QUBIC: specificities and status

Q-U Bolometric Interferometer for Cosmology

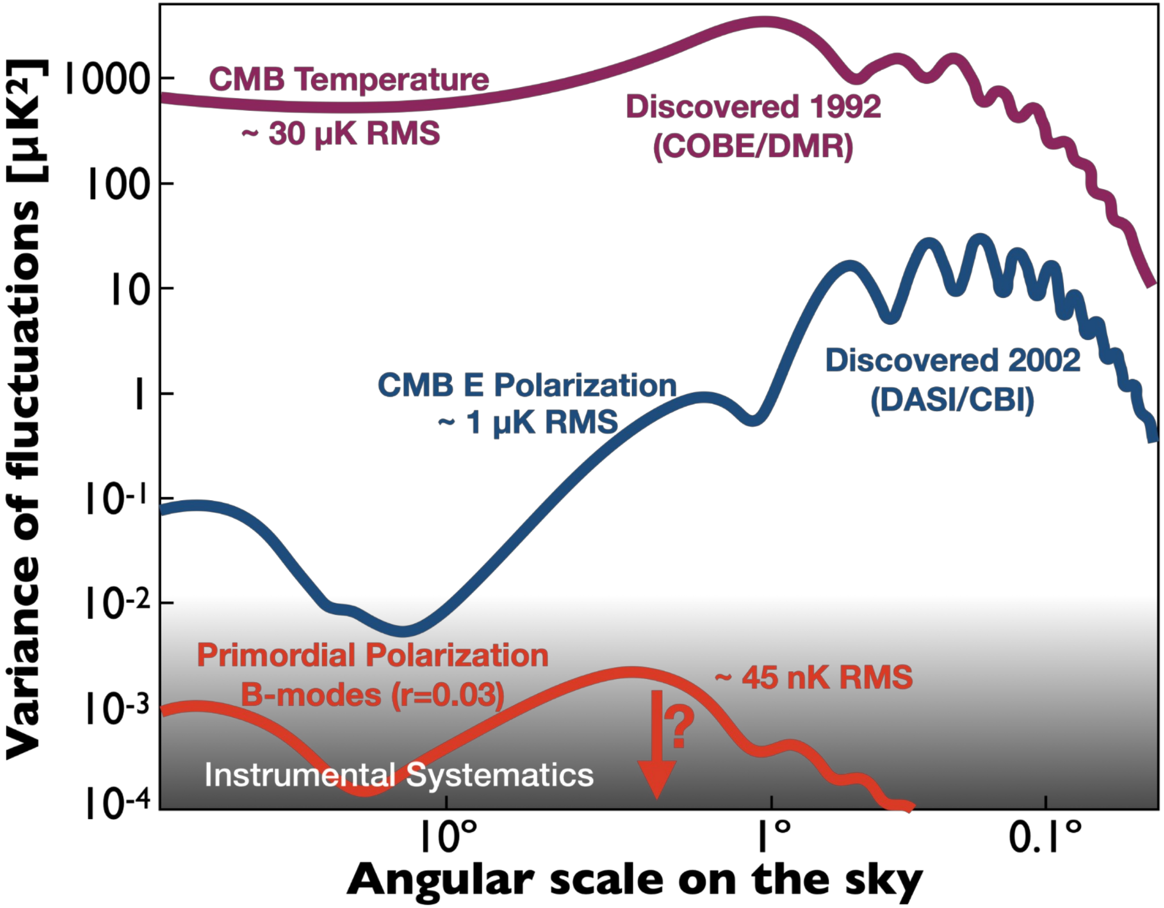
CMB-France #7

Plan

1. Primordial B modes
2. Bolometric interferometry
3. Map reconstruction
4. Current status

Primordial B modes

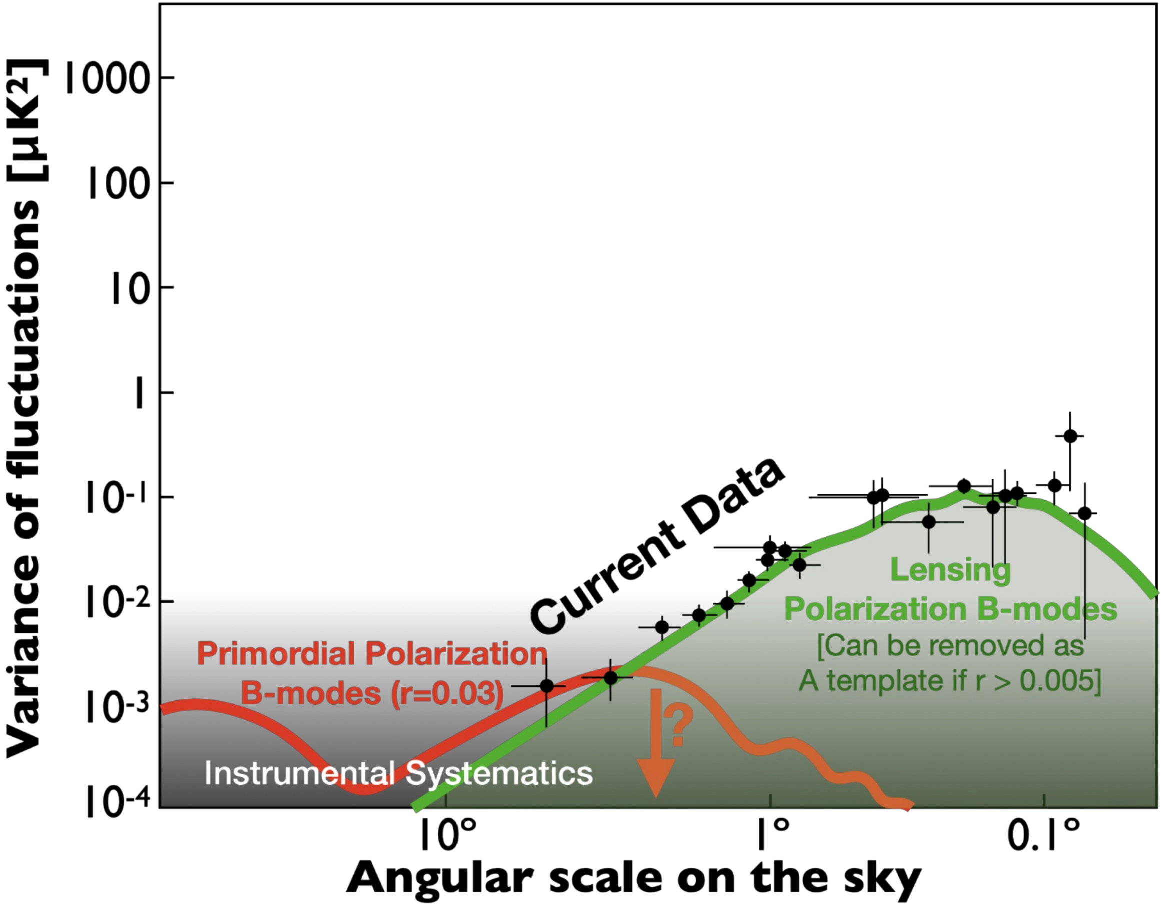
Detect primordial B-modes



Current upper limit for r from BK18 + PR4 : r < 0.032 at 95% C.L.

[Tristram et al., arXiv:2112.07961]

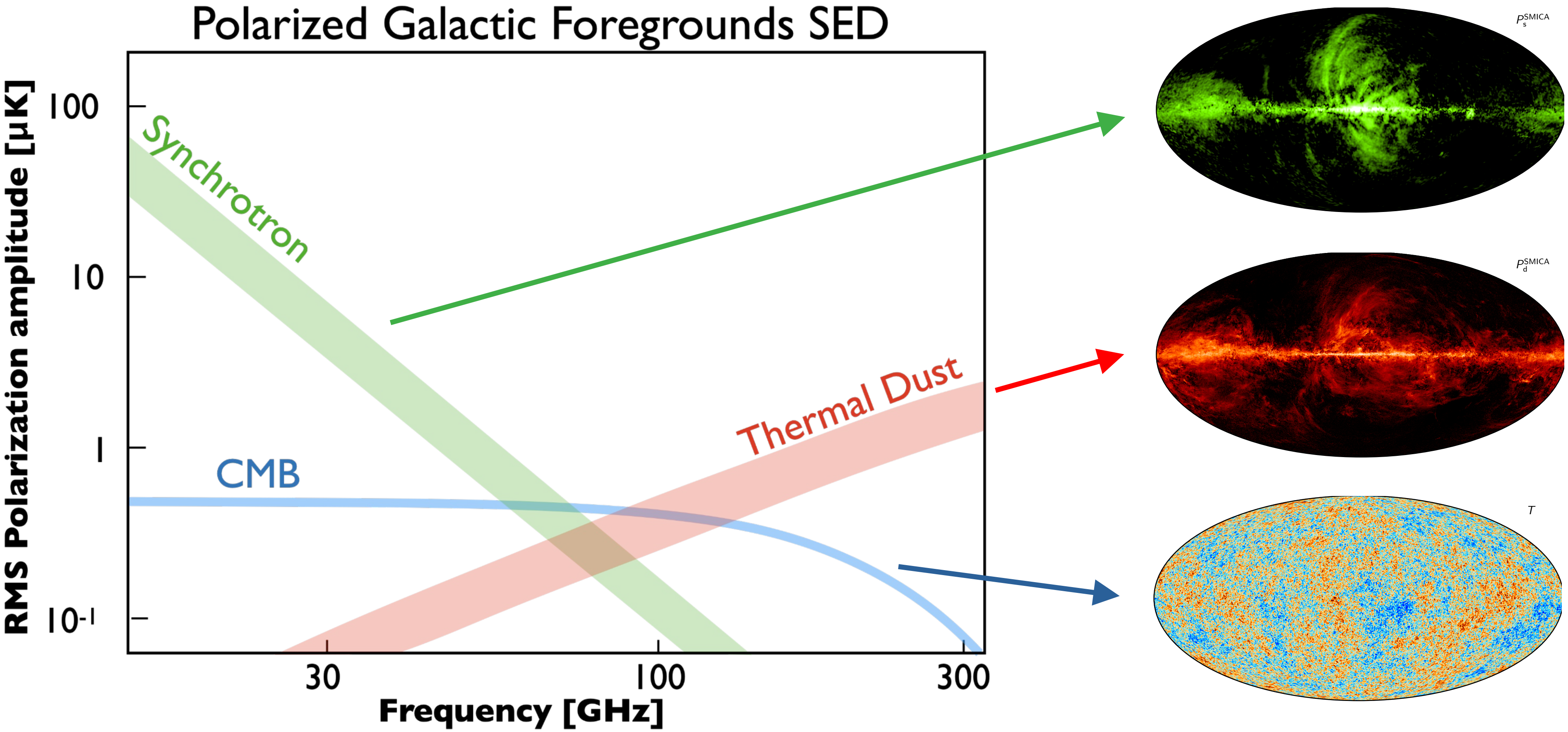
Complex foregrounds: lensing



Current upper limit for r from BK18 + PR4 : r < 0.032 at 95% C.L.

