New edges-analysis pipeline: Reproducing Bowman et al. 2018

Nivedita Mahesh
David and Ellen Lee Postdoctoral Fellow
California Institute of technology

Collaboration: **Steven G Murray**, Judd Bowman, Alan EE Rogers, Raul Monsalve, Peter Sims

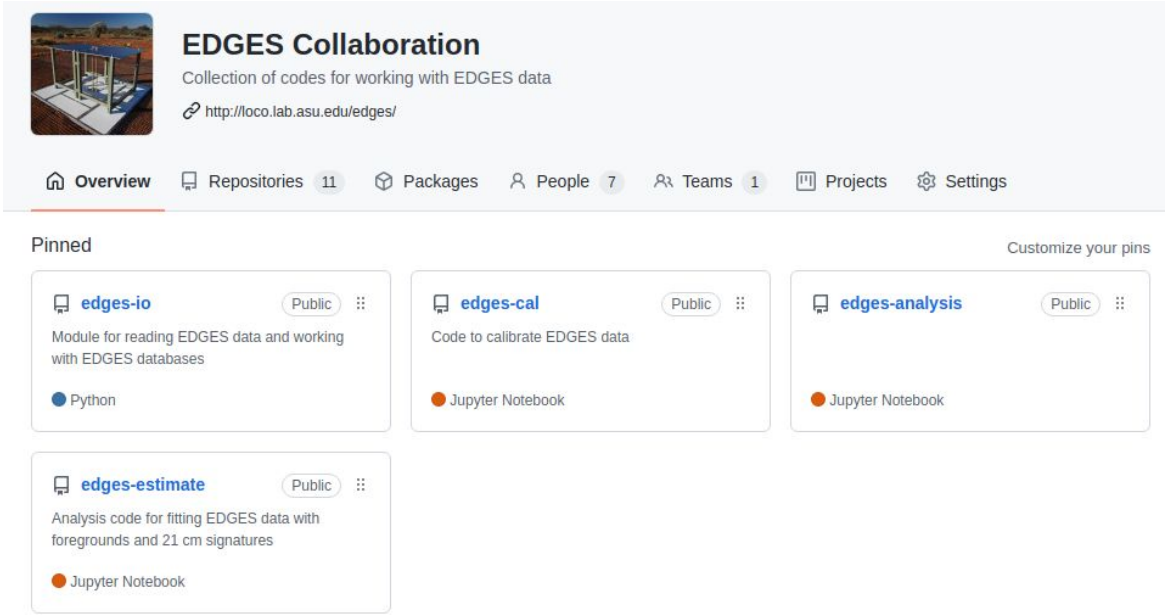
School of Earth and Space Exploration
Arizona State University

Caltech

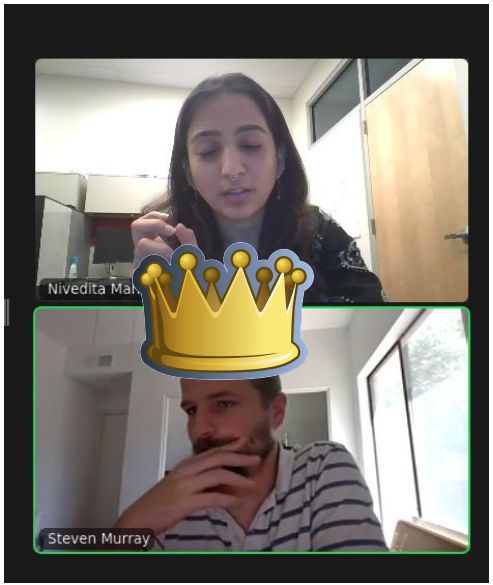
MIT HAYSTACK OBSERVATORY

New EDGES data processing pipeline

*EDGES collaboration has developed a **new, open-source** data processing pipeline with repositories to processes data all the way from field data to the final products for various analyses*



Led by Steven G Murray



New EDGES data processing pipeline

*EDGES collaboration has developed (led by Steven Murray) a **new, open-source** data processing pipeline with repos to processes all the way from raw field data to final products for various analyses*

Why did we spend countless hours understanding, improving and building upon the 10000+ lines of the 2018 legacy C pipeline?

- Need for an independent processing pipeline
  - Provides modularity and full traceability
  - Allows simple switching of analysis choices & techniques
- Independently process the same EDGES low-band data
- Understand the impact of different data processing choices at various stages of the analysis
  - Forward modelling effects on the inferred astrophysical & cosmological parameters
  - Enable future Bayesian frameworks for more fidelity in inference
- Will accompany EDGES-3
- We want to develop interoperable tools for this growing community.

GSData and the new pipeline

Backbone of the code is new data interface: gsdata. **This will be a standalone package for the community. Please talk to us if you're interested!**

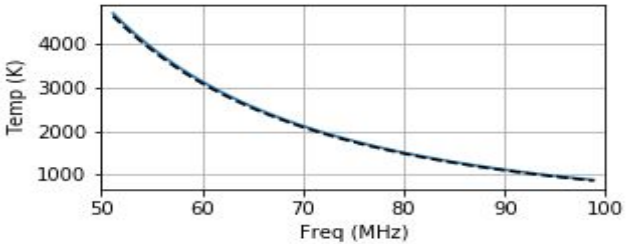
Analysis code modularised into modules for: RFI flagging, filtering, calibration, averaging, LST-binning, modelling, …

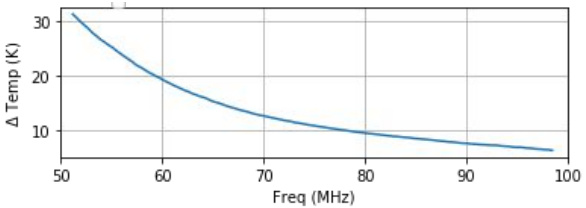
Pipeline helpers to pull it all together and maintain traceability.

From last year: reprocessed data with settings *as close as possible* to B18

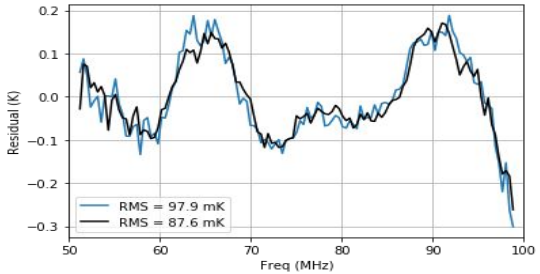
Lowband 1: 2016-260 to 2017-094

- Non trivial differences remained at levels of ~ 10s of mK
- Before doing any further analysis or tests we needed to show we could reproduce the processed spectra & residuals with the same processing steps & choices





PhysicalLin; 51-99 MHz



A test of the new pipeline

If we give the same data to both pipelines & process it with the same parameters ..

