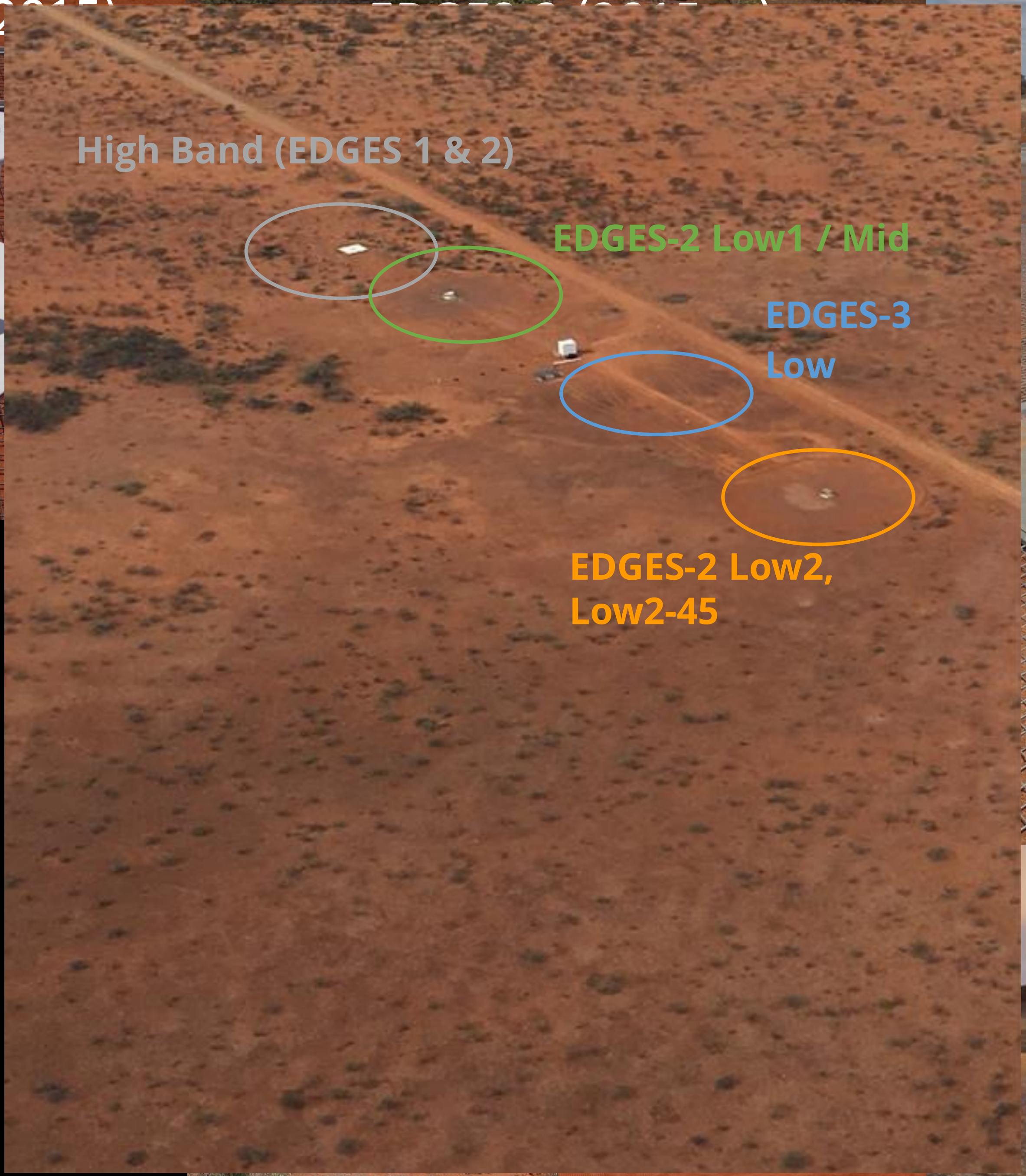
Nivedita Mahesh

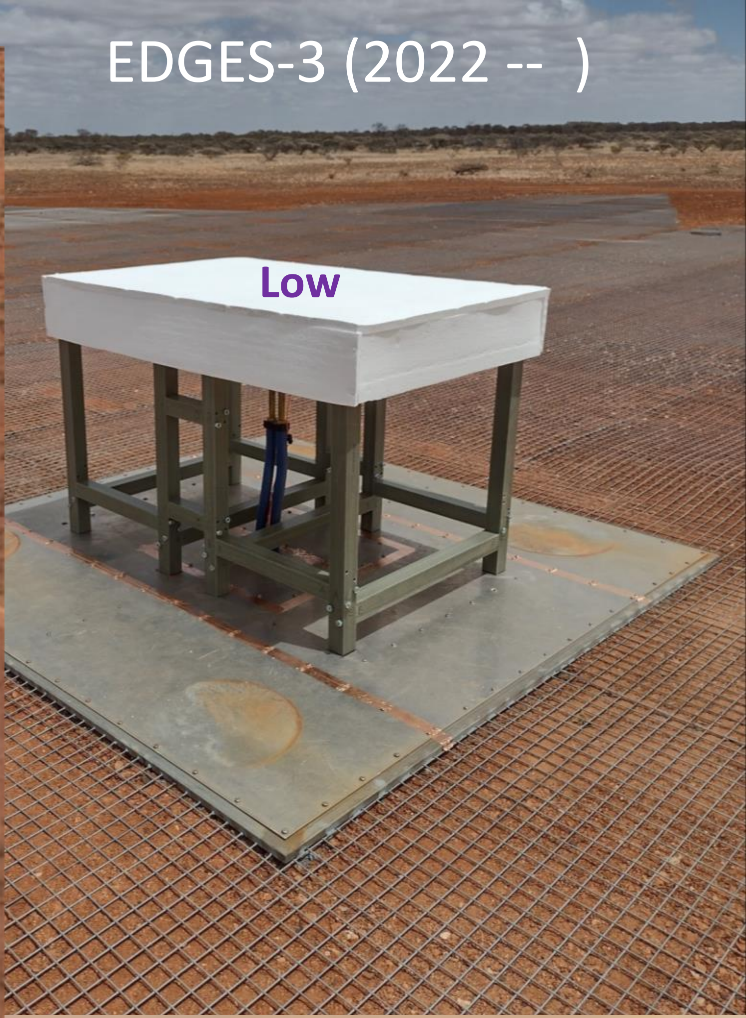
PhD

Akshatha Vydula

EDGES is an evolving experiment…

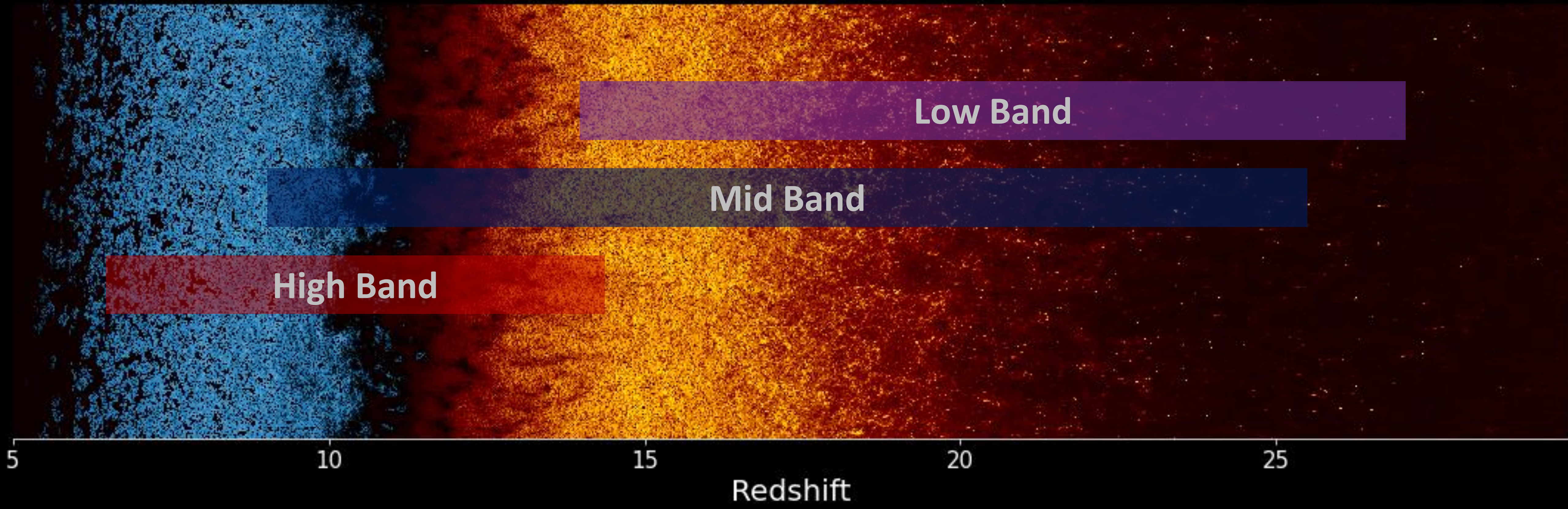

EDGES-1 (2012-2
High