[Tristram et al., arXiv:2112.07961]

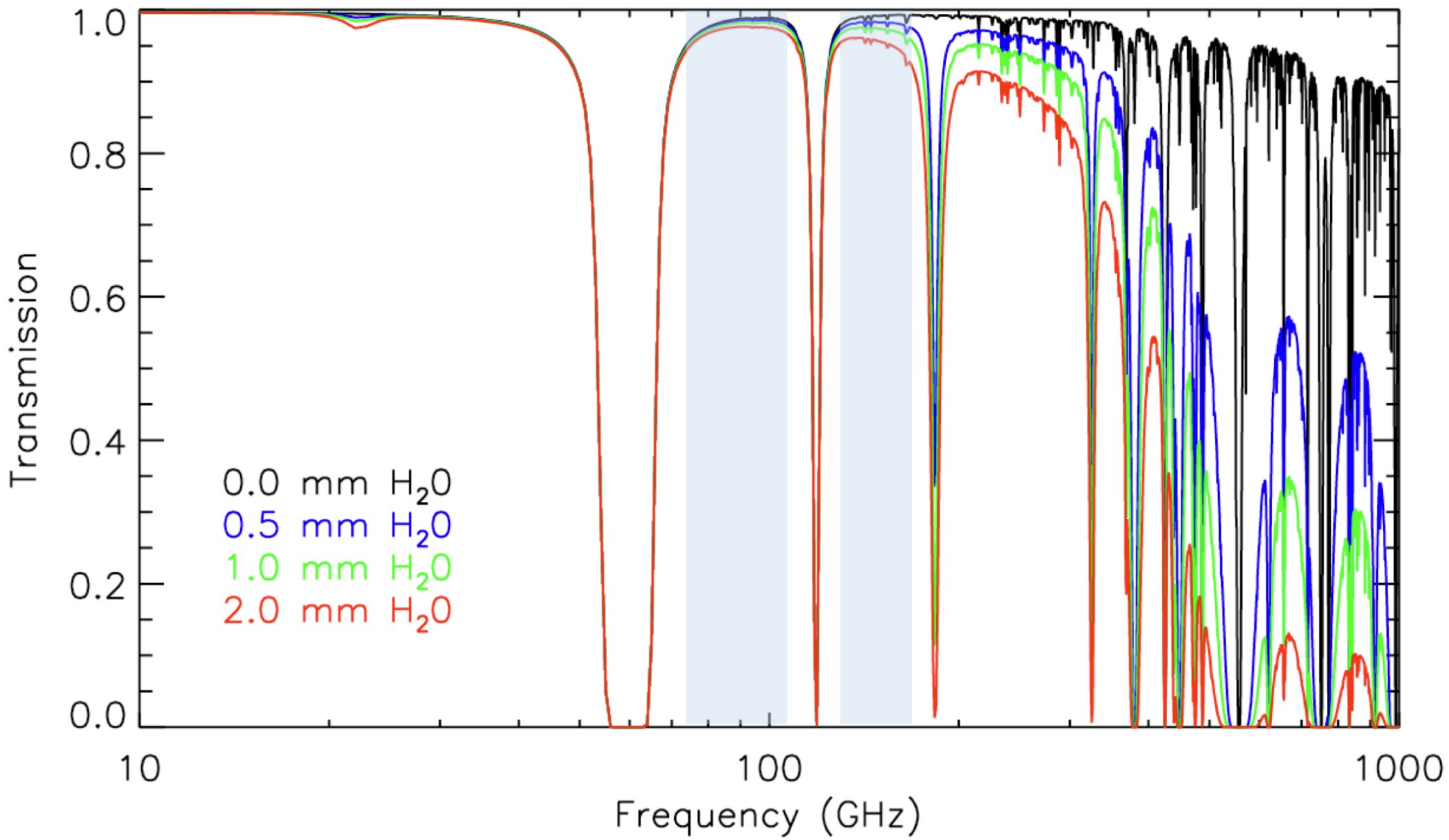
Complex foregrounds: galactic



Complex foregrounds: atmosphere

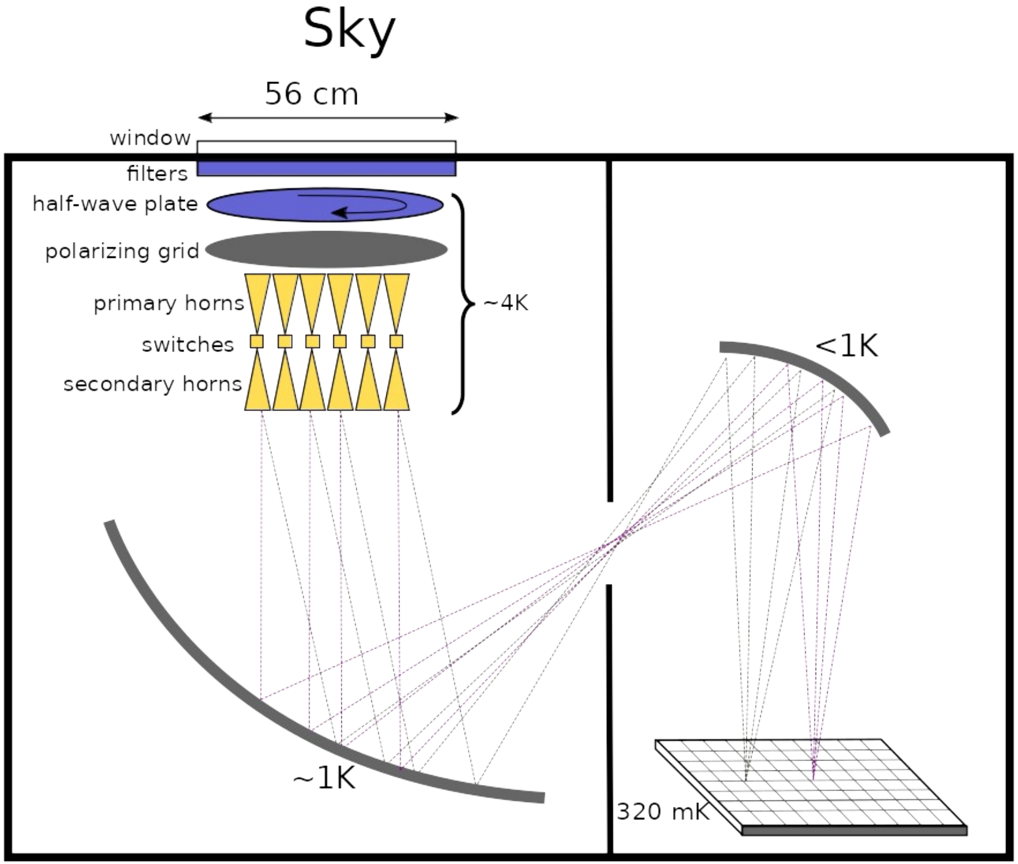
Transmission
+
Emission

→ Time and space variability



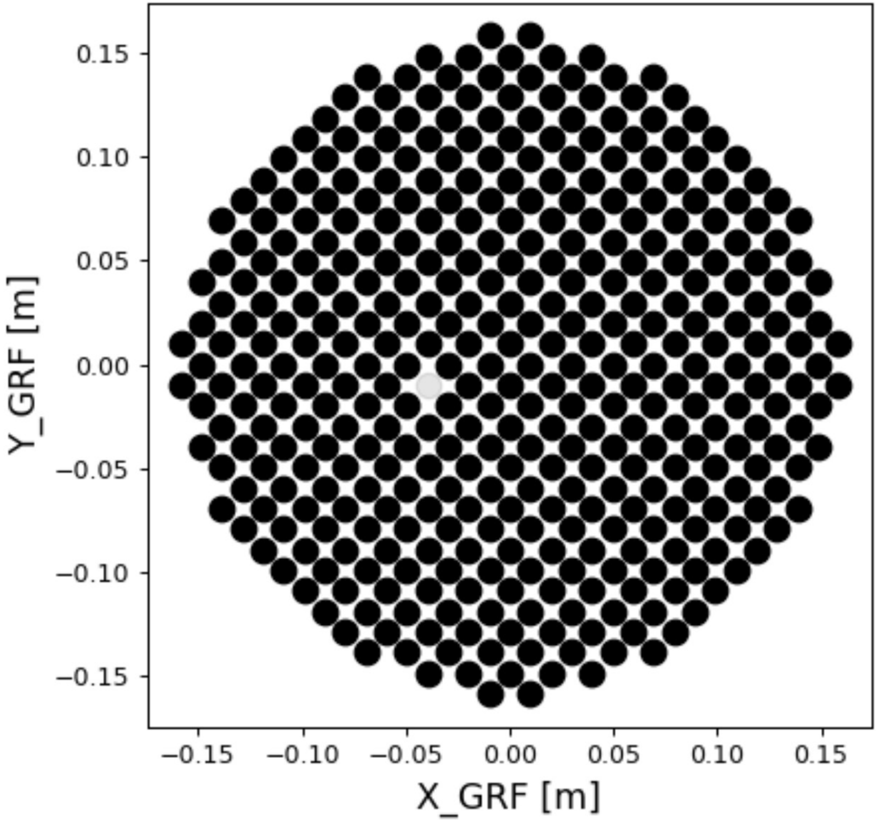
Bolometric interferometry

QUBIC architecture

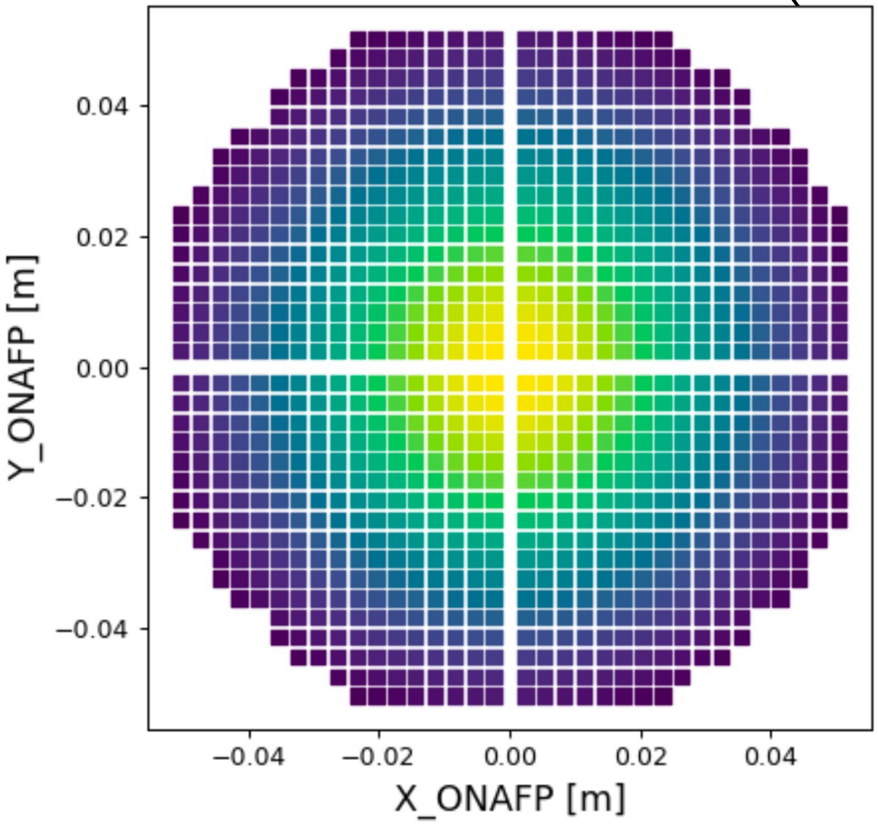


QUBIC synthetized beam

Credit: Louise Mousset's PhD (2021)