Can we get the same result down to machine precision?

Let’s check each step of the pipeline explicitly on a few days’ observation…

In addition, it illuminates all the choices that went into Bowman+2018

Step by step comparison of the two pipelines for a few days

RAW DATA
3-pos switch output

adcmax <0.4

LST SELECT
GHA: 6 to 18 hr

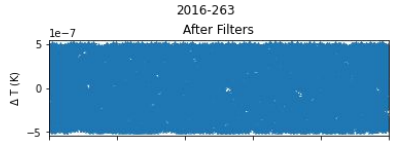
Orbcomm filter

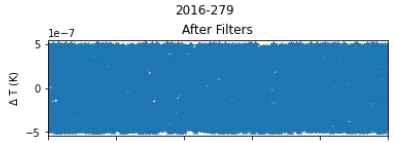
MaxFM filter

RMS filter

Peak Power filter

LST BINNING
GHA: 6 to 18 hr





Step by step comparison of the two pipelines for a few days

RAW DATA
3-pos switch output

adcmax <0.4

LST SELECT
GHA: 6 to 18 hr

Orbcomm filter

MaxFM filter

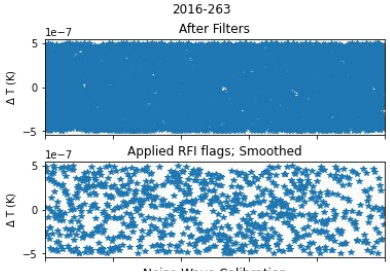
RMS filter

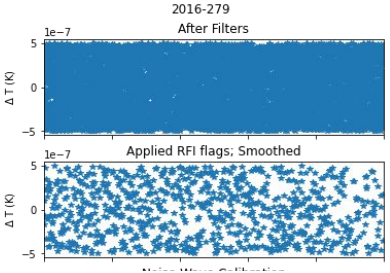
Peak Power filter

LST BINNING
GHA: 6 to 18 hr

XRFI: Fourier Series

GAUSS SMOOTHING
factor: 8





Step by step comparison of the two pipelines for a few days

RAW DATA
3-pos switch output

adcmax <0.4

LST SELECT
GHA: 6 to 18 hr

Orbcomm filter

MaxFM filter

RMS filter

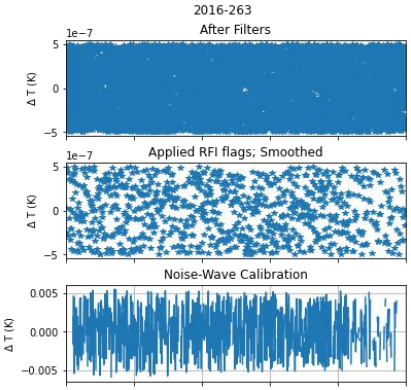
Peak Power filter

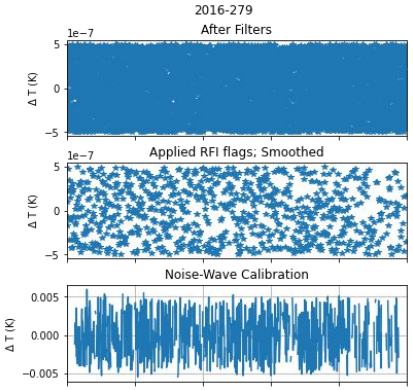
LST BINNING
GHA: 6 to 18 hr

XRFI: Fourier Series

GAUSS SMOOTHING
factor: 8

RCV CALIBRATION





Step by step comparison of the two pipelines for a few days

RAW DATA
3-pos switch output

adcmax <0.4

LST SELECT
GHA: 6 to 18 hr

Orbcomm filter

MaxFM filter

RMS filter

Peak Power filter

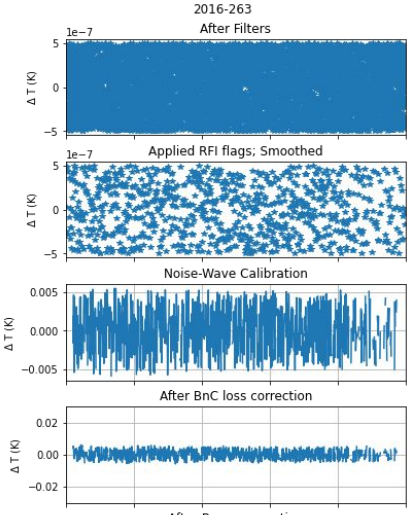
LST BINNING
GHA: 6 to 18 hr

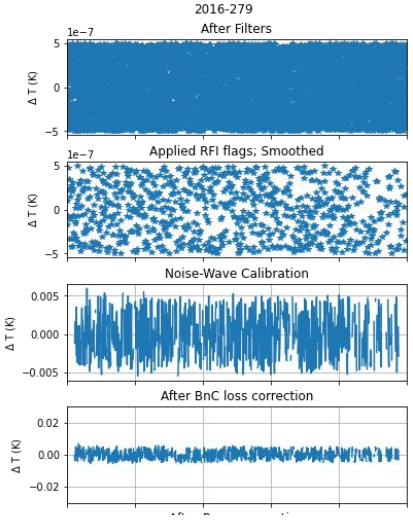
XRFI: Fourier Series

GAUSS SMOOTHING
factor: 8

RCV CALIBRATION

LOSS CORRECTION
Balun + connector loss: **B18**
Antenna Loss & Ground correction : **False**