High Band (EDGES 1 & 2)
EDGES-2 Low1 / Mid
EDGES-3
Low
EDGES-2 Low2,
Low2-45


EDGES-3 (2022 --)
Low


Low (Devon)

EDGES Observing Bands



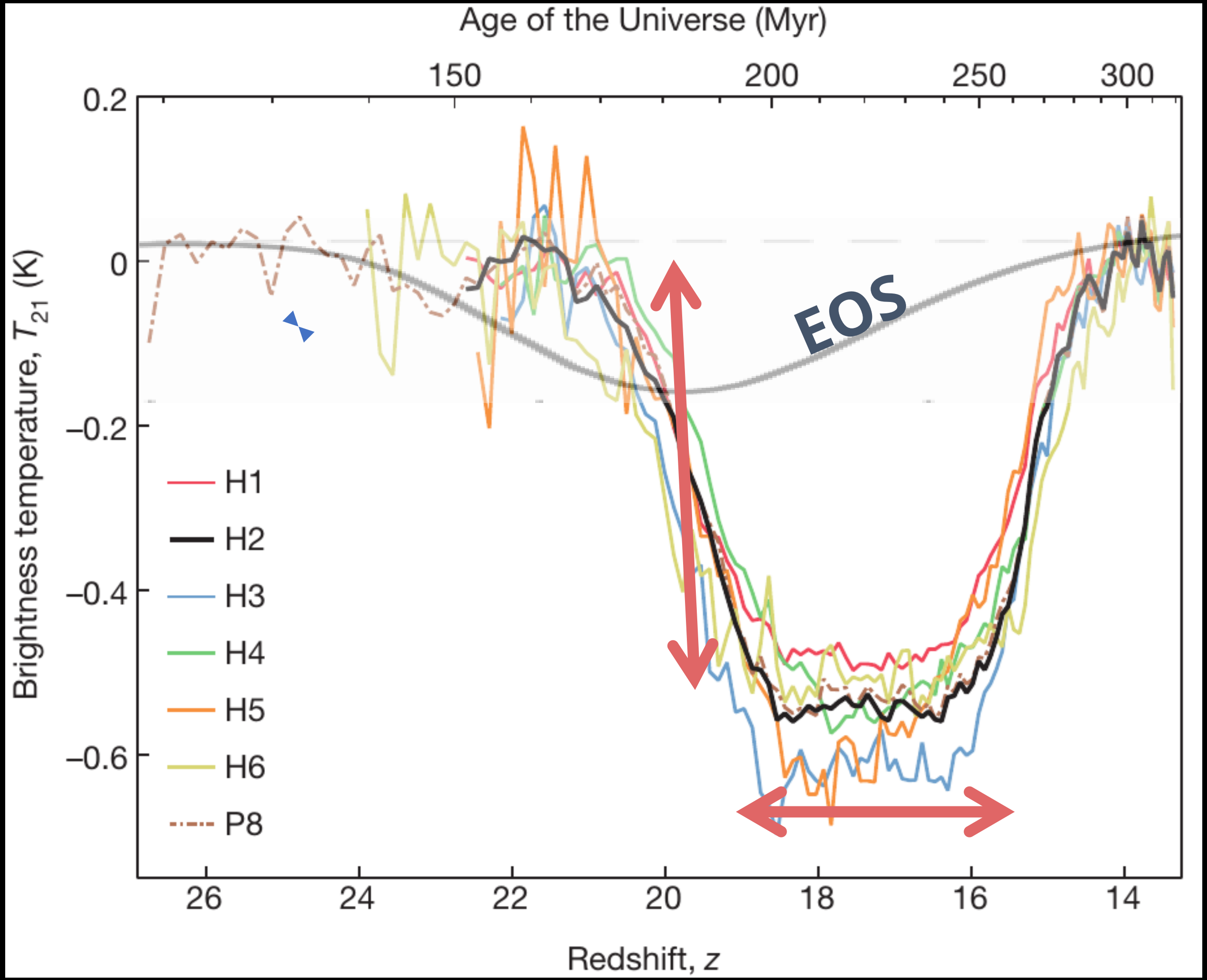
Munoz, Qin, Mesinger, **SGM** (EOS, 2022)