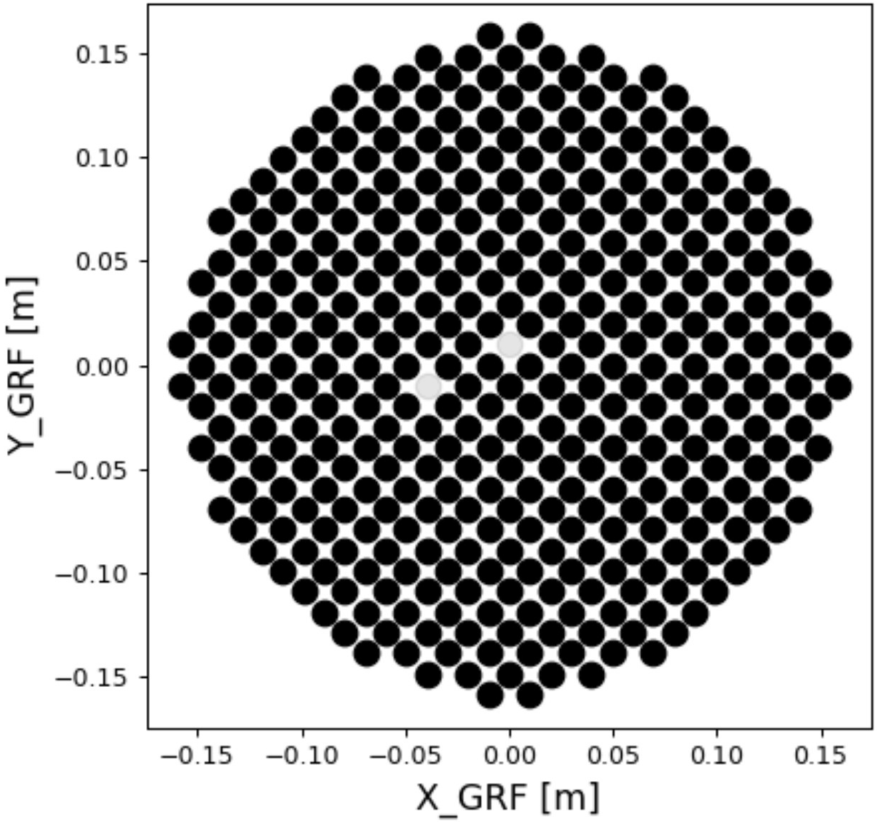
Horn array



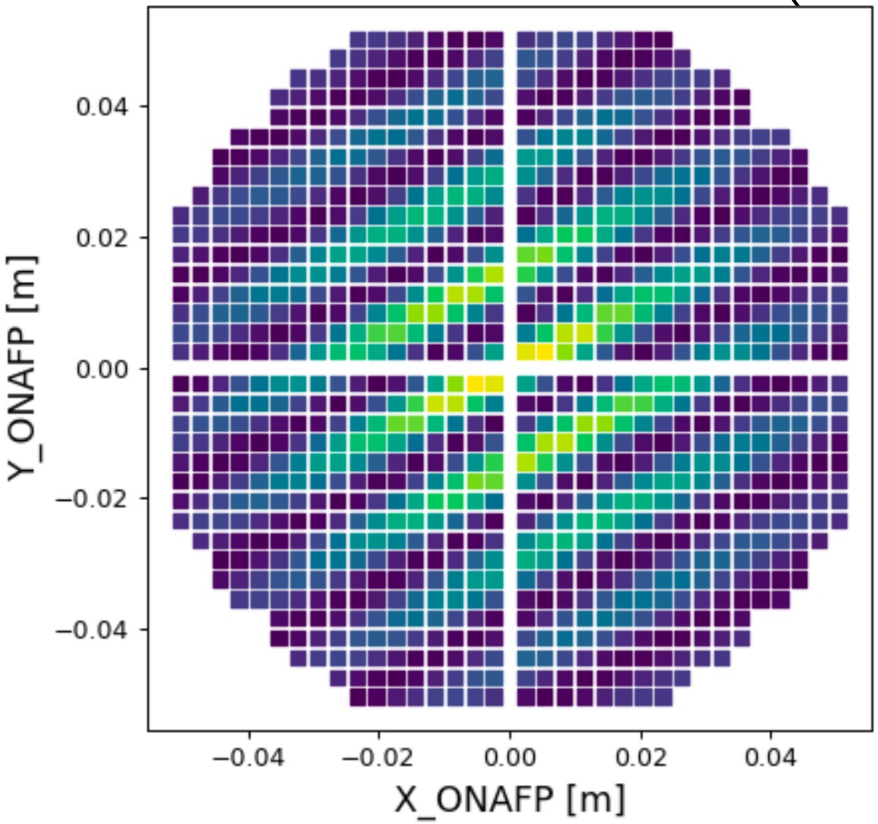
Focal plane (TES)

QUBIC synthetized beam

Credit: Louise Mousset’s PhD (2021)



Horn array



Focal plane (TES)

QUBIC synthetized beam

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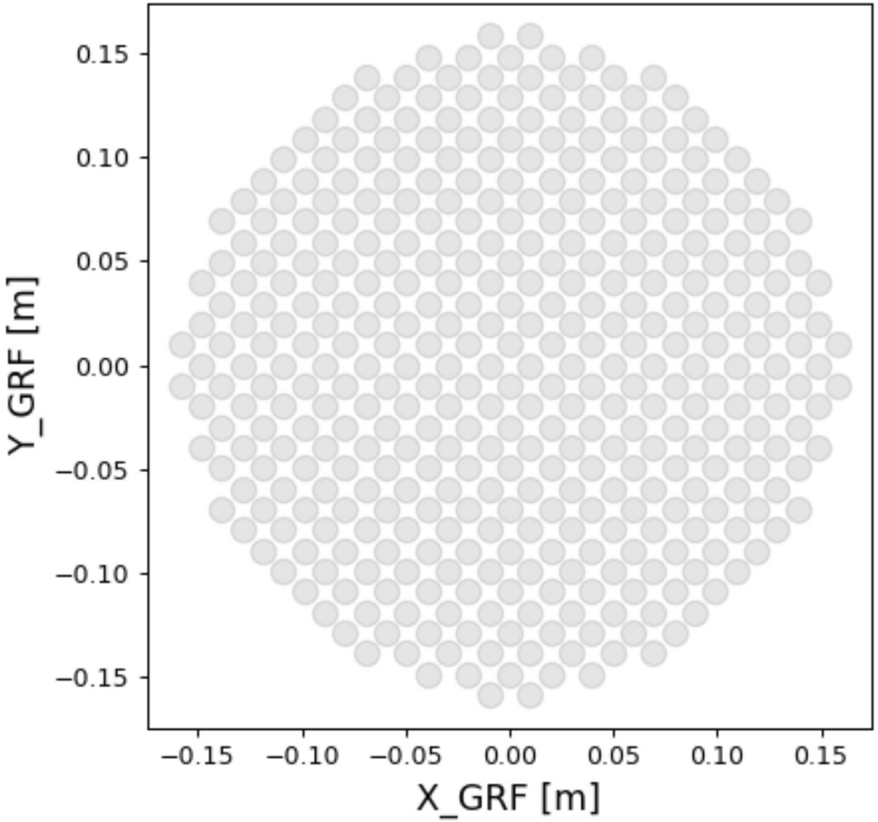
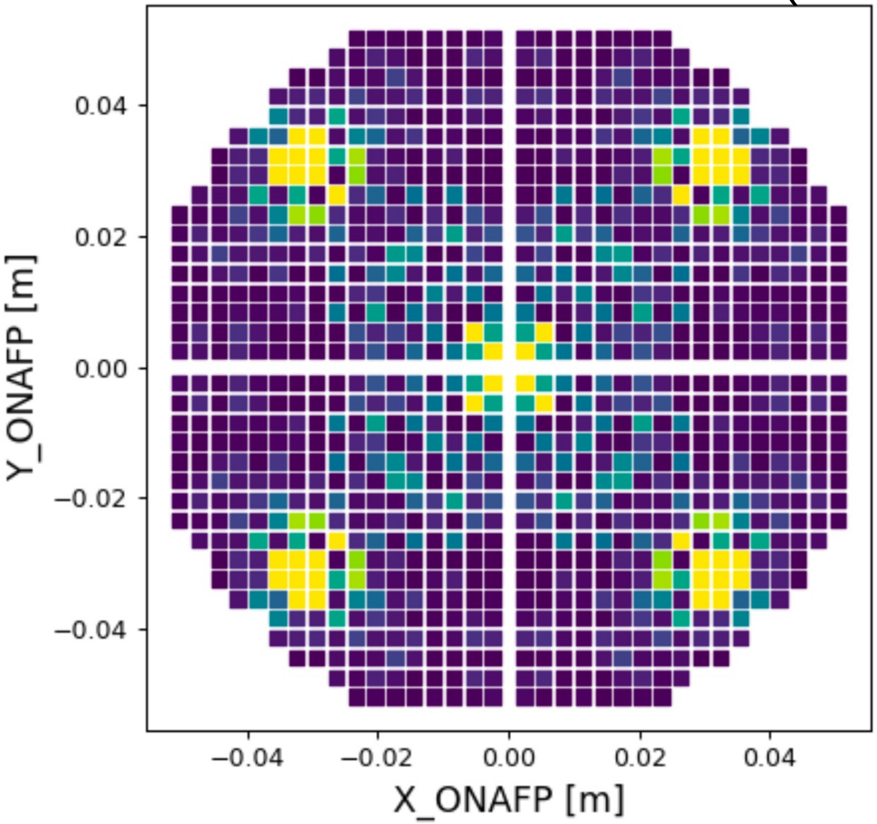
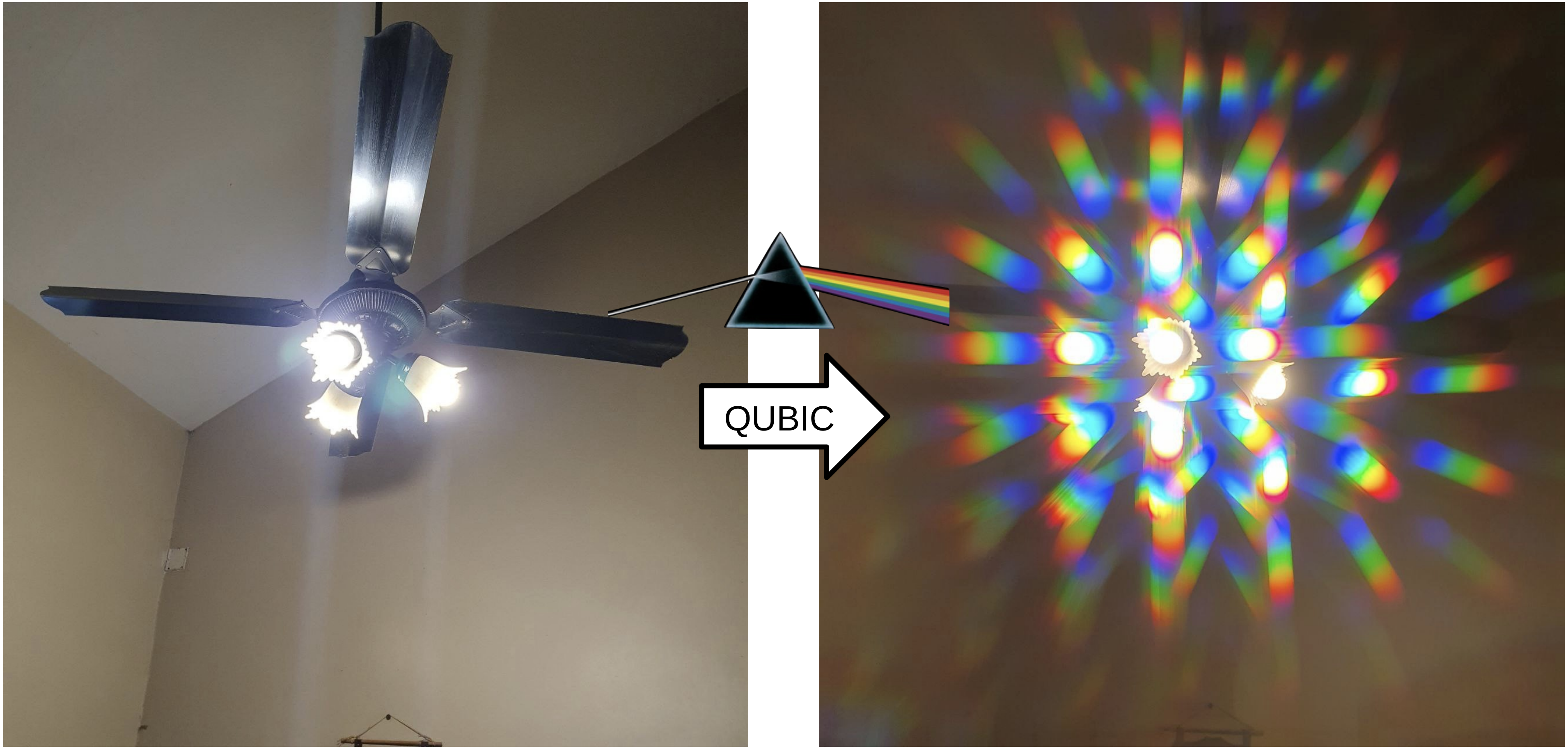