Step by step comparison of the two pipelines for a few days

RAW DATA
3-pos switch output

adcmax <0.4

LST SELECT
GHA: 6 to 18 hr

Orbcomm filter

MaxFM filter

RMS filter

Peak Power filter

LST BINNING
GHA: 6 to 18 hr

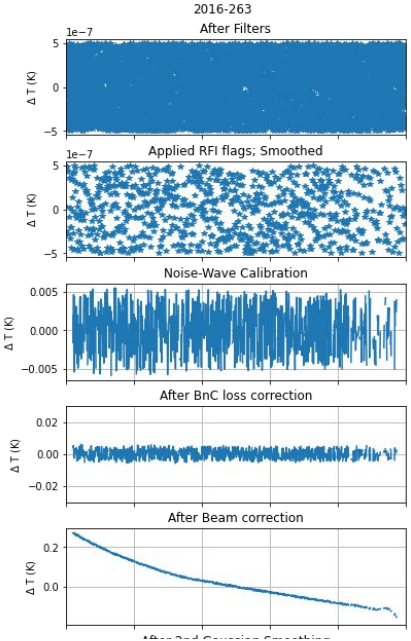
XRFI: Fourier Series

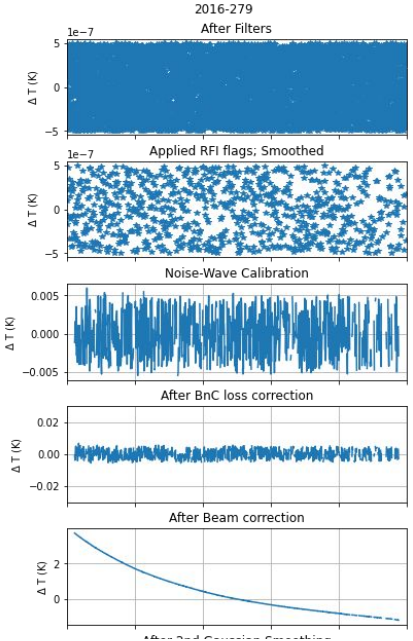
GAUSS SMOOTHING
factor: 8

RCV CALIBRATION

LOSS CORRECTION
Balun + connector loss: **B18**
Antenna Loss & Ground correction : **False**

BEAM CORRECTION





Step by step comparison of the two pipelines for a few days

RAW DATA
3-pos switch output

adcmax <0.4

LST SELECT
GHA: 6 to 18 hr

Orbcomm filter

MaxFM filter

RMS filter

Peak Power filter

LST BINNING
GHA: 6 to 18 hr

XRFI: Fourier Series

GAUSS SMOOTHING
factor: 8

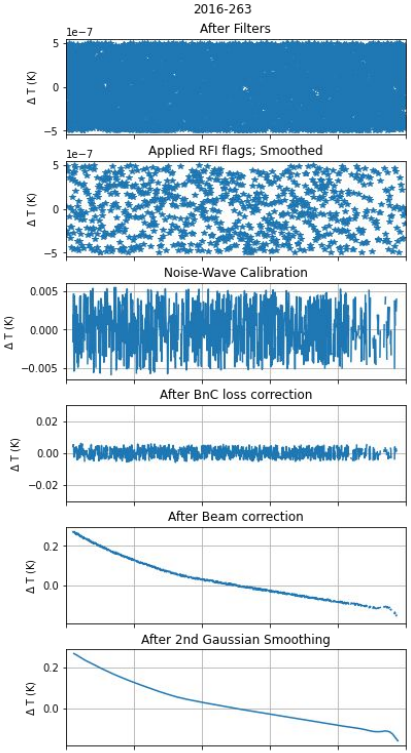
RCV CALIBRATION

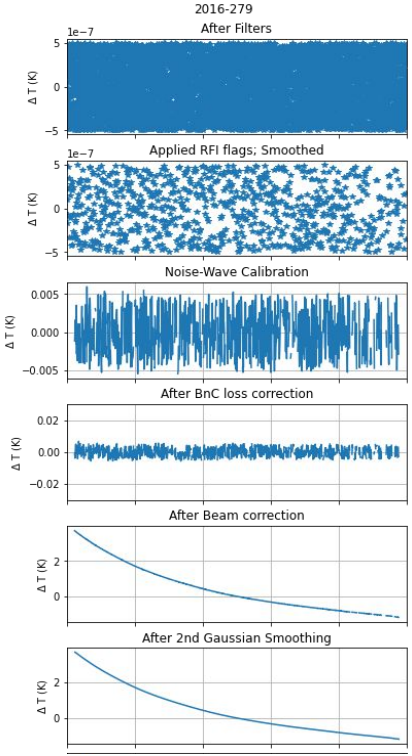
LOSS CORRECTION
Balun + connector loss: **B18**
Antenna Loss & Ground correction : **False**