Evidence of the first stars

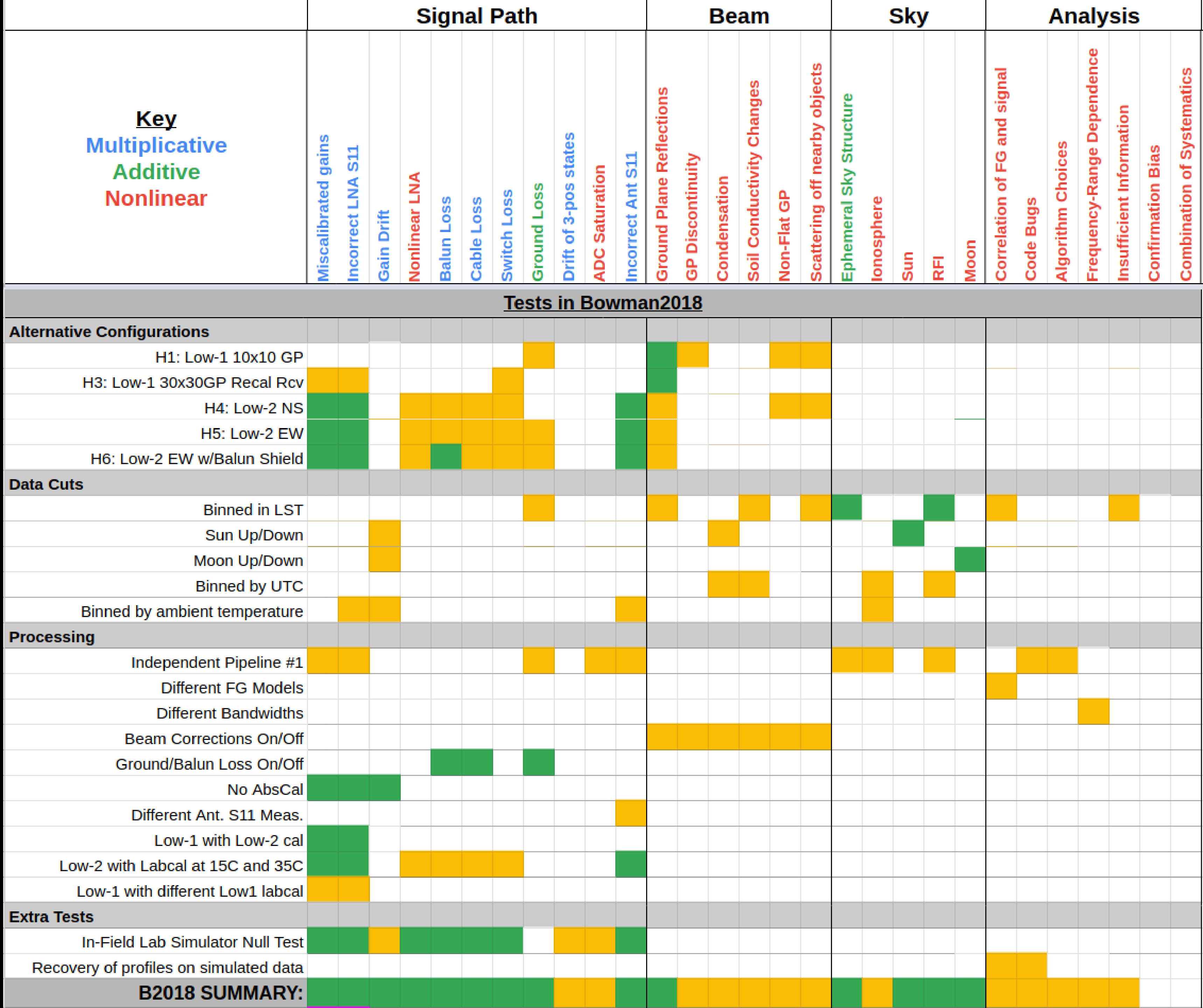
Bowman+2018

- Surprising depth, timing and shape.
- Possible indication of:
    - Excess radio background (eg. Fialkov & Barkana 2019)
    - DM-baryon interactions
        - eg. Millicharged DM (eg. Barkana 2018, Liu+2019, Berlin+2018)
    - High-z black holes (eg. Ewall-Wice+2018)
    - Soft-photon emission from light dark matter (eg. Fraser+2018)
    - Early Dark Energy (eg. Hills & Baxter 2018)
- **… or does it suffer from systematics?** (eg. Hills+2018, Sims+2020, Singh+2020)

Disconfirmation from SARAS-3 (Singh+2022)

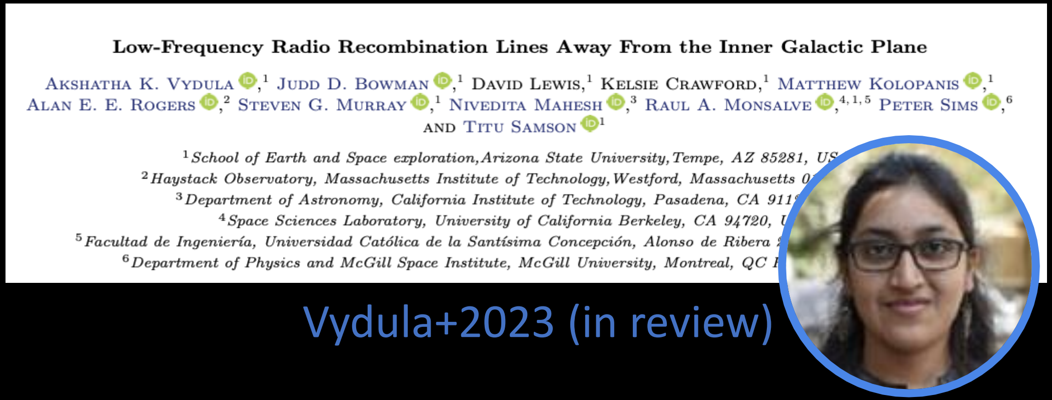


The Big Matrix of EDGES Tests



Recent Progress

Radio Recombination Lines



Low-Frequency Radio Recombination Lines Away From the Inner Galactic Plane

Akshatha K. Vydula,[1] Judd D. Bowman,[1] David Lewis,[1] Kelsie Crawford,[1] Matthew Kolopanis,[1] Alan E. E. Rogers,[2] Steven G. Murray,[1] Nivedita Mahesh,[3] Raul A. Monsalve,[4,1,5] Peter Sims,[6] and Titu Samson[1]

[1] School of Earth and Space exploration, Arizona State University, Tempe, AZ 85281, US
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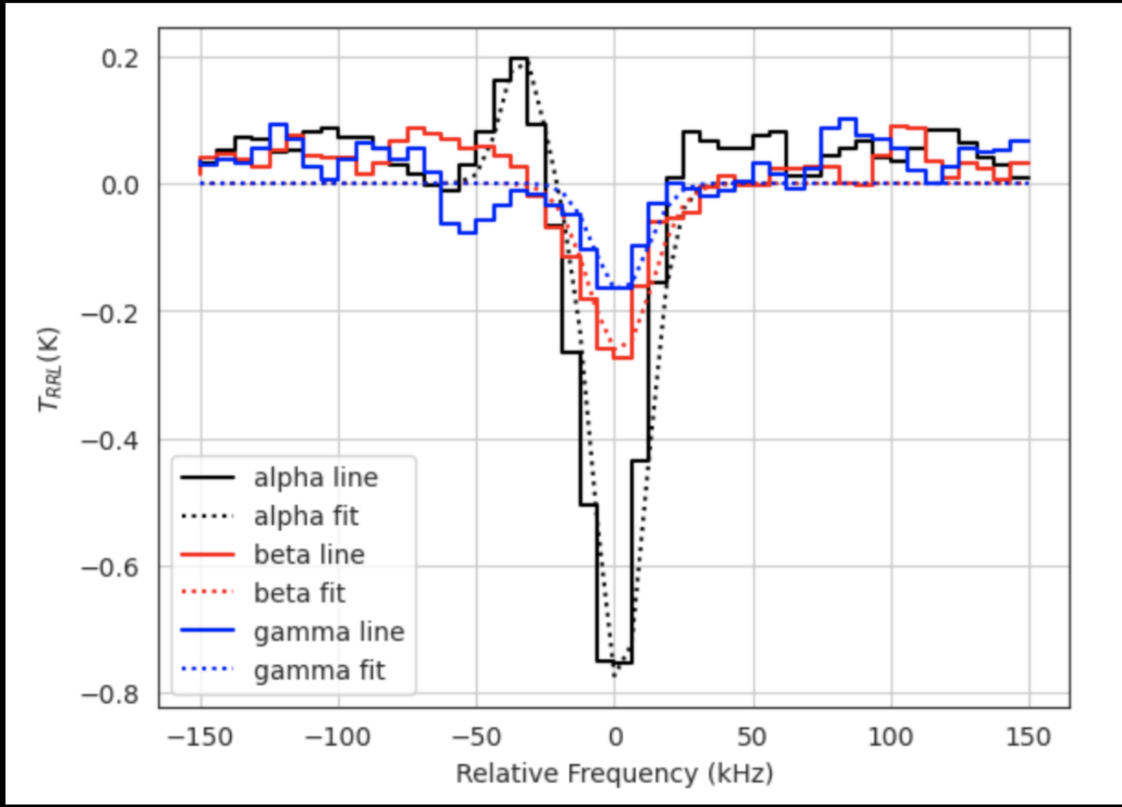
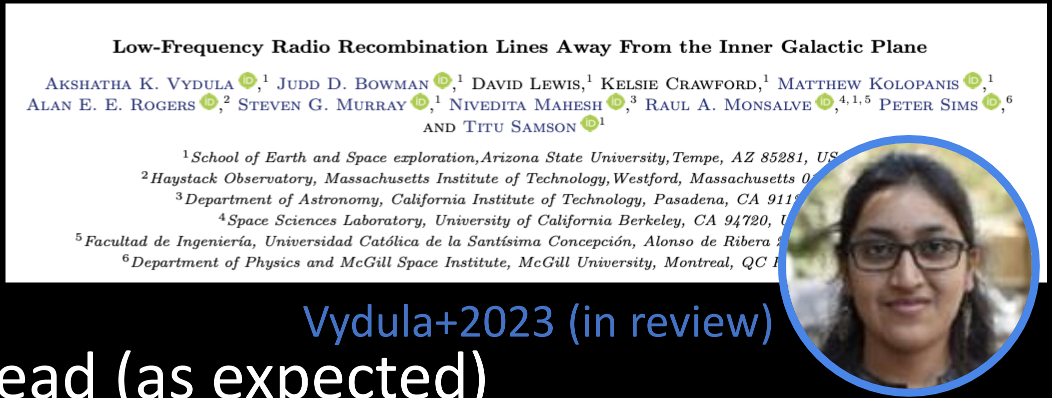
[4] Space Sciences Laboratory, University of California Berkeley, CA 94720, U
[5] Facultad de Ingeniería, Universidad Católica de la Santísima Concepción, Alonso de Ribera
[6] Department of Physics and McGill Space Institute, McGill University, Montreal, QC