Horn array

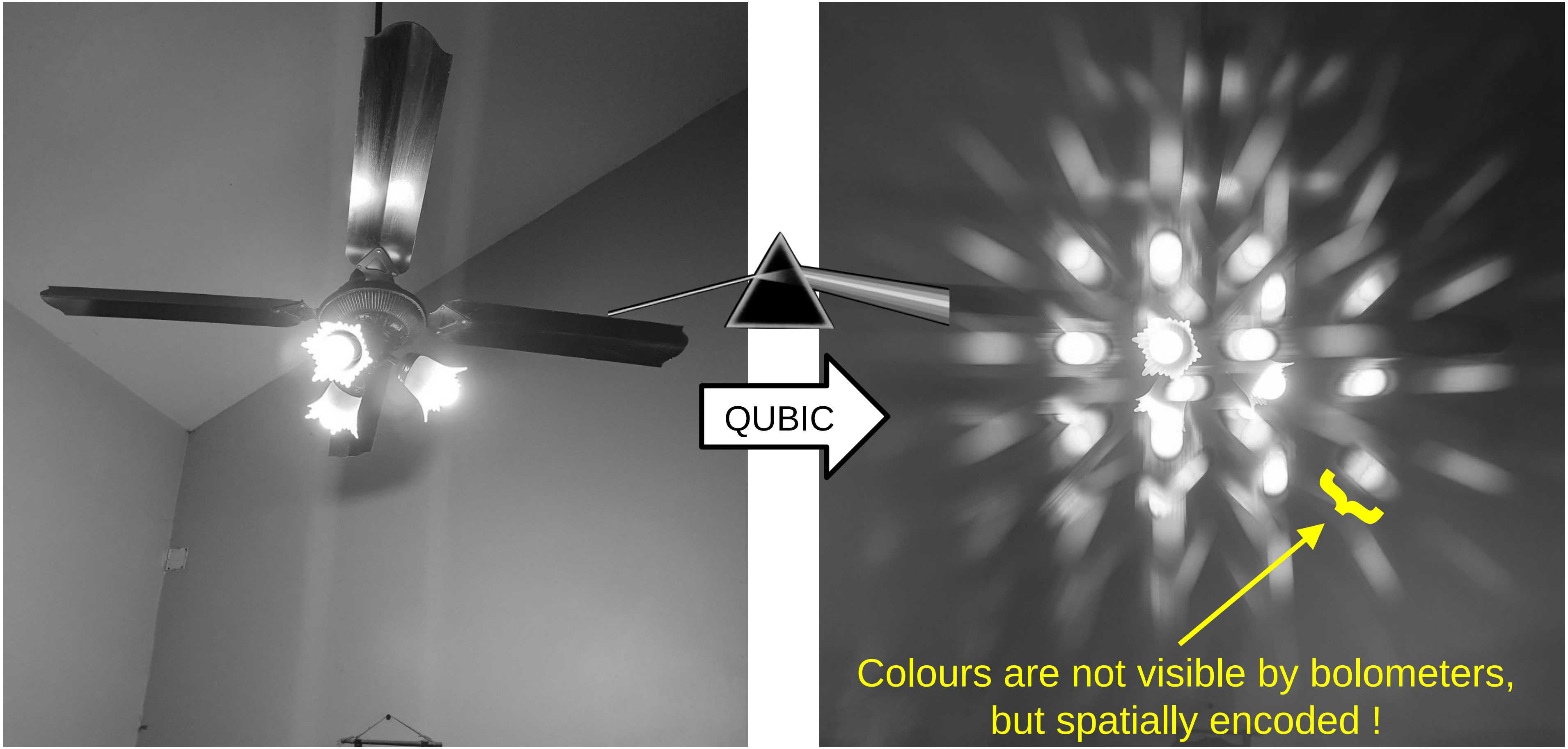


Focal plane (TES)