BEAM CORRECTION

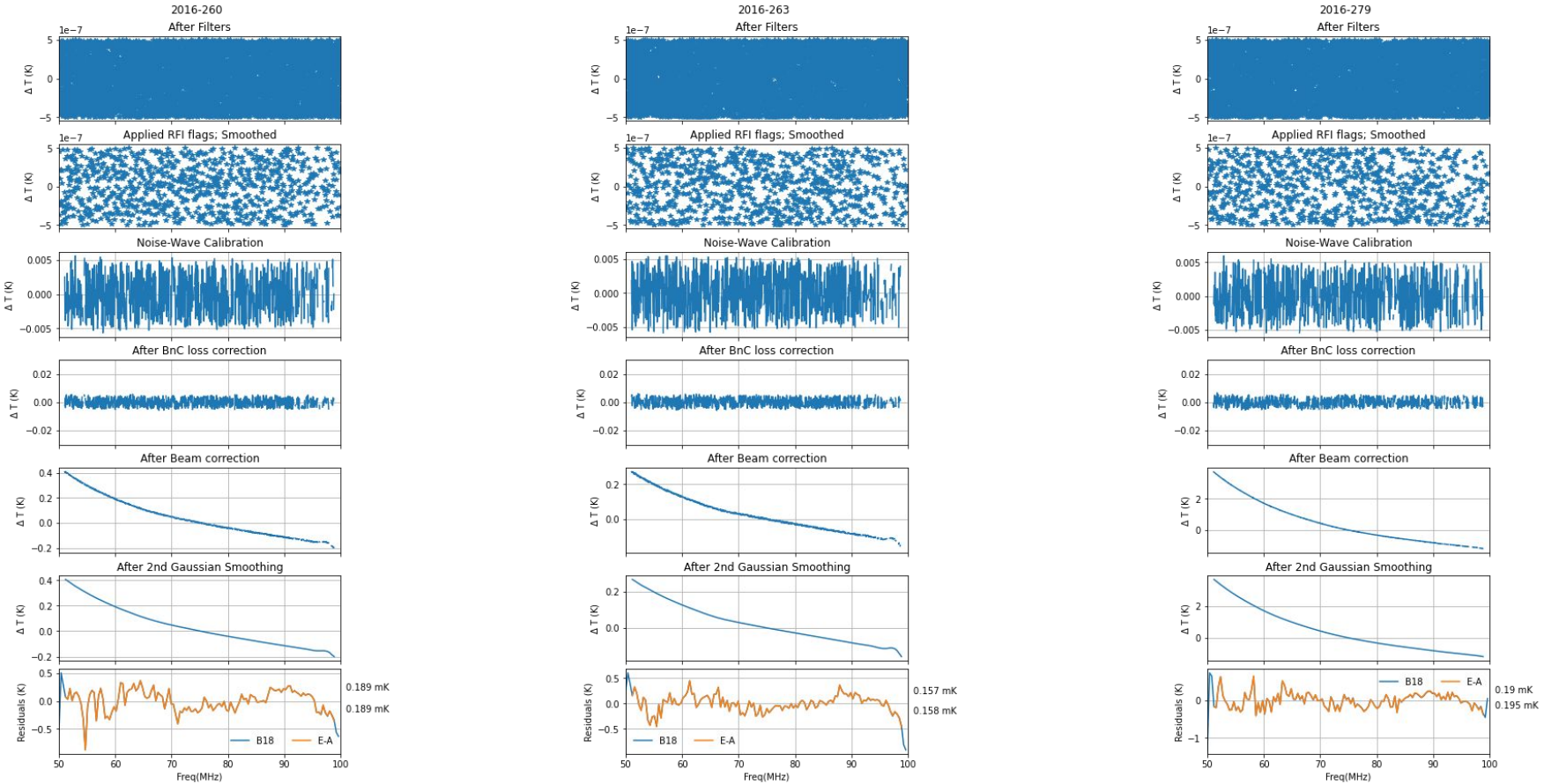
MODELED DATA
3-term PhysicalLin

GAUSS SMOOTHING
factor: 8

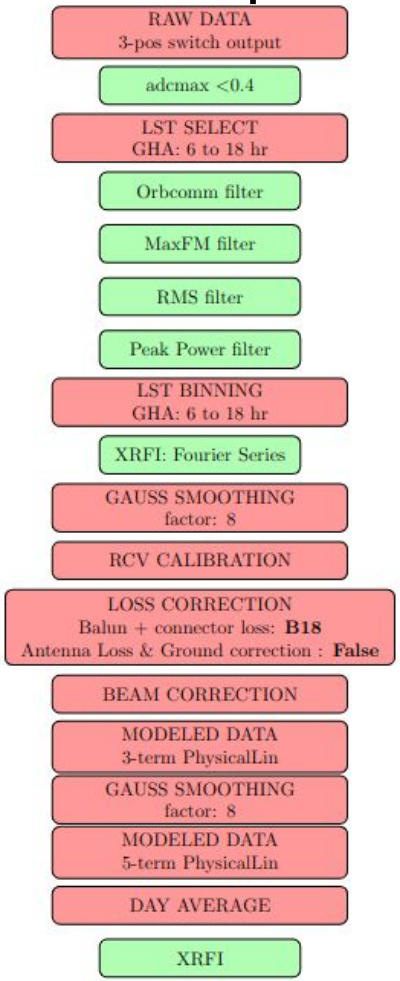




Step by step comparison of the two pipelines for a few days



Reproducing Bowman et al. 2018 with edges-analysis



Using the same dataset and the same analysis choices as 2018

Reproducing Bowman et al. 2018 with edges-analysis

RAW DATA
3-pos switch output

adcmax <0.4

LST SELECT
GHA: 6 to 18 hr

Orbcomm filter

MaxFM filter

RMS filter

Peak Power filter

LST BINNING
GHA: 6 to 18 hr

XRFI: Fourier Series

GAUSS SMOOTHING
factor: 8

RCV CALIBRATION

LOSS CORRECTION
Balun + connector loss: **B18**
Antenna Loss & Ground correction : **False**

BEAM CORRECTION

MODELED DATA
3-term PhysicalLin

GAUSS SMOOTHING
factor: 8

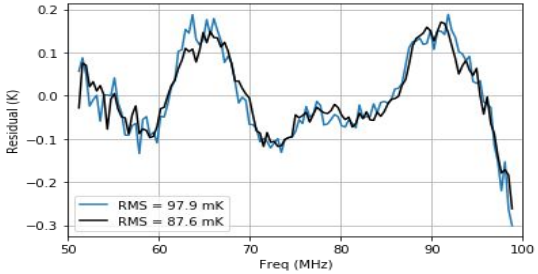
MODELED DATA
5-term PhysicalLin

DAY AVERAGE

XRFI

Using the same dataset and the same analysis choices as 2018

From last year: PhysicalLin; 51-99 MHz



PhysicalLin; 51-99 MHz

New edges-analysis pipeline: Investigating effects of *a few* processing techniques on the cosmological signal

ASU School of Earth and Space Exploration
Arizona State University

Caltech

MIT HAYSTACK OBSERVATORY

Sensitivity to analysis choices: LST calculation schemes

RAW DATA
3-pos switch output

adcmax <0.4

LST SELECT
GHA: 6 to 18 hr

Orbcomm filter

MaxFM filter

RMS filter

Peak Power filter

LST BINNING
GHA: 6 to 18 hr

XRFI: Fourier Series

GAUSS SMOOTHING
factor: 8

RCV CALIBRATION

LOSS CORRECTION
Balun + connector loss: **B18**
Antenna Loss & Ground correction : **False**

BEAM CORRECTION

MODELED DATA
3-term PhysicalLin

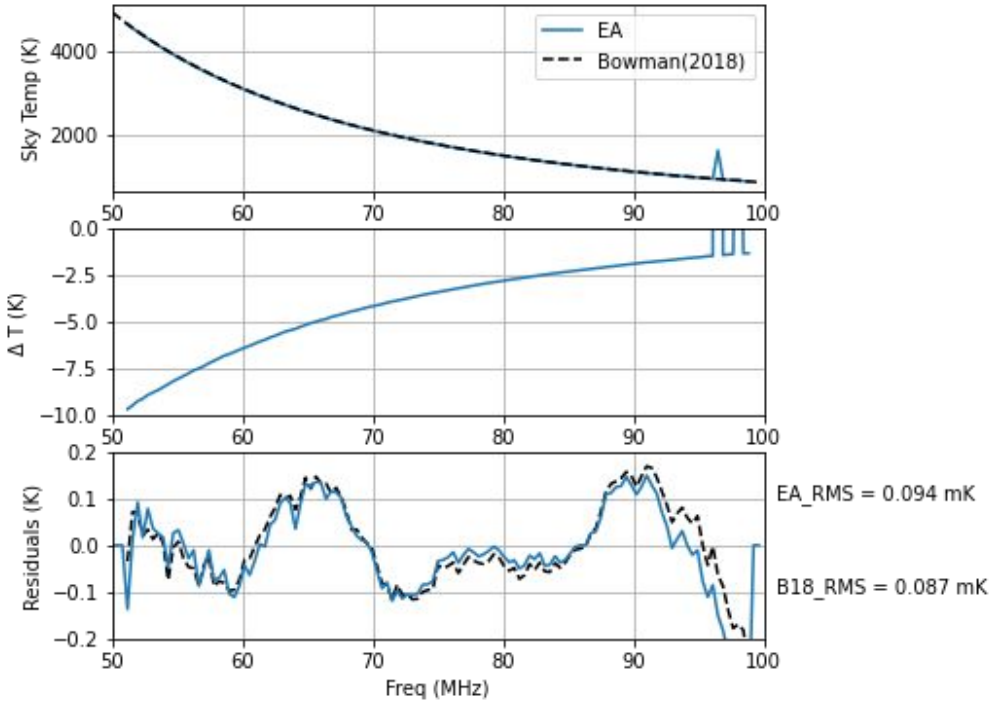
GAUSS SMOOTHING
factor: 8

MODELED DATA
5-term PhysicalLin

DAY AVERAGE

XRFI

RAW DATA
Time to LST conversion: legacy function (blue) → astropy (blue)