Vydula+2023 (in review)

- Cascade of spectral lines from electron recombining with ion
- Used to understand composition, structure and distance of stellar emitting regions.
- Also a potential non-smooth foreground…
- Used EDGES-2 Low/Mid to find *average* RRL magnitude per LST.



Radio Recombination Lines



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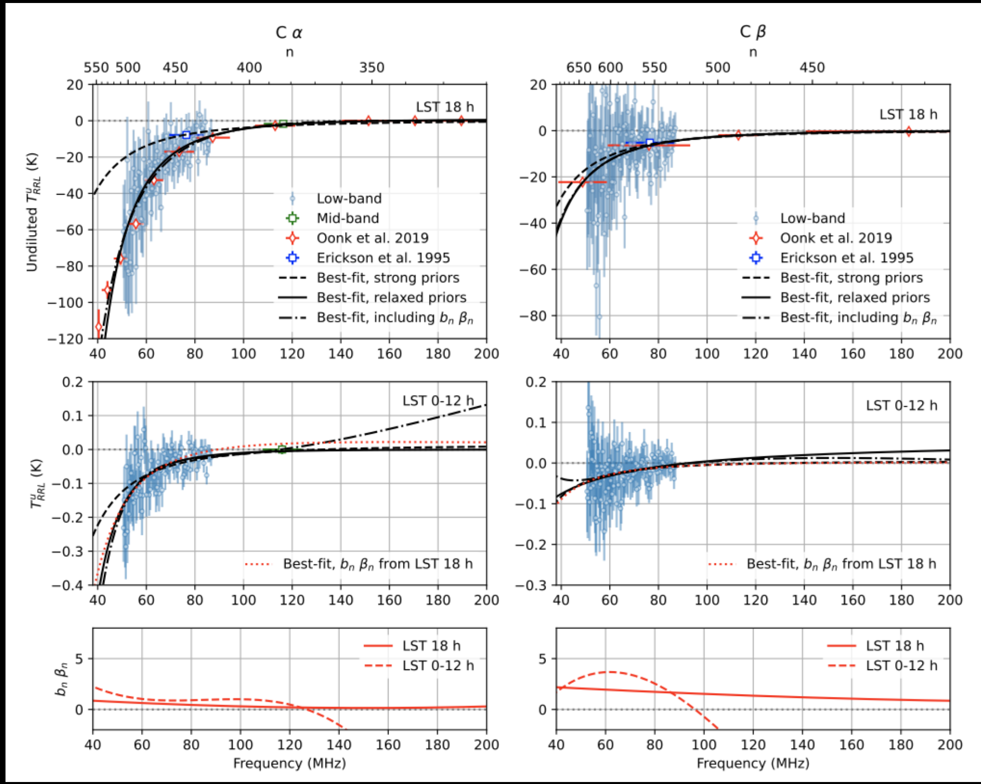
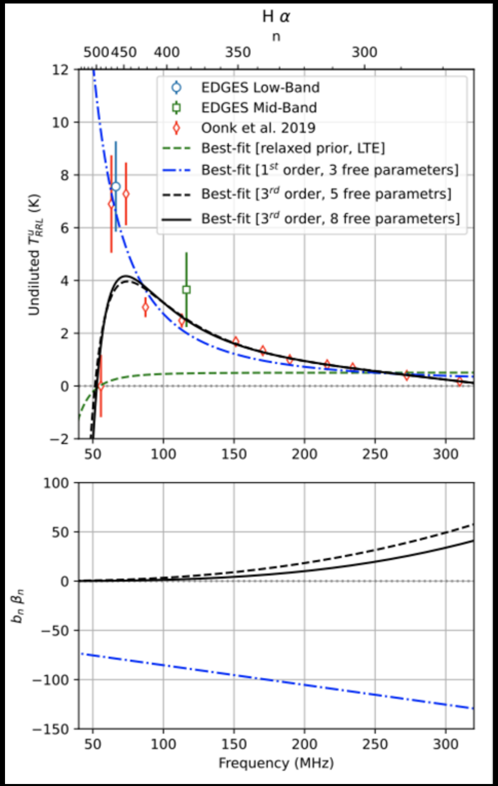
[6] Department of Physics and McGill Space Institute, McGill University, Montreal, QC

Vydula+2023 (in review)

- Detect **strongest** lines when Galaxy is overhead (as expected)
- Used a double-gaussian model to fit stacked Cα, Cβ, Cγ, Hα lines.
  - >5σ detection for each.
- Intensity dependent on frequency. Consistent with LOFAR observations.
- Hα **not** consistent with LTE.
- **NO PROBLEM FOR GLOBAL SIGNAL**
- Flagging increases high-k power for interferometers