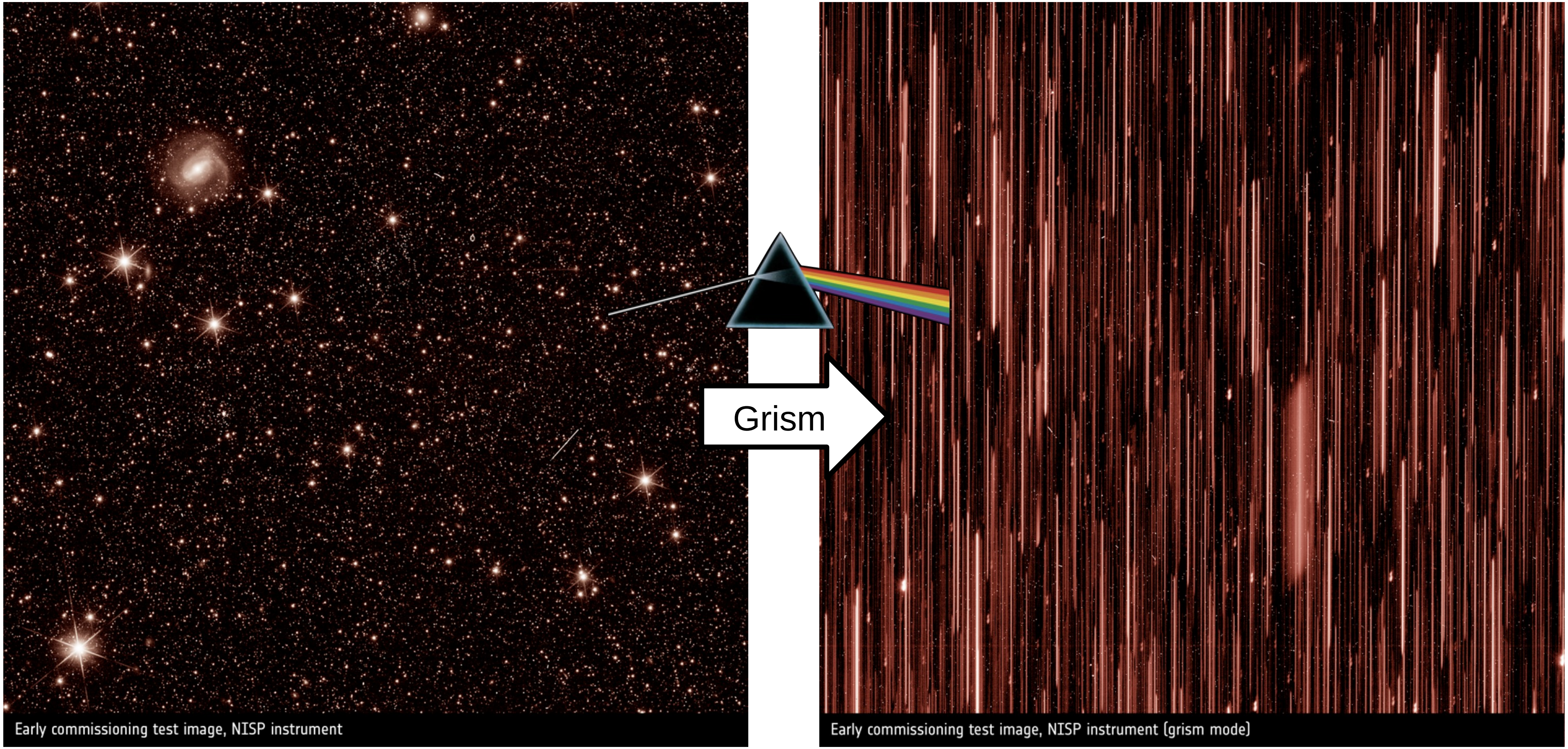
Bolometric interferometry



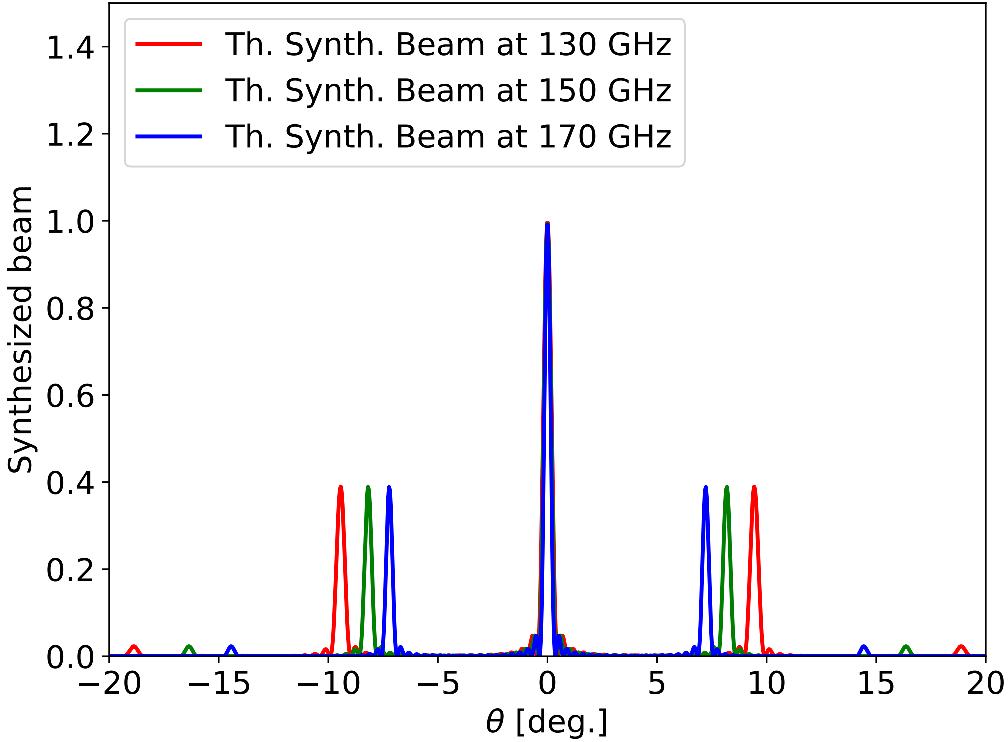
Bolometric interferometry



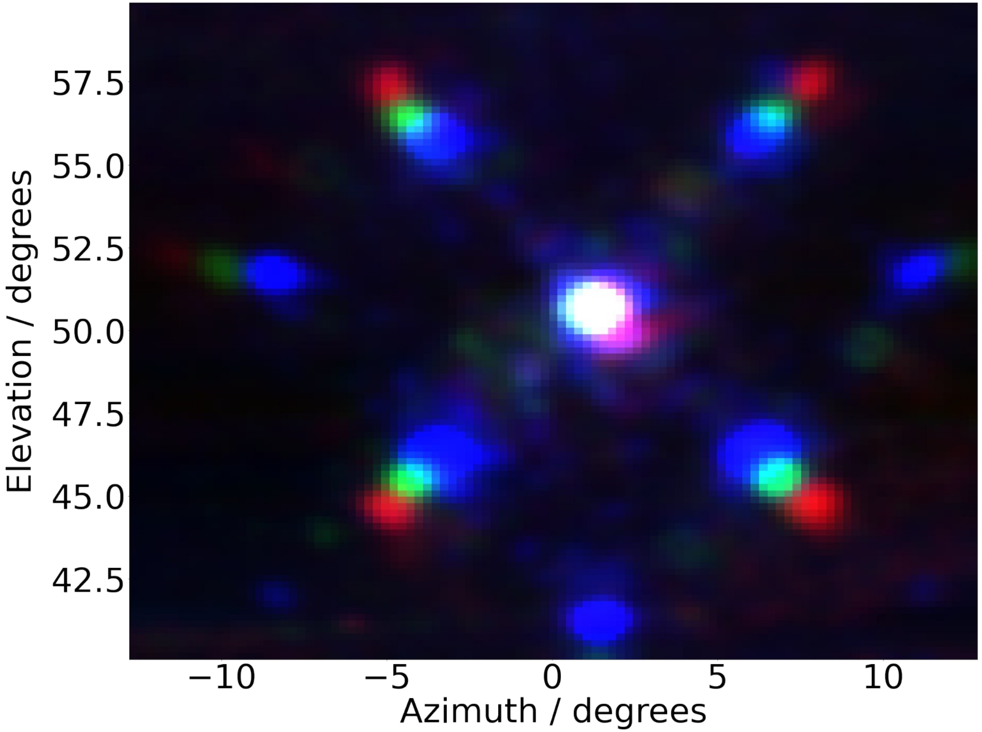
Bolometric interferometry ⟷ Grism



QUBIC beam

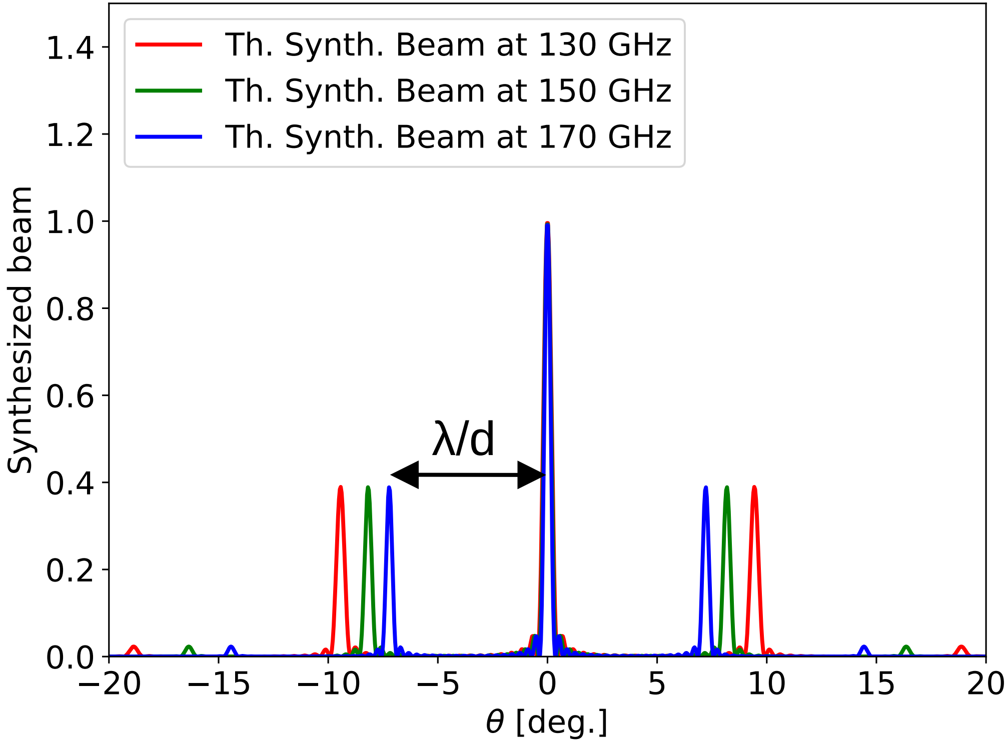


1 dimension, theory

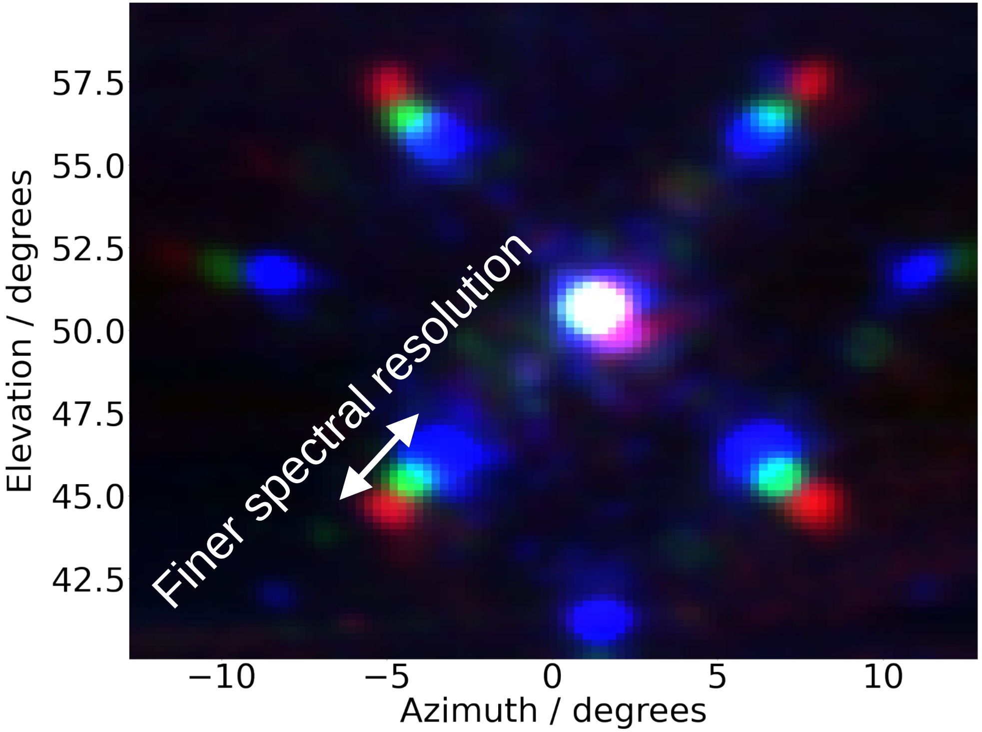


2 dimensions, lab

QUBIC beam

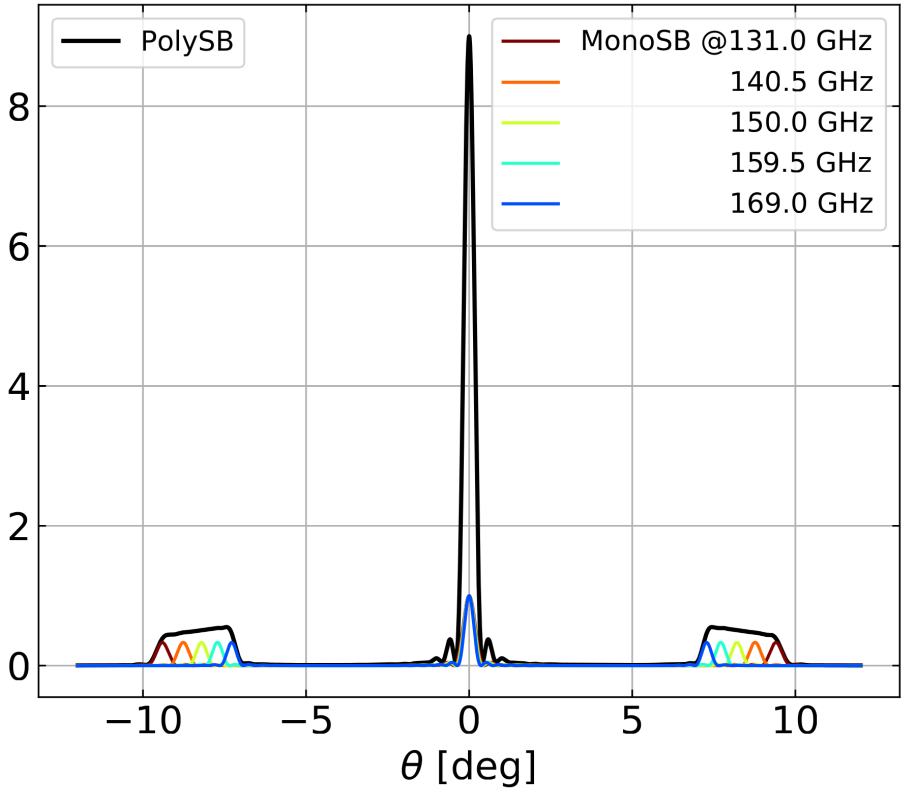


1 dimension, theory

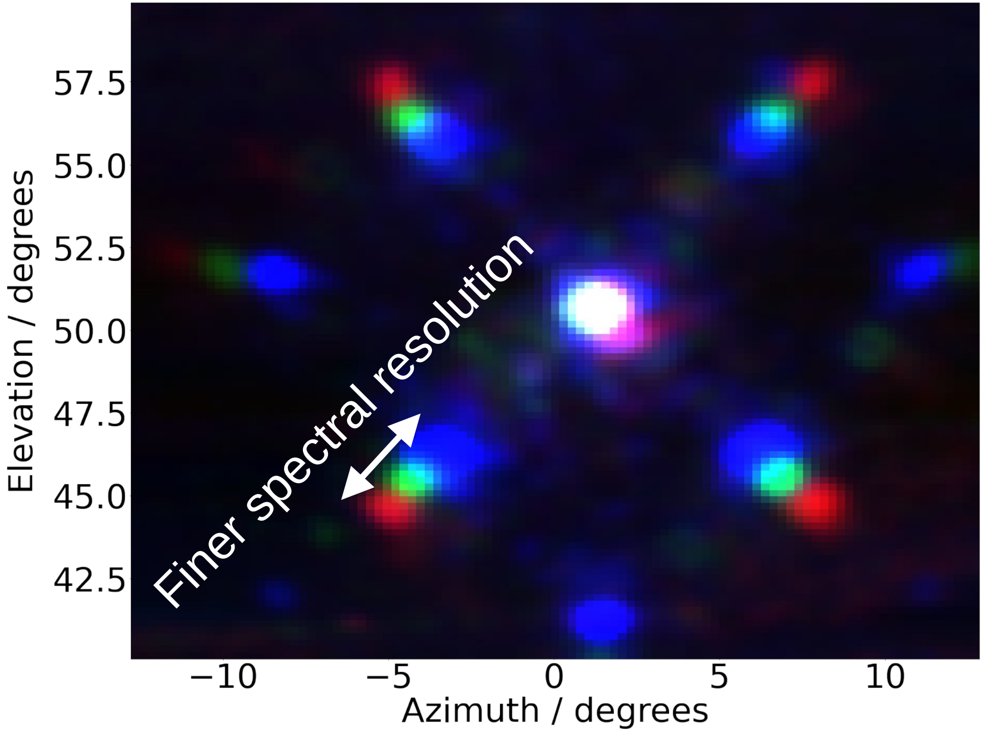


2 dimensions, lab

QUBIC beam

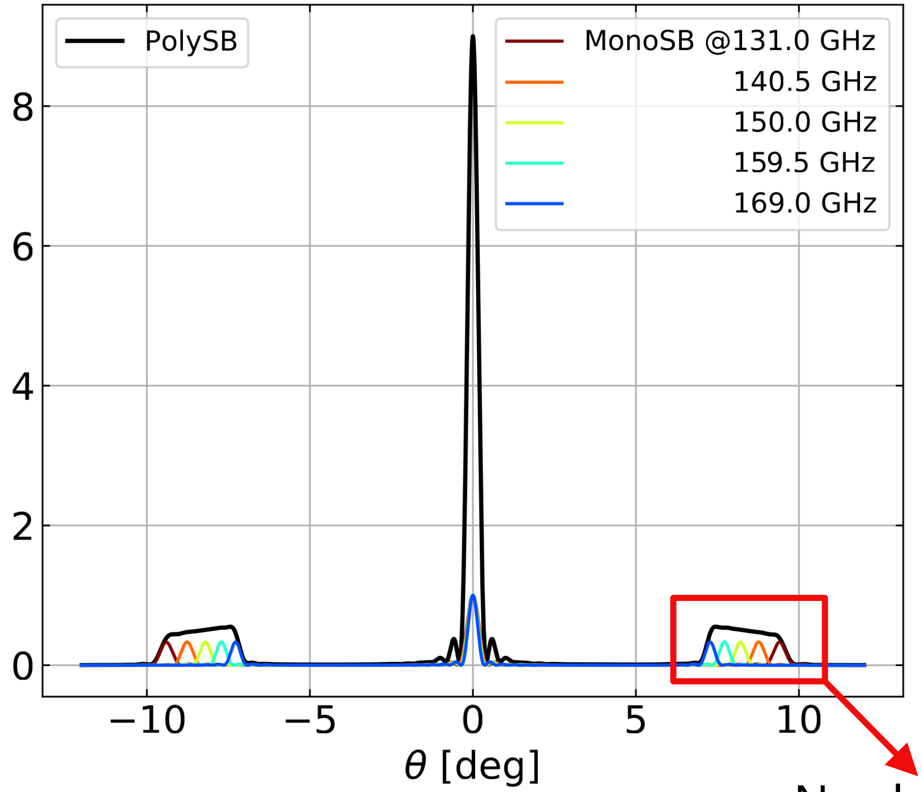


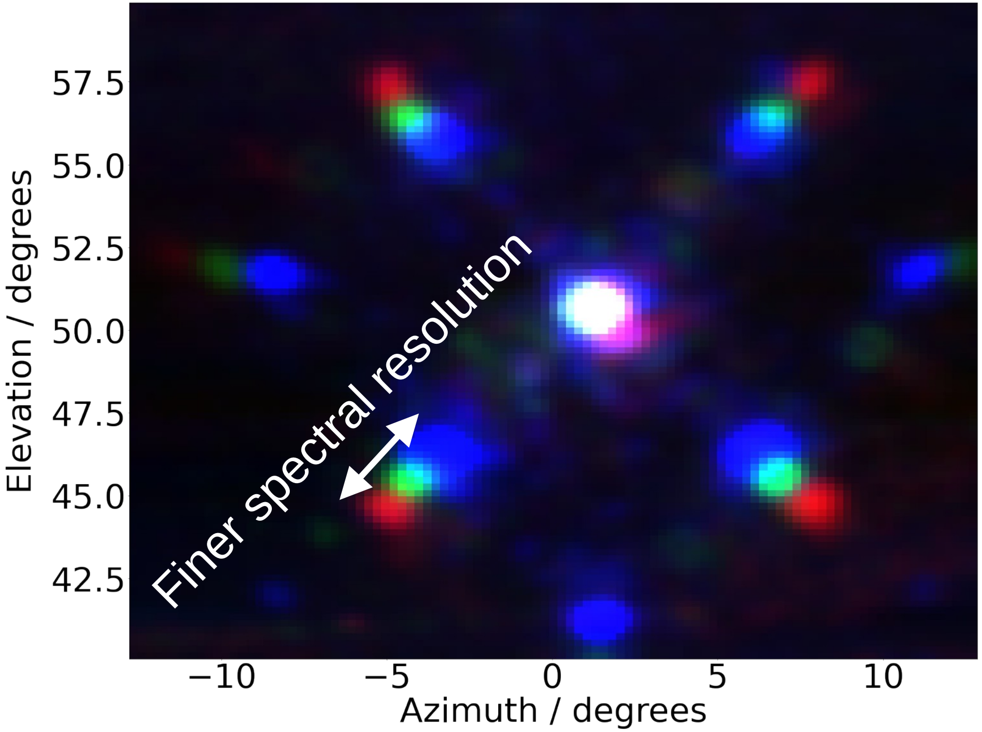
1 dimension, theory



2 dimensions, lab

QUBIC beam



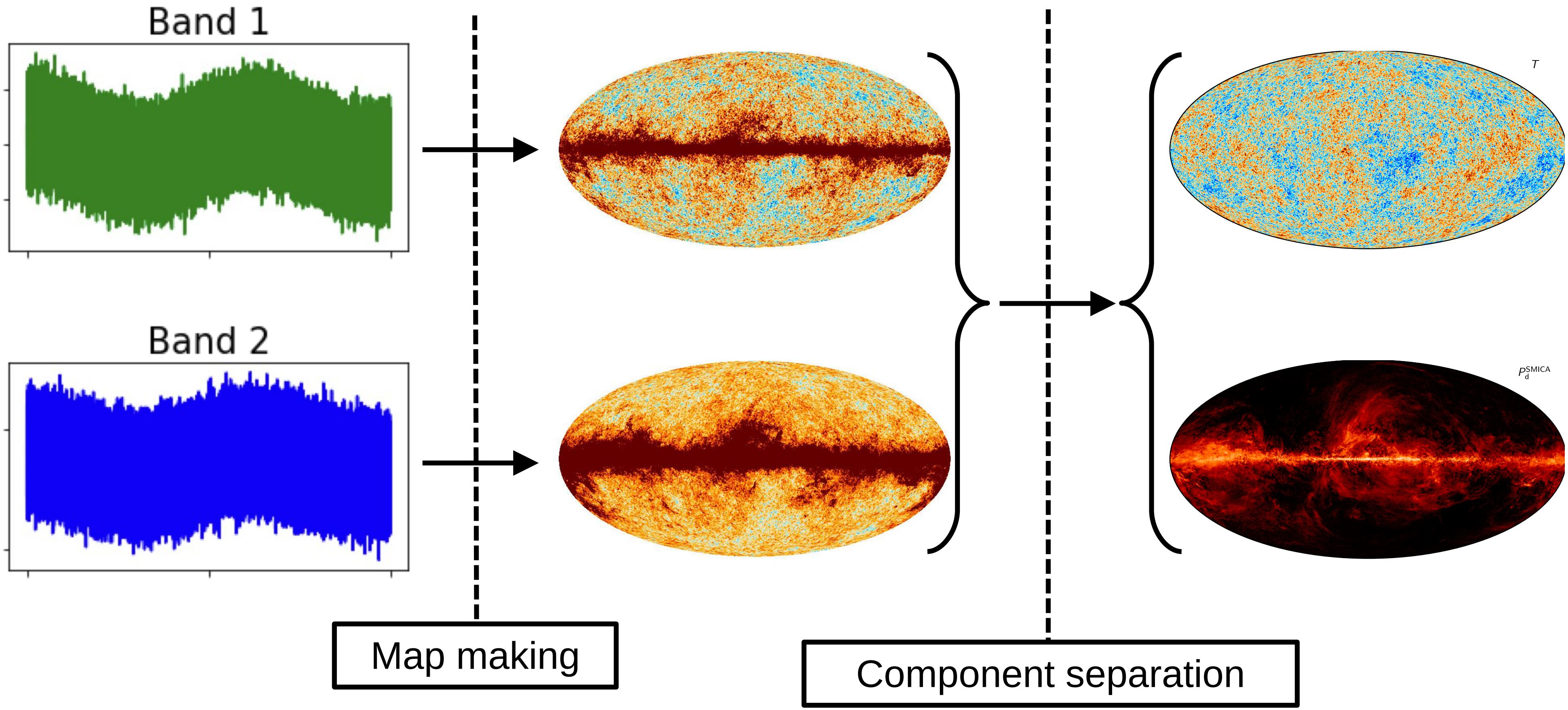


N sub-bands

→ spectral imaging

Map reconstruction

Classical map making



Classical map making

$$\vec{d_i} = H_i \cdot \vec{s_i} + \vec{n_i}$$