Sensitivity to analysis choices: Receiver Temp filtering

RAW DATA
3-pos switch output

adcmax <0.4

LST SELECT
GHA: 6 to 18 hr

Orbcomm filter

MaxFM filter

RMS filter

Peak Power filter

LST BINNING
GHA: 6 to 18 hr

XRFI: Fourier Series

GAUSS SMOOTHING
factor: 8

RCV CALIBRATION

LOSS CORRECTION
Balun + connector loss: **B18**
Antenna Loss & Ground correction : **False**

BEAM CORRECTION

MODELED DATA
3-term PhysicalLin

GAUSS SMOOTHING
factor: 8

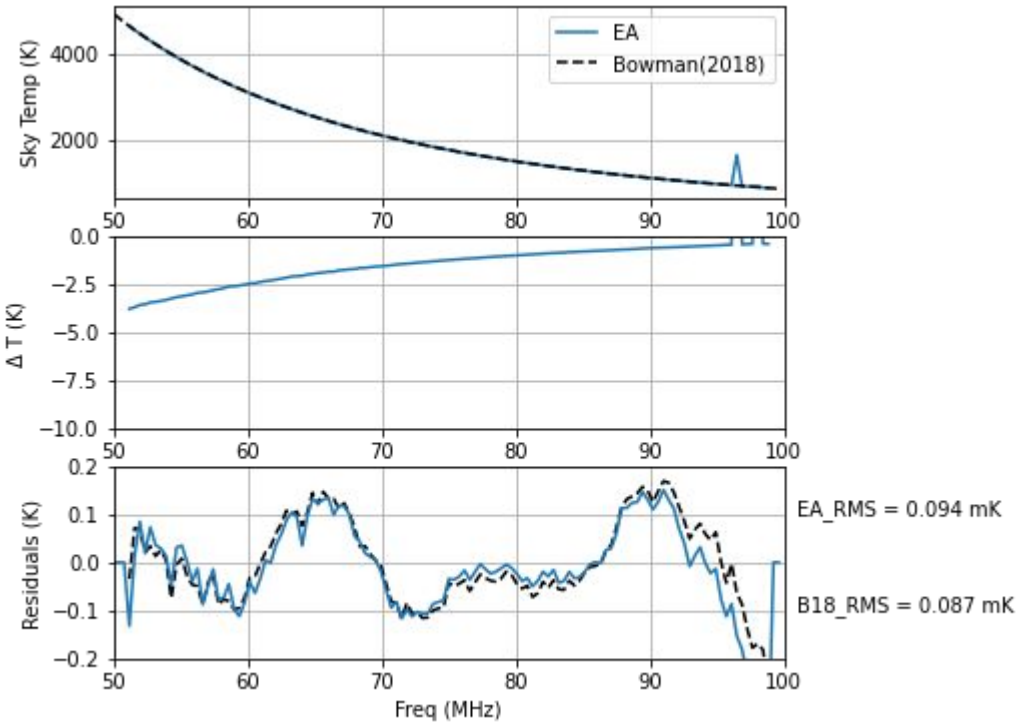
MODELED DATA
5-term PhysicalLin

DAY AVERAGE

XRFI

AUX Filter

No Rcv Temp check (blue) ⟶
0°C < Rcv Temp< 100°C (blue)



Sensitivity to analysis choices: Receiver calibration choices

RAW DATA
3-pos switch output

adcmax <0.4

LST SELECT
GHA: 6 to 18 hr

Orbcomm filter

MaxFM filter

RMS filter

Peak Power filter

LST BINNING
GHA: 6 to 18 hr

XRFI: Fourier Series

GAUSS SMOOTHING
factor: 8

RCV CALIBRATION

LOSS CORRECTION
Balun + connector loss: **B18**
Antenna Loss & Ground correction : **False**

BEAM CORRECTION

MODELED DATA
3-term PhysicalLin

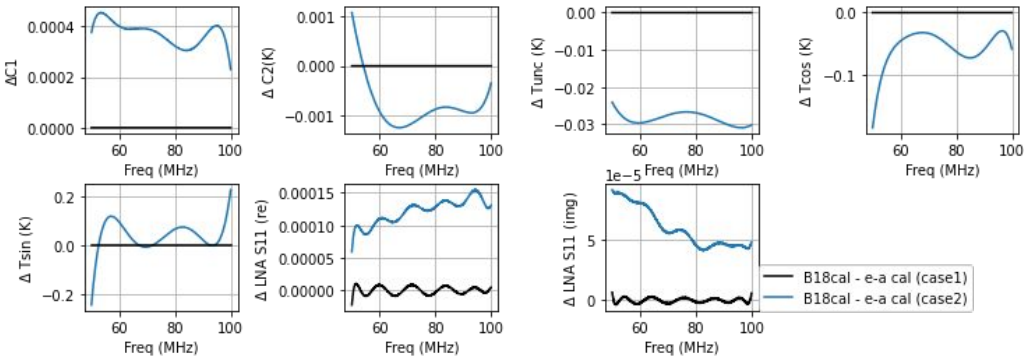
GAUSS SMOOTHING
factor: 8

MODELED DATA
5-term PhysicalLin

DAY AVERAGE

XRFI

CALIBRATION
B18 cal parameters (case1; black) → EA rcv cal (case2; blue)
[Murray et. al. 2022]



Sensitivity to analysis choices: Receiver calibration choices

RAW DATA
3-pos switch output

adcmax <0.4

LST SELECT
GHA: 6 to 18 hr

Orbcomm filter

MaxFM filter

RMS filter

Peak Power filter

LST BINNING
GHA: 6 to 18 hr

XRFI: Fourier Series

GAUSS SMOOTHING
factor: 8

RCV CALIBRATION

LOSS CORRECTION
Balun + connector loss: **B18**
Antenna Loss & Ground correction : **False**