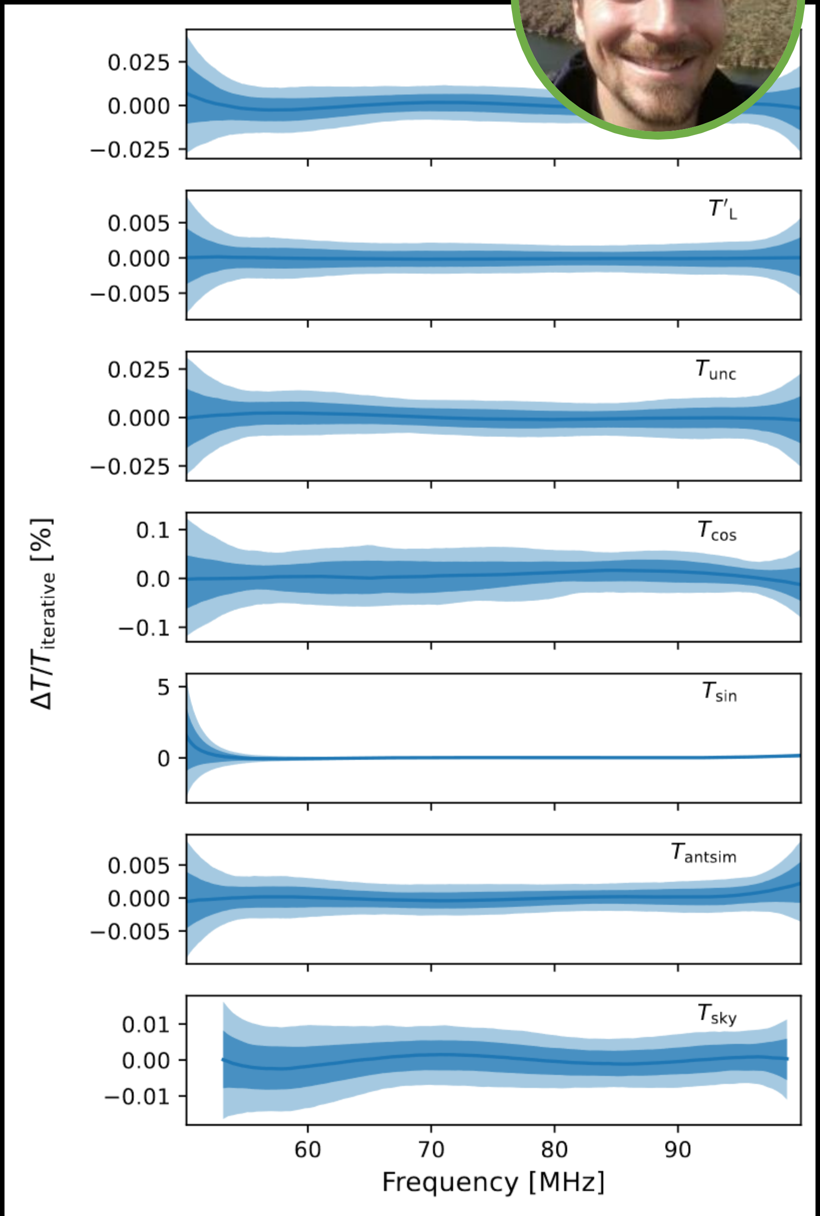




Bayesian Receiver Calibration

SGM+2022

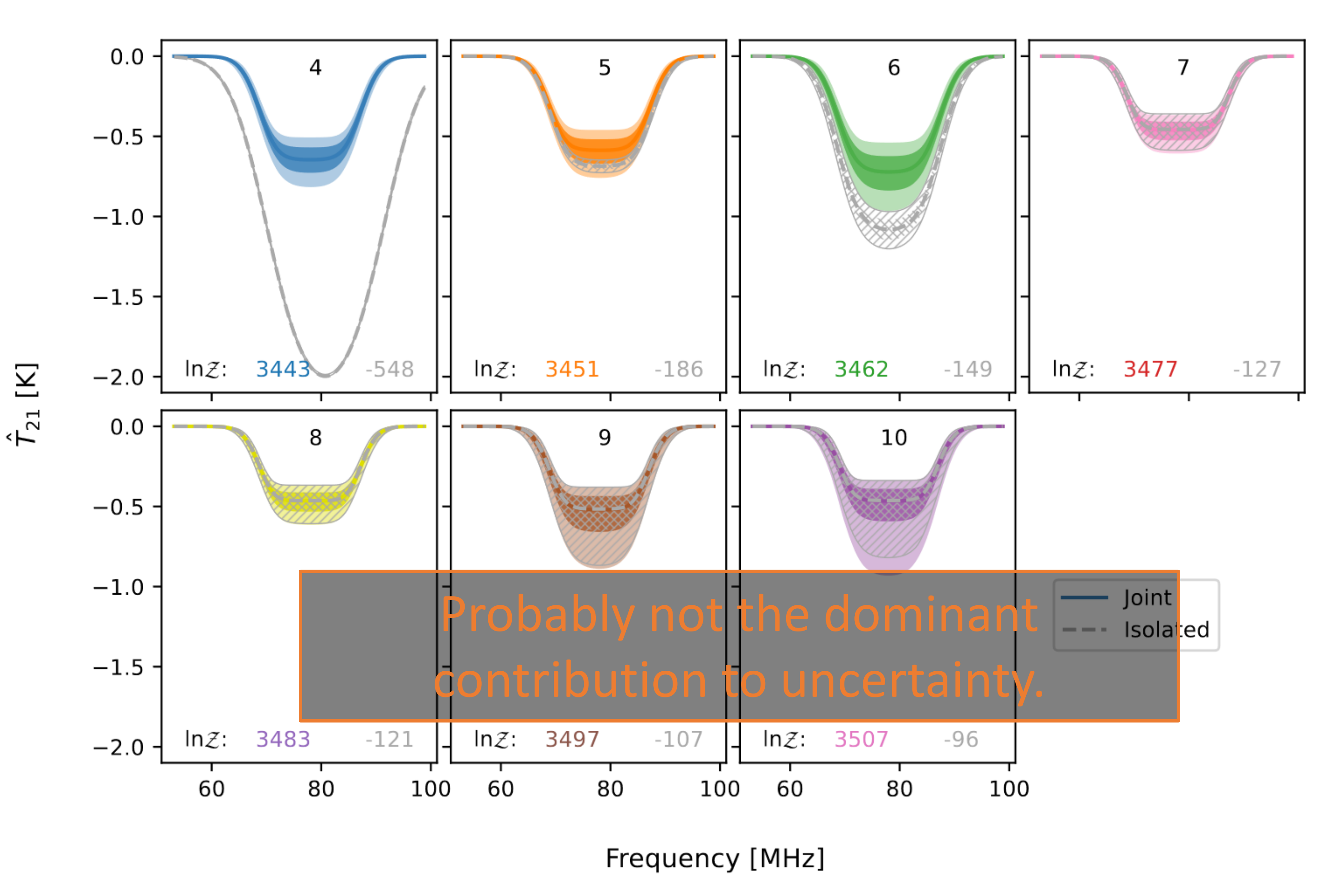
- Absolute calibration done by comparing four known inputs with differing characteristics to find “Noise Wave Temperatures”.
- New >50 parameter Bayesian formalism to propagate correlated errors from calibration.
- Posterior on calibration solutions and calibration sky temperature is reasonably tight.