Data (TOD)

Instrument model

Sky map

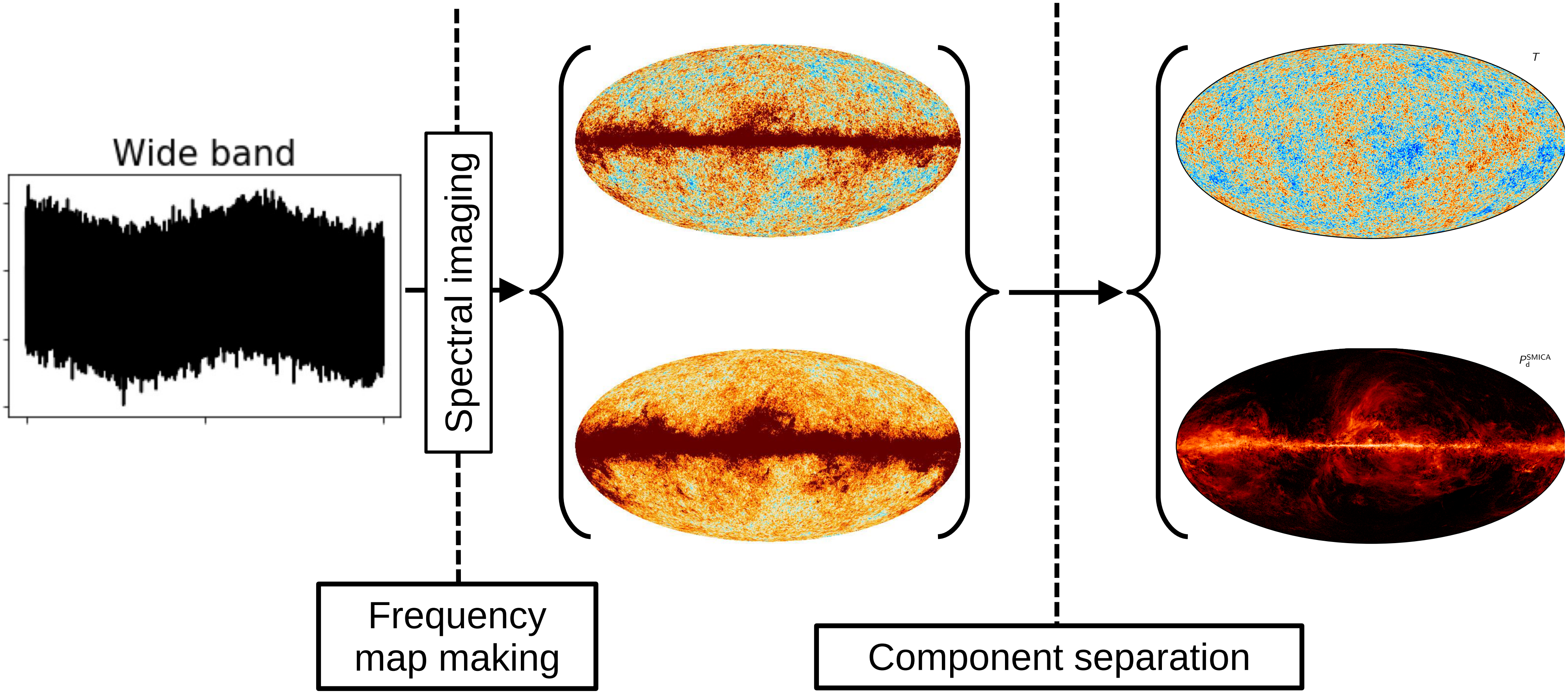
Noise

Classical map making

$$\underset{\text{Data (TOD)}}{\overset{\text{Input}}{\boxed{\vec{d_i}}}} = \underset{\text{Instrument model}}{H_i} \cdot \underset{\text{Sky map}}{\overset{\text{Output}}{\boxed{\vec{s_i}}}} + \underset{\text{Noise}}{\vec{n_i}}$$

Impossible to invert H $\rightarrow$ can use a Preconditioned Conjugate Gradient method (PCG)

Frequency map making



Frequency map making

$$\vec{d} = \sum_{i=1}^{Nsub} \Delta\nu_i H_{\nu_i} \cdot \vec{s_{\nu_i}} + \vec{n}$$

Data

Sub-instrument model

Sky map

Noise

[Chanial, Régnier, et al., arXiv:2409.18698]

Frequency map making

Input

Output

$$\boxed{\vec{d}} = \sum_{i=1}^{Nsub} \Delta\nu_i H_{\nu_i} \cdot \boxed{\vec{s_{\nu_i}}} + \vec{n}$$