BEAM CORRECTION

MODELED DATA
3-term PhysicalLin

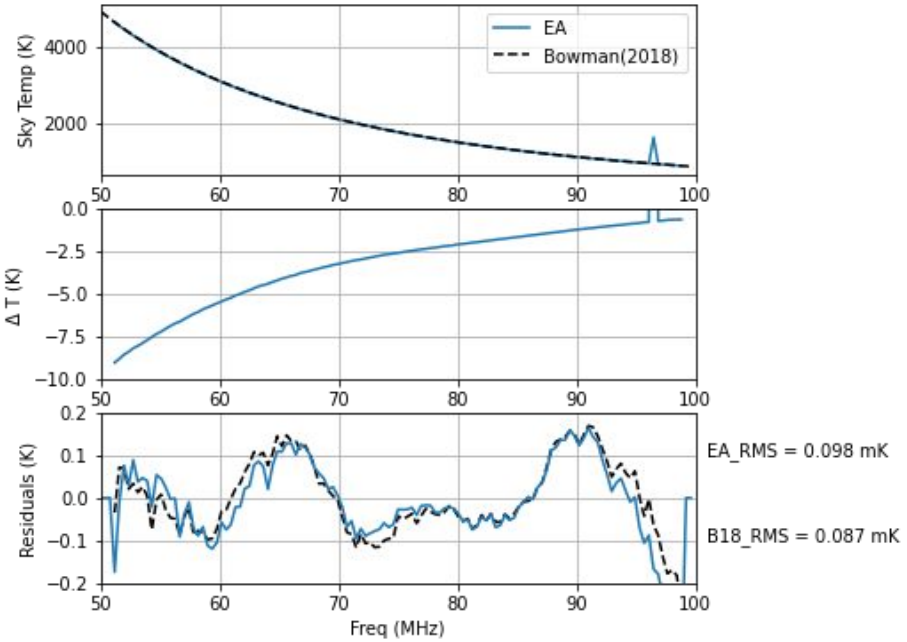
GAUSS SMOOTHING
factor: 8

MODELED DATA
5-term PhysicalLin

DAY AVERAGE

XRFI

CALIBRATION
B18 cal parameters (case1; black) → EA rcv cal (case2; blue)
[Murray et. al. 2022]



Sensitivity to analysis choices: Balun connector length

RAW DATA
3-pos switch output

adcmax <0.4

LST SELECT
GHA: 6 to 18 hr

Orbcomm filter

MaxFM filter

RMS filter

Peak Power filter

LST BINNING
GHA: 6 to 18 hr

XRFI: Fourier Series

GAUSS SMOOTHING
factor: 8

RCV CALIBRATION

LOSS CORRECTION
Balun + connector loss: **B18**
Antenna Loss & Ground correction : **False**