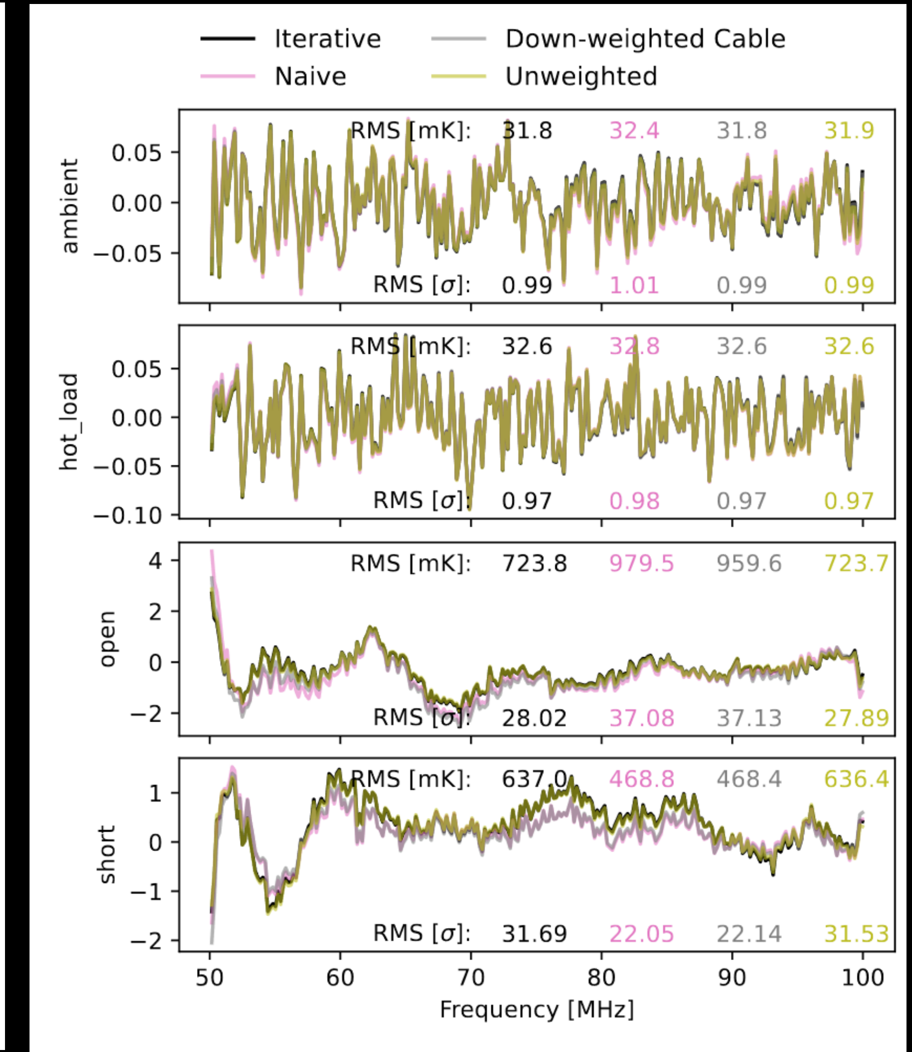
Bayesian Receiver Calibration

SGM+2022

CAVEAT



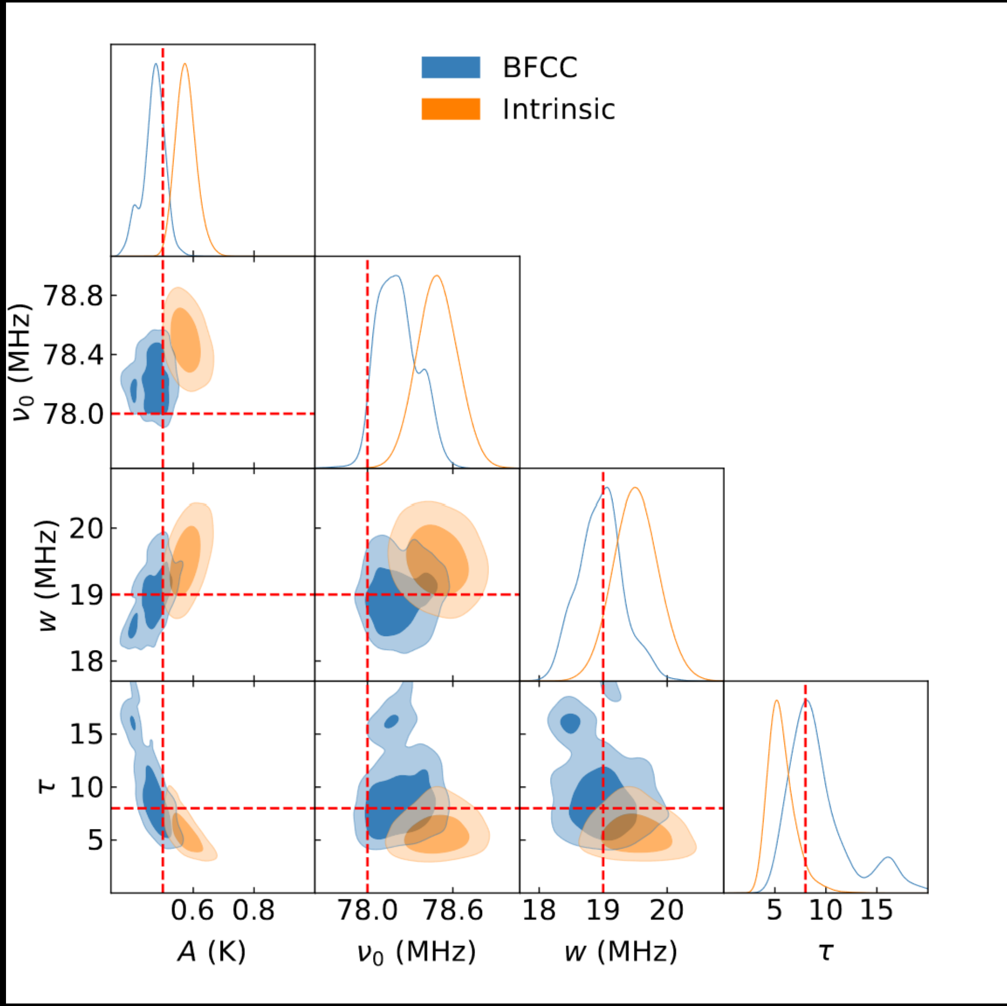
Probably not the dominant contribution to uncertainty.



Sims+2023

Beam Chromaticity Correction

- Change in shape of angular sensitivity of antenna ('beam') with frequency distorts observed spectrum.
- Sims+2023 assesses 'correction' methods and defines requirements for their suitability.
- Defines a new low-order expansion that is suitable in realistic scenarios.
- Application to data coming soon…



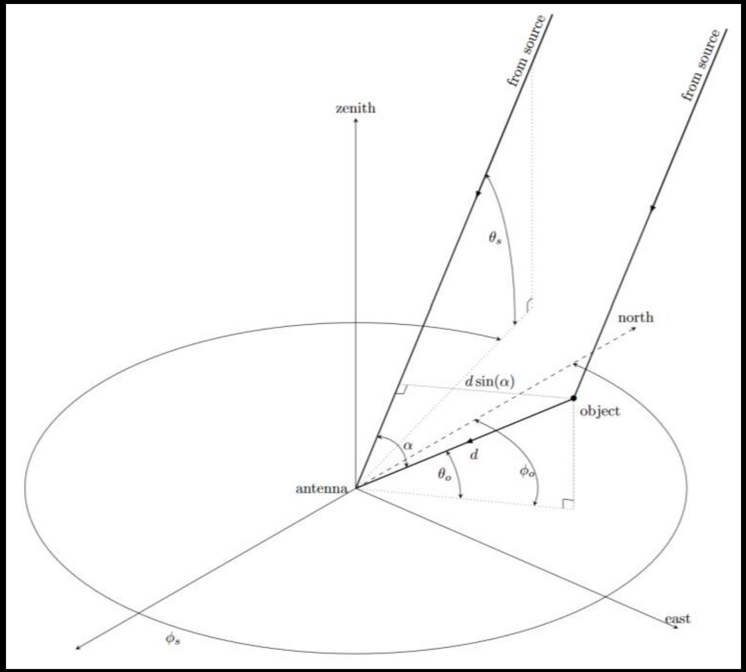
Rogers+2022

Scattering from nearby objects

- 5 – 20 MHz period ‘ripples’ are problematic for global signal measurements (e.g. Sims+2020).
- Scatter of incoming radiation from close objects at a delay can induce these ripples.
- Rogers+2022 characterizes this effect

$$P_{\text{total}} = P_{\text{source}} \left\{ 1 + 2\cos(\omega\tau) \left[\frac{A_{\text{scat}}}{A_{\text{source}}} \frac{\sigma}{4\pi d^2} \right]^{1/2} \right\}$$