Data

Sub-instrument model

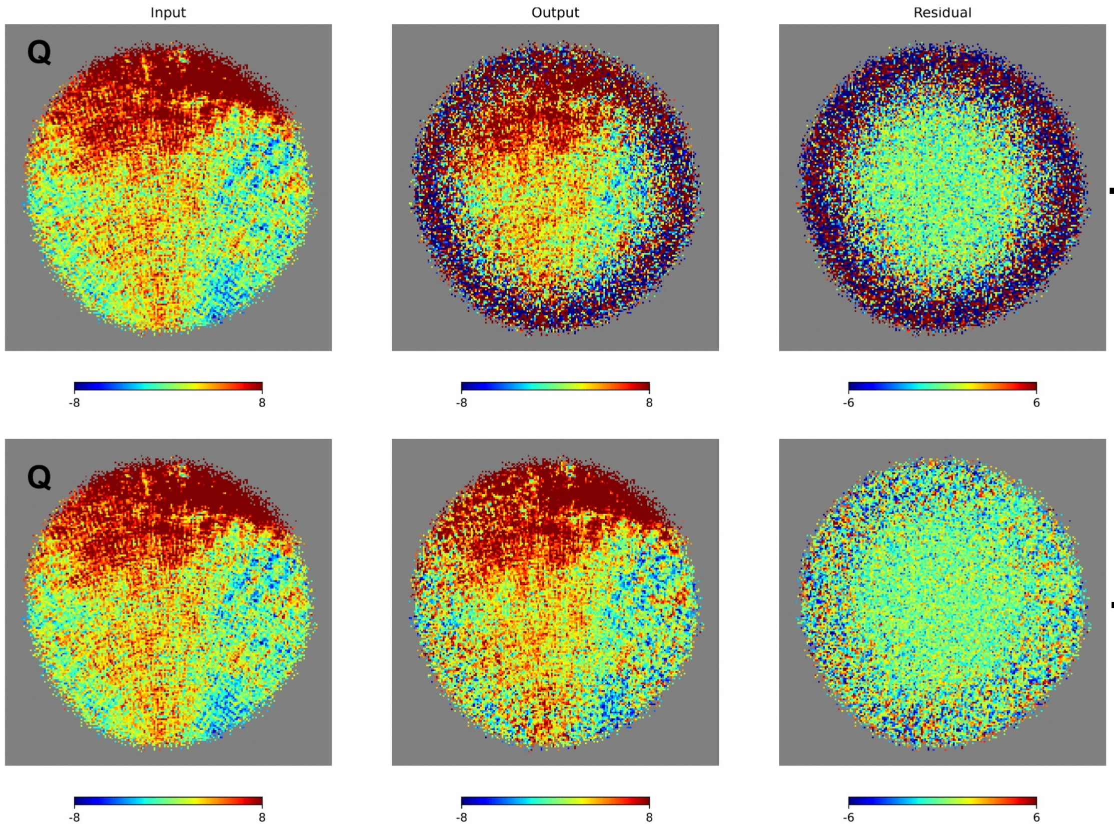
Sky map

Noise

Impossible to invert H $\rightarrow$ can use a Preconditioned Conjugate Gradient method (PCG)

[Chanial, Régnier, et al., arXiv:2409.18698]

Frequency map making

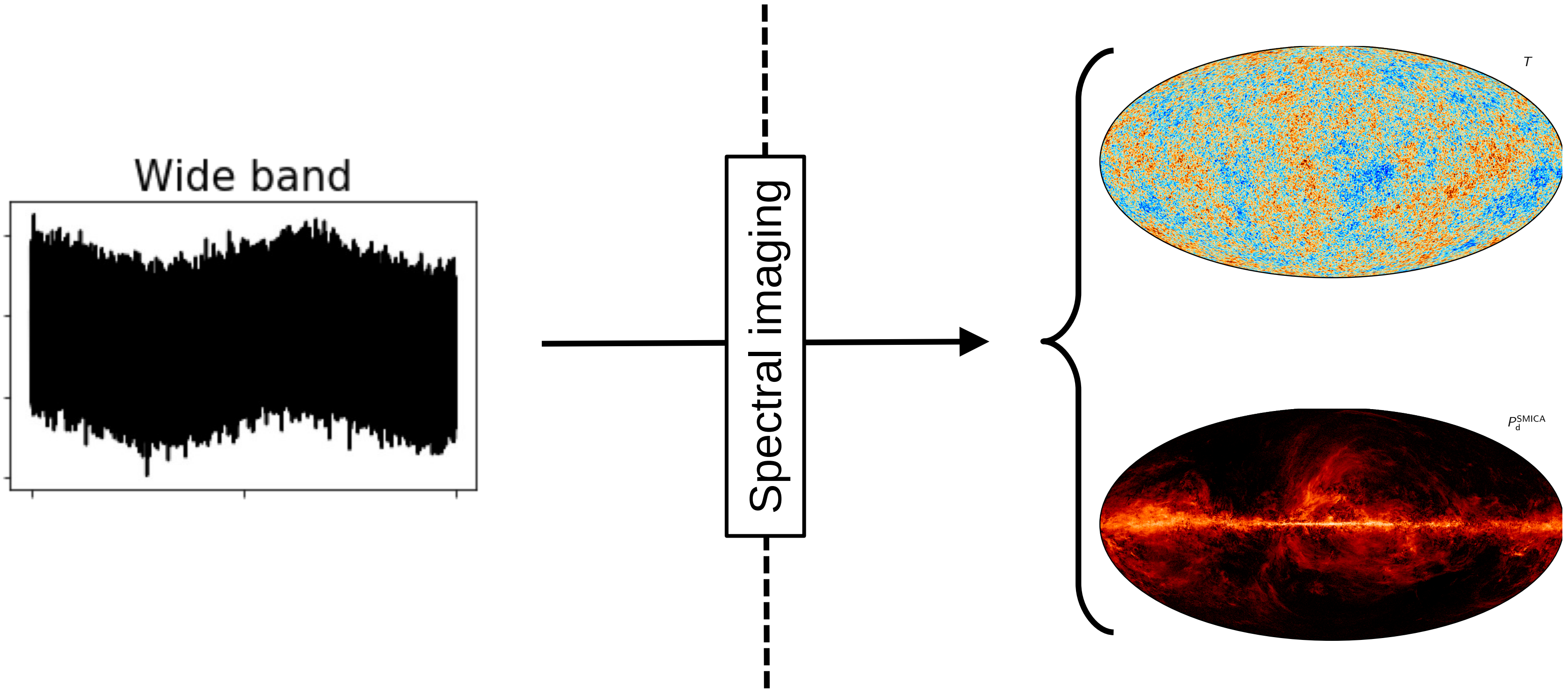


PCG has trouble with edge effect: degeneracy

Adding Planck/HFI helps breaking it

[Chanial, Régnier, et al., arXiv:2409.18698]

Component map making



Component map making

Component map making

$$\vec{d} = \sum_{i=1}^{Nsub} \underbrace{\Delta\nu_i H_{\nu_i}}_{\text{Sub-instrument model}} \cdot \underbrace{A_{\nu_i}}_{\text{Mixing matrix}} \underbrace{\vec{c}}_{\text{Component maps}} + \underbrace{\vec{n}}_{\text{Noise}}$$

Data

Sub-instrument model

Mixing matrix

Component maps

Noise

[Régnier, Laclavère, et al., arXiv:2409.18714]

Component map making

$$\overset{\text{Input}}{\boxed{\vec{d}}} = \sum_{i=1}^{Nsub} \Delta\nu_i H_{\nu_i} \cdot \overset{\text{Byproduct}}{\boxed{A_{\nu_i}}} \overset{\text{Output}}{\boxed{\vec{c}}} + \vec{n}$$

Data

Sub-instrument model

Mixing matrix

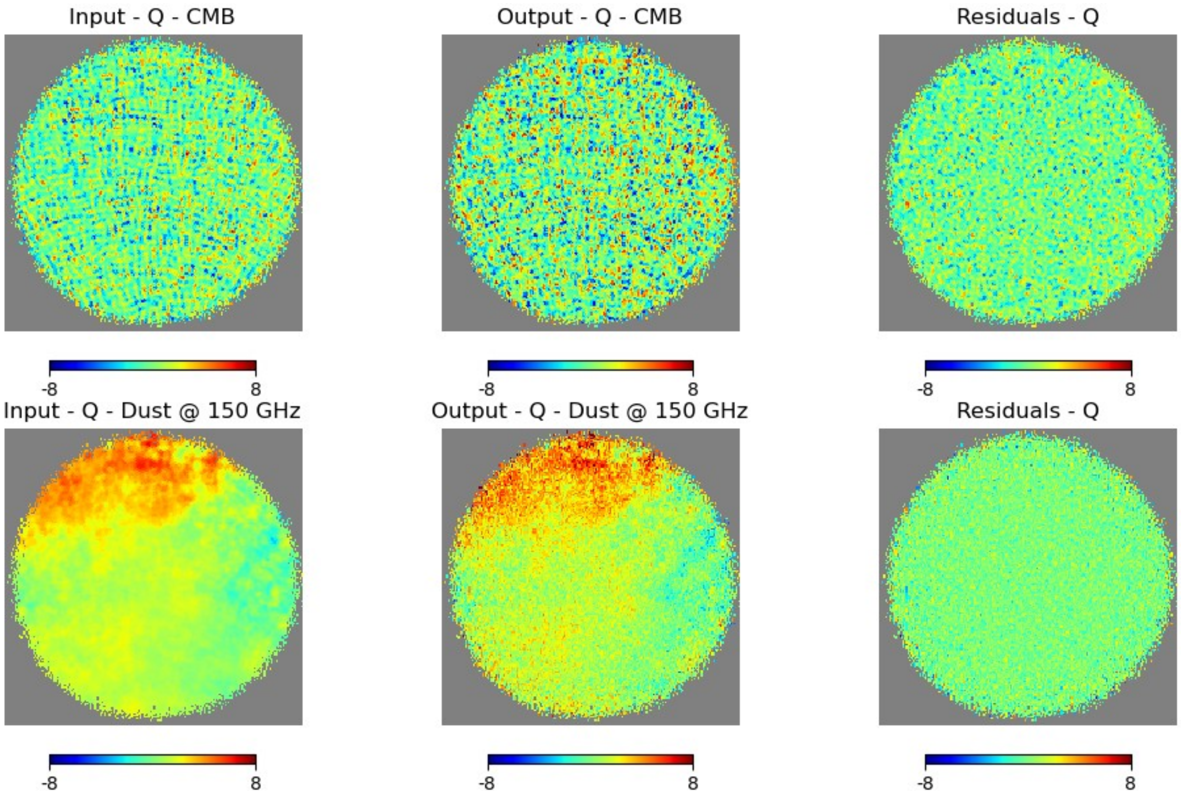
Component maps

Noise

Impossible to invert H $\rightarrow$ can use a Preconditioned Conjugate Gradient method (PCG)

[Régnier, Laclavère, et al., arXiv:2409.18714]