BEAM CORRECTION

MODELED DATA
3-term PhysicalLin

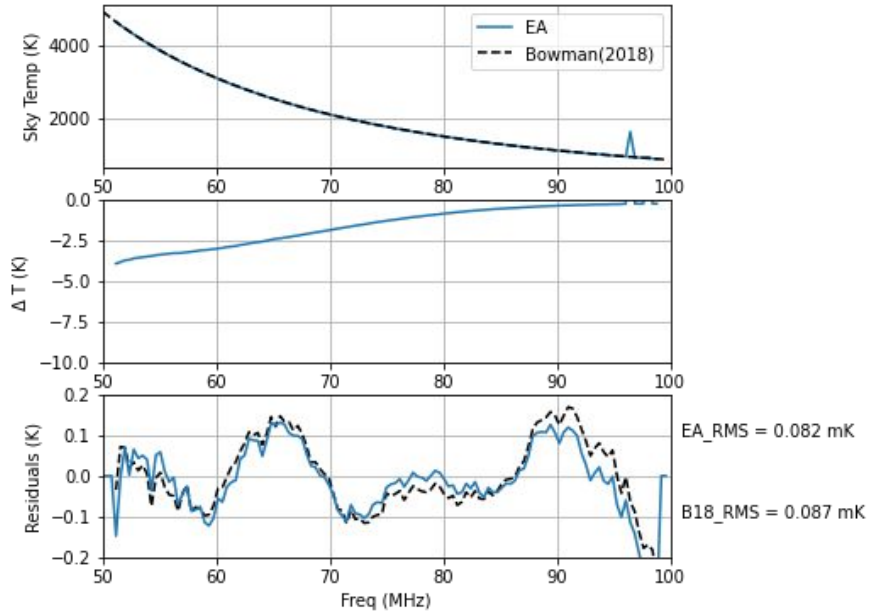
GAUSS SMOOTHING
factor: 8

MODELED DATA
5-term PhysicalLin

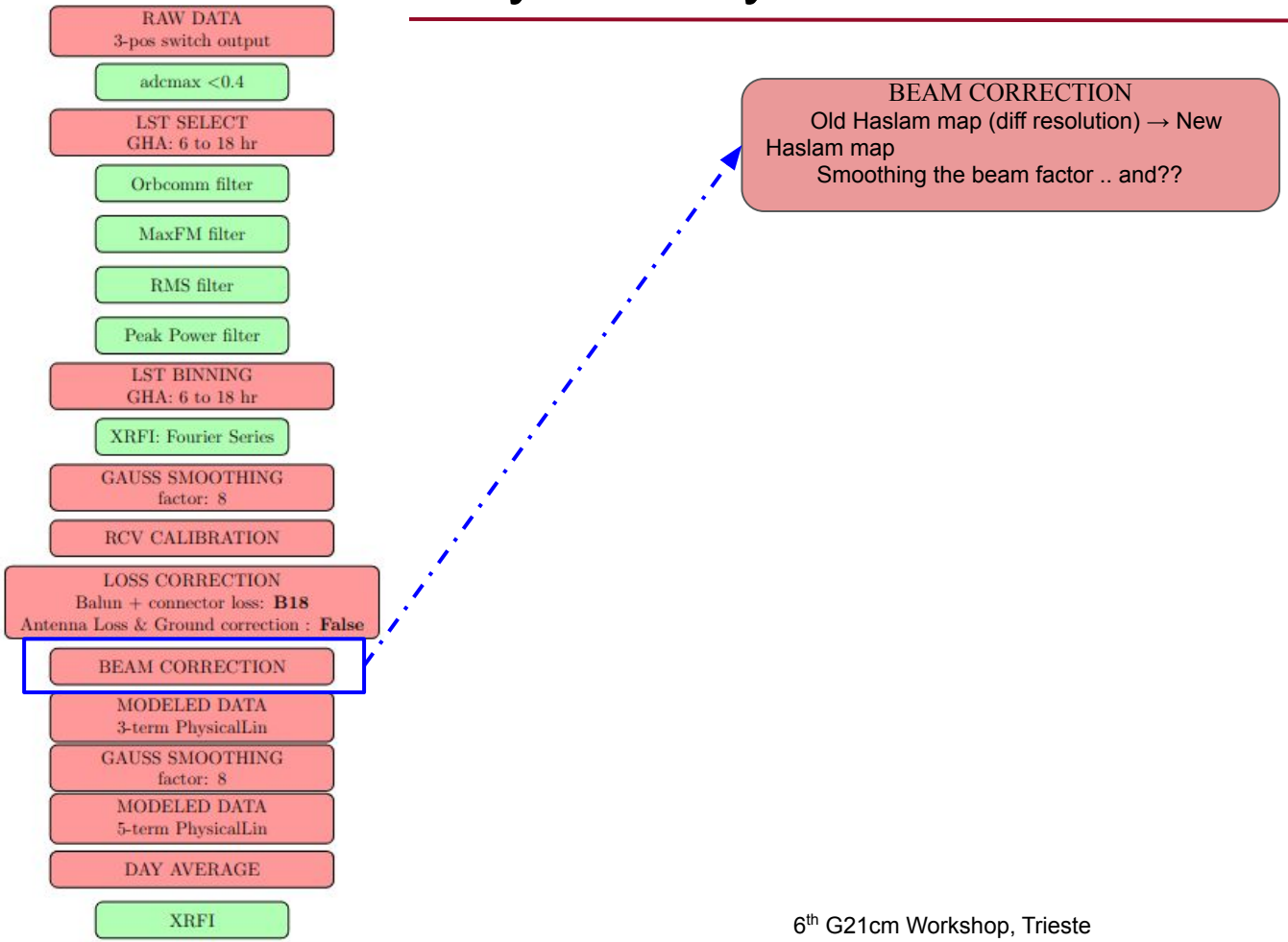
DAY AVERAGE

XRFI

LOSS CORRECTION
Balun and corrector dimensions:
1.18” (black) → 0.8” (blue)



Sensitivity to analysis choices: Beam correction choices



Sensitivity to analysis choices: RFI filtering algorithm

RAW DATA
3-pos switch output

adcmax <0.4

LST SELECT
GHA: 6 to 18 hr

Orbcomm filter

MaxFM filter

RMS filter

Peak Power filter

LST BINNING
GHA: 6 to 18 hr

XRFI: Fourier Series

GAUSS SMOOTHING
factor: 8

RCV CALIBRATION

LOSS CORRECTION
Balun + connector loss: **B18**
Antenna Loss & Ground correction : **False**

BEAM CORRECTION

MODELED DATA
3-term PhysicalLin

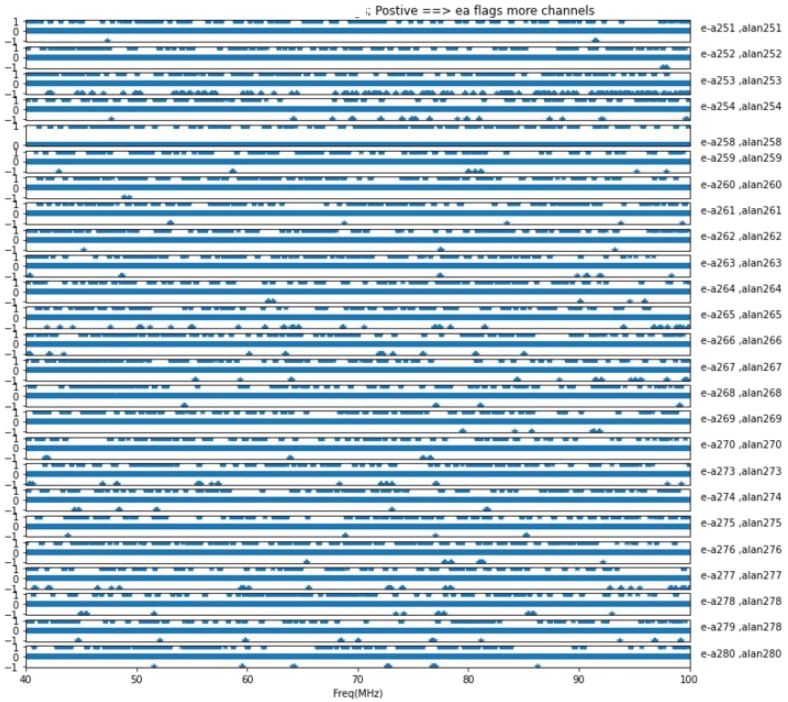
GAUSS SMOOTHING
factor: 8

MODELED DATA
5-term PhysicalLin

DAY AVERAGE

XRFI

xRFI Filter
Legacy RFI → E-A's xRFI algorithm



Conclusions & Lots of future work!

- We have **verified!!** all the steps of the new pipeline with the Bowman+2018 data!!
- **Reproduced!!** the 2018 processed spectra using the same dataset and analysis choices

Now for all the interesting analysis to come:

- Forward model all the significant processing choices
- Will compare the parameter estimates for the various choices
- LST binned analysis
- Process data from different EDGES configurations
- Test different foreground models and systematics..

Now, The possibilities are endless…

LST binned analysis of EDGES data

Simultaneous analysis of multiple LST bins of data with time-variant foreground models & a constant 21 cm signal model

- Test the true global nature of the 21cm absorption feature.
- Quantitatively address concerns related to beam, sky and local environment
- Better utilize the foreground angular structure to help separate it from the 21cm signal model.
- Improved parameter estimation of the cosmological signal

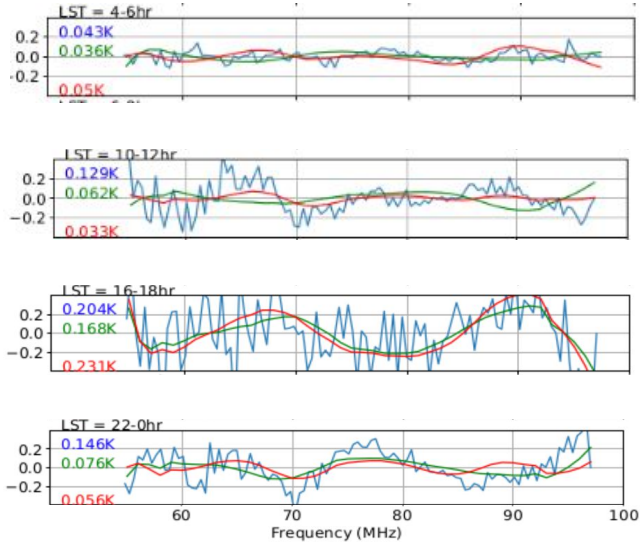
To enable this: we needed a new pipeline and it had to be tested by re-processing & re-analyzing the Bowman et. al. (2018).