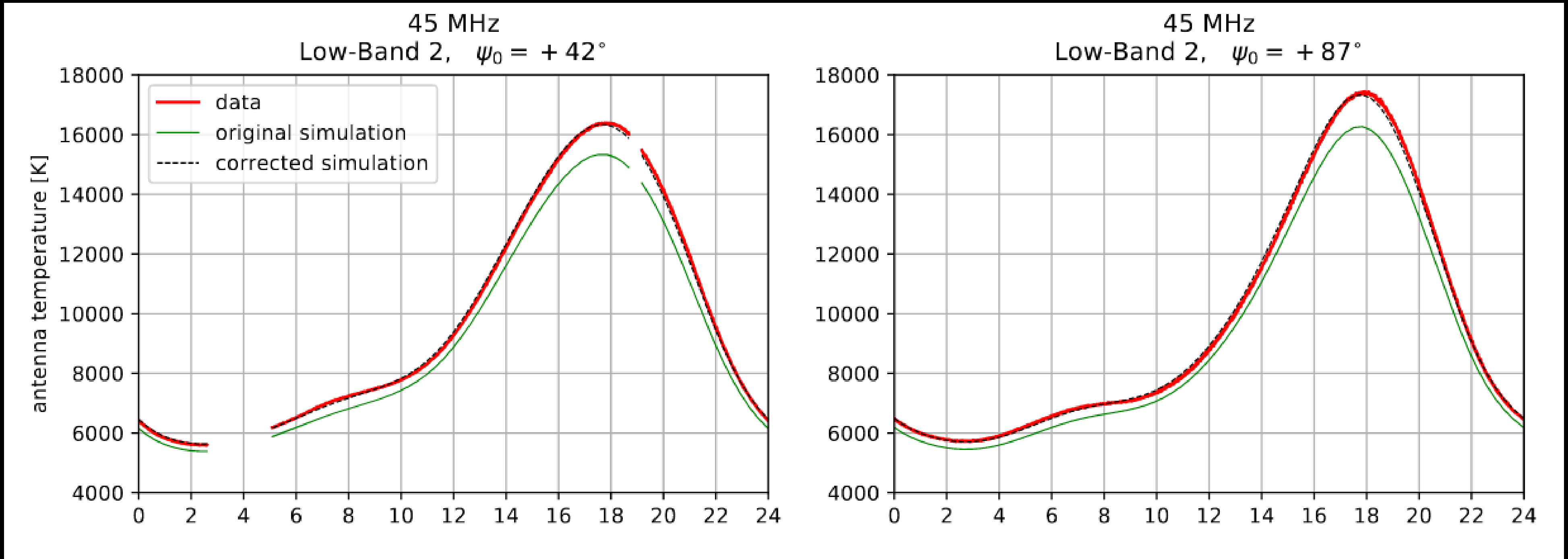
- Simple way of determining minimum distances to small objects (eg rocks, hut)



Absolute Sky Model Calibration

Monsalve+2021

An improvement to the absolute flux scale of sky models…



… and a verification of the EDGES beam model.


EDGES-3

Why EDGES-3?

Upgrades

- ❖ Less chromatic beam
    - ❖ larger 50x50m ground plane, eg. Mahesh+2021
- ❖ Receiver embedded in antenna
    - ❖ Shorter delays → longer wavelengths
    - ❖ No balun! (See Nivedita's talk…)
- ❖ In-situ, regular, calibration
- ❖ More portable design
- ❖ Larger usable bandwidth

Downsides

In-situ VNA lower quality than bench-top VNA

Will perform crucial tests for whether systematics from the beam or signal path are important. Portability allows to test sky model systematics.

Challenges – Gaps in Mesh-Plate Welding

The problem: 0.3mm (!) gaps

MIT EDGES Memo #407

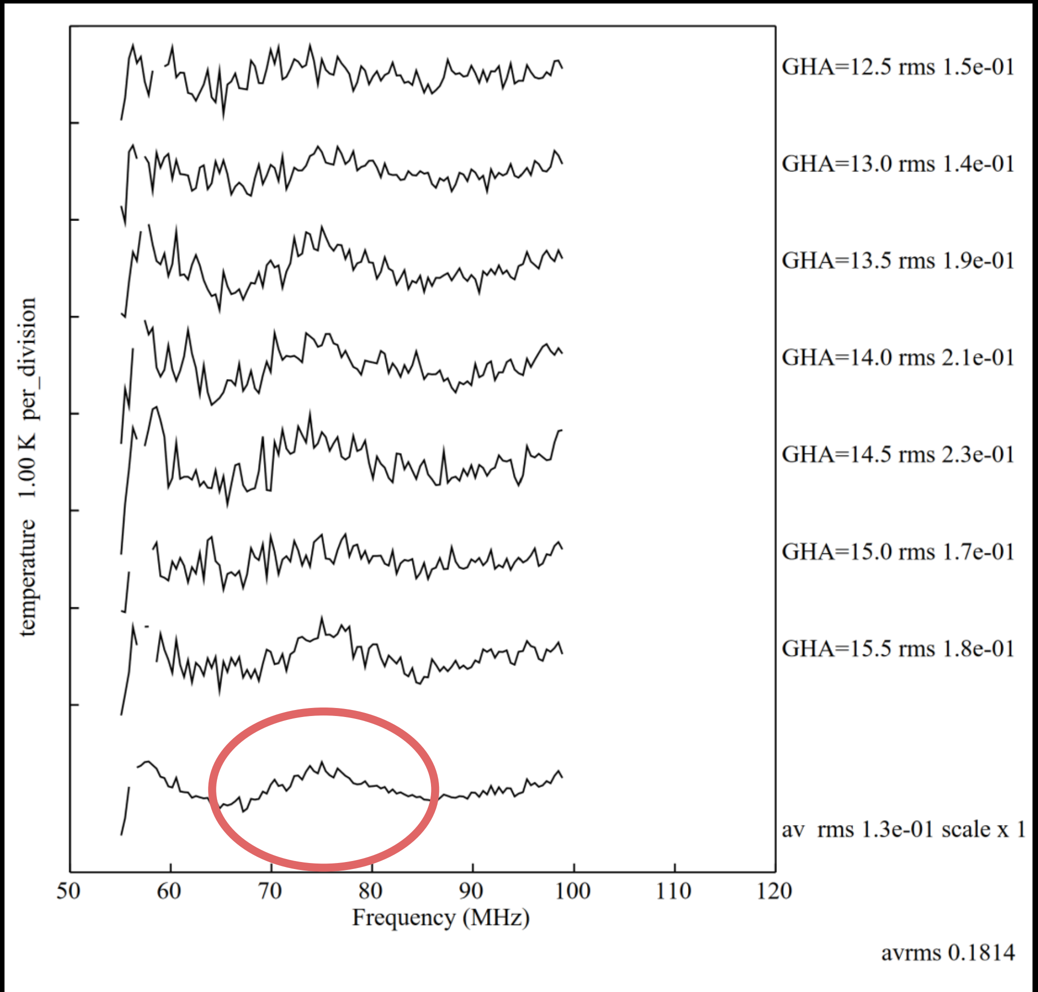
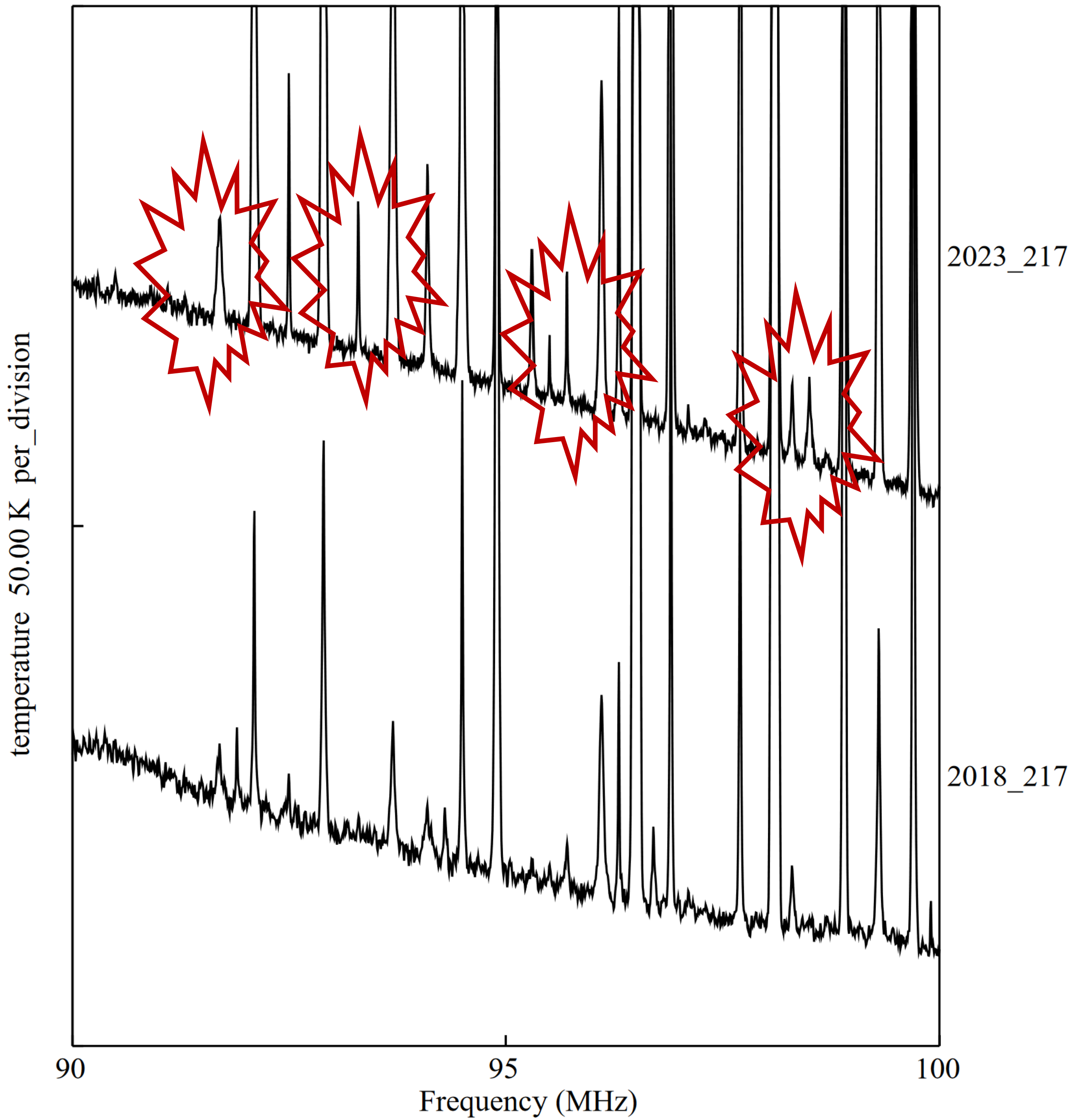