Inching closer to LST binned analysis; one year at a time

3rd G21cm workshop (2019)

- LST binned analysis for studying the beam

Extended Ground Plane



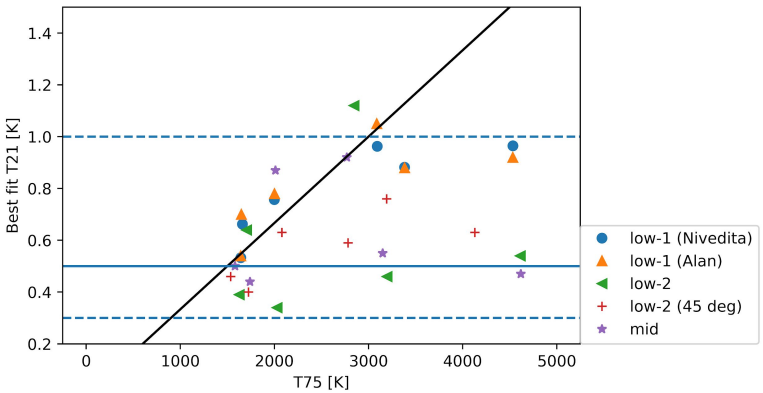
4th G21cm workshop (2021)

5th G21cm workshop (2022)

Inching closer to LST binned analysis; one year at a time

3rd G21cm workshop (2019)

- LST binned analysis for studying the beam
- Very preliminary, basic least squares fit



4th G21cm workshop (2021)

5th G21cm workshop (2022)

Inching closer to LST binned analysis; one year at a time

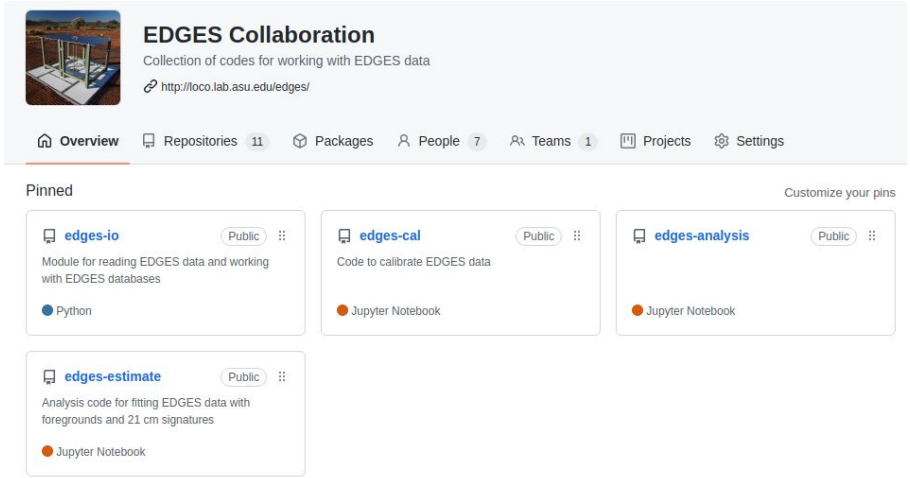
3rd G21cm workshop (2019)

- LST binned analysis for studying the beam
- Very preliminary, basic least squares fit

4th G21cm workshop (2021)

- A new independent pipeline from 2018 was successfully developed

5th G21cm workshop (2022)



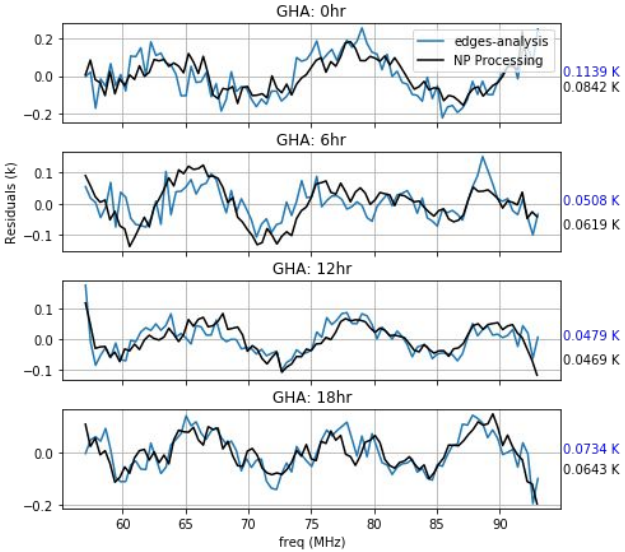
Inching closer to LST binned analysis; one year at a time

3rd G21cm workshop (2019)

- LST binned analysis for studying the beam
- Very preliminary, basic least squares fit

4th G21cm workshop (2021)

- A new independent pipeline from 2018 was successfully developed
- Same Lowband 1 data was processed and **Residuals** were found to be **consistent** with what was reported



5th G21cm workshop (2022)

Inching closer to LST binned analysis; one year at a time

3rd G21cm workshop (2019)

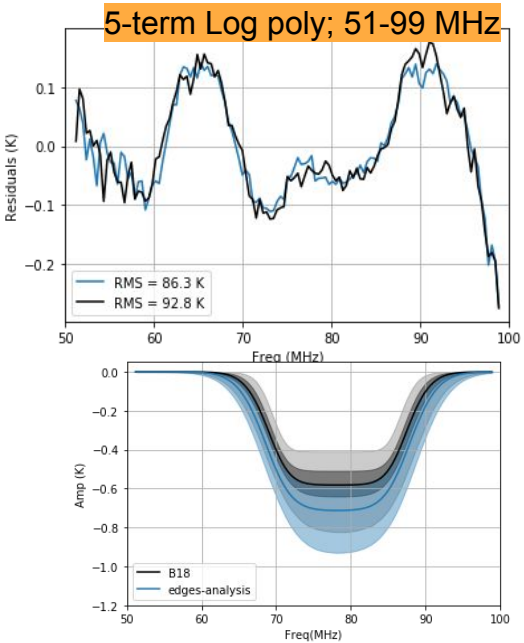
- LST binned analysis for studying the beam
- Very preliminary, basic least squares fit

4th G21cm workshop (2021)

- A new independent pipeline from 2018 was successfully developed
- Same Lowband 1 data was processed and **Residuals** were found to be **consistent** with what was reported.

5th G21cm workshop (2022)

- Lowband 1 data processed with settings similar to 2018 analysis and Small differences ~2.5 mK was found to be significant.



Inching closer to LST binned analysis; one year at a time

3rd G21cm workshop (2019)

- LST binned analysis for studying the beam
- Very preliminary, basic least squares fit

4th G21cm workshop (2021)

- A new independent pipeline from 2018 was successfully developed
- Same Lowband 1 data was processed and **Residuals** were found to be **consistent** with what was reported.

5th G21cm workshop (2022)

- Lowband 1 data processed with settings similar to 2018 analysis and Small differences ~2.5 mK was found to be significant.
- Still presented preliminary LST binned analysis!!!