Figure 3. Residuals in 30 minute blocks for data from 2022:319 to 2022:332.

Challenges - RFI

- Data taken in 2023 has significantly more RFI than 2018.
- Possibly due to increase in satellites, e.g. Starlink

- Must avoid stations to 5000km (from 2000km).
- Motivates more remote locations… Wake Island… the Moon…



Systematics that have been checked

VNA temperature drift (Memo #411)

Adjacent ground planes (#413)

Feedback (Memo #425)

Calibration / Filtering parameters (Memo #423)

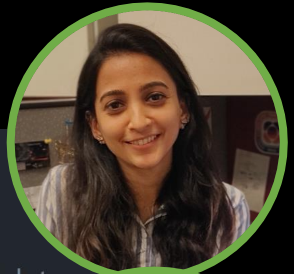
So… what do we see?

See Rigel’s Talk…

The Future

(but pre-2030)

New Analysis Pipeline



- Independent code to keep us honest.
- Motivated by Bayesian forward modelling.
- Easy to switch between analysis choices/techniques.
  - Data QA never simple: the data always wins.
- Created with the **community in mind** (docs, tests, re-useable components)
- Currently adapting the pipeline for EDGES-3

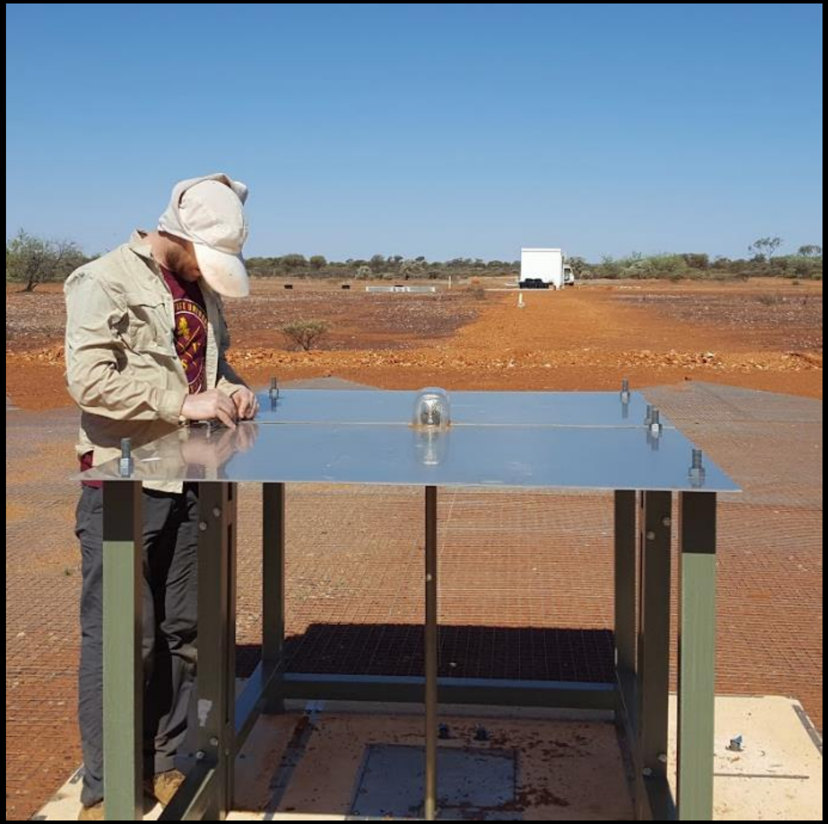
Global-signal data interface built for the needs of all experiments.
Check it out! Collaborate!

New Data

(Re-)Analysis with the new pipeline, convergence on what the data tells us in different cuts.

EDGES-3 LOW

EDGES-2 MID



EDGES-2 LOW 45º

Where will we get confidence from?

- Independent signal chain, beam.
- Extend frequency range (difficult with FM)
- Constancy of signal across LST
- Constancy of signal with latitude
- Move from phenomenological models to physically-motivated models (21cmFAST, semi-analytic, emulators…)

- Independent global experiments (except for SARAS because they don’t agree with us :-P)
- Interferometers?

Conclusions

- Lots of work done by the EDGES collaboration to increase our confidence in our instrument.
- Focus on the two weakest aspects of B18: beam systematics, and analysis choices.
- Analysis moving in a forward-modelling direction.
- Lots of data still to process and understand, including EDGES-3.