Component map making



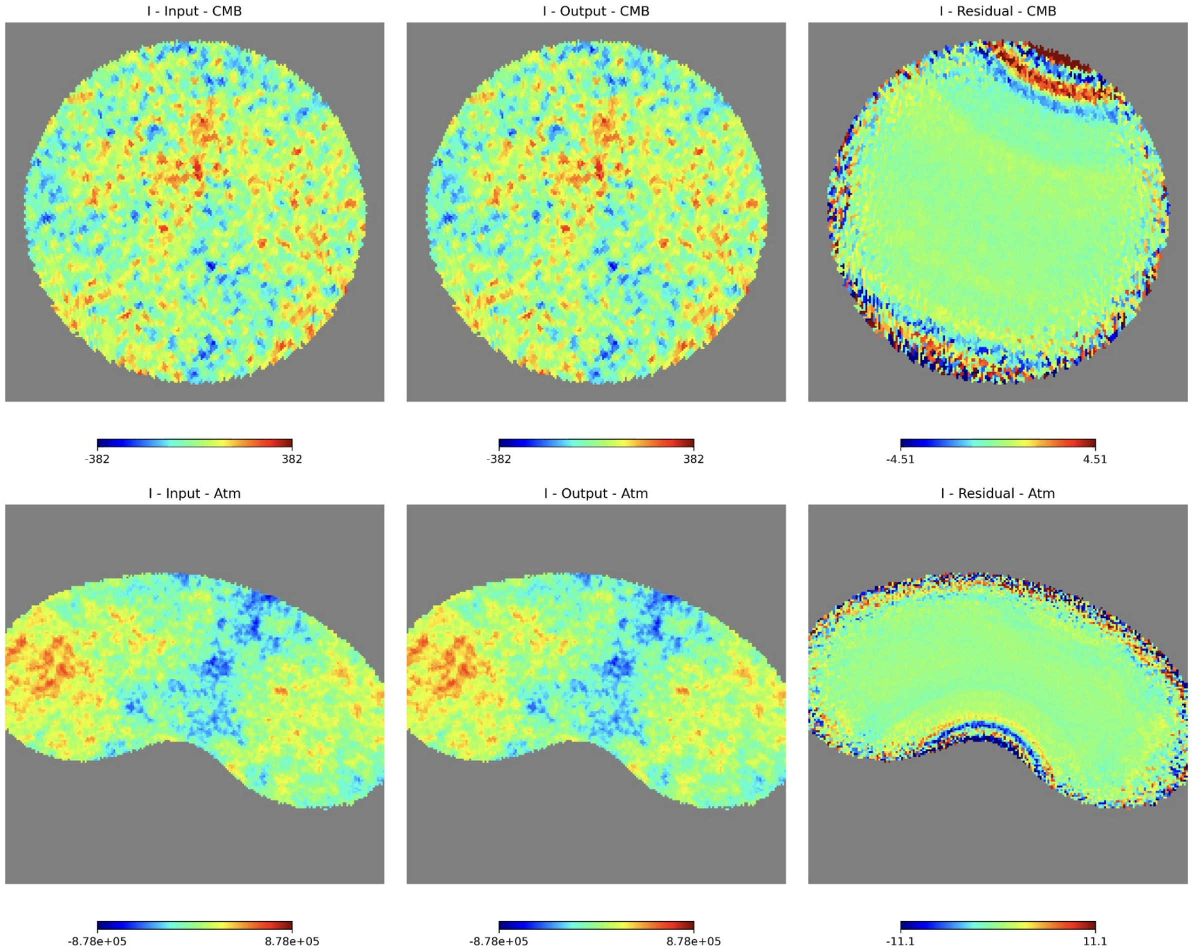
Planck HFI was added to mitigate the edge effect

[Régnier, Laclavère, et al., arXiv:2409.18714]

Map-making at APC

Atmosphere as component

Simple modelling:
- no noise
- no wind
- 2D atmosphere



I CMB

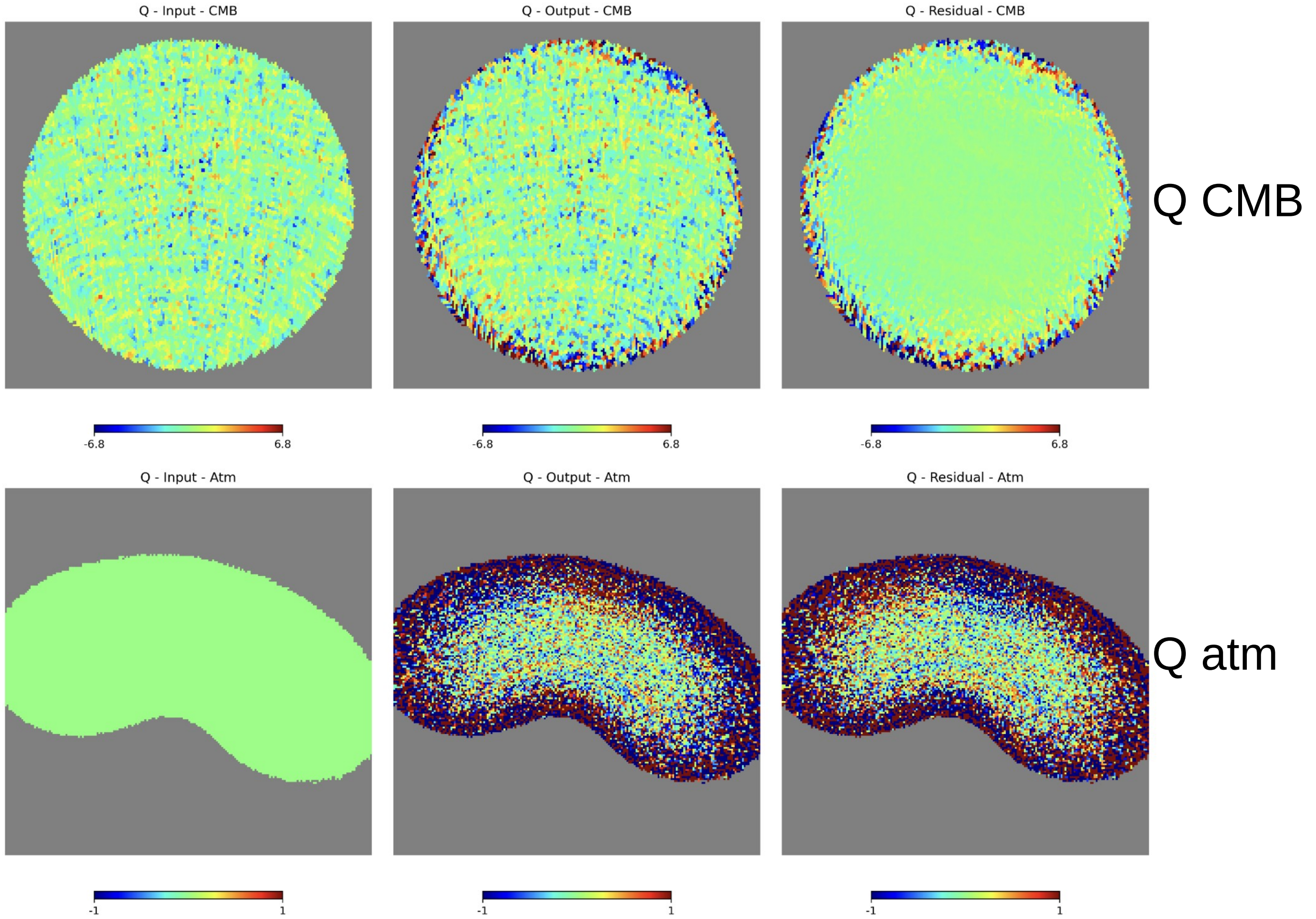
I atm

Tom Laclavère, PhD (APC)

Atmosphere as component

Simple modelling:

- no noise
- no wind
- 2D atmosphere



Tom Laclavère, PhD (APC)

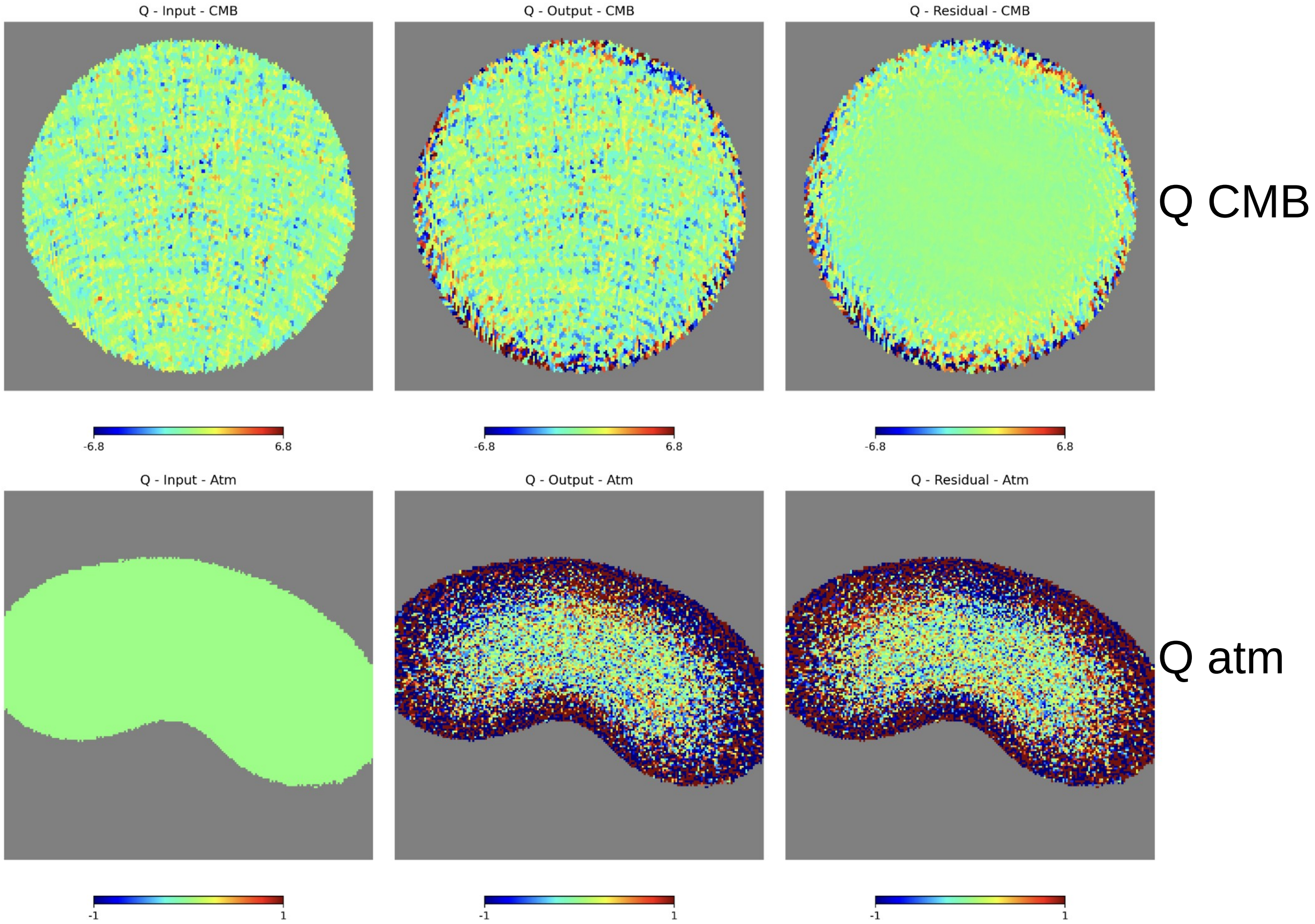
Atmosphere as component

Simple modelling:

- no noise
- no wind
- 2D atmosphere

Information to add:

- Planck
- Atmosphere is not polarised



Tom Laclavère, PhD (APC)

Physics-guided Machine Learning

Input

Output

$$\boxed{\vec{d_i}} = H_i \cdot \boxed{\vec{s_i}} + \vec{n_i}$$

Data (TOD)

Instrument model

Sky map

Noise

Approximate an invert of H with Machine Learning

Leonora Kardum, postdoc (APC)

Physics-guided Machine Learning

$$H = \underbrace{B \cdot I \cdot D \cdot L \cdot Hw \cdot P \cdot F \cdot A \cdot T \cdot U}^{\text{All steps between sky and TOD}}$$

Leonora Kardum, postdoc (APC)

Physics-guided Machine Learning

$$H = \underbrace{B \cdot I \cdot D \cdot L \cdot Hw \cdot P \cdot F \cdot A \cdot T \cdot U}^{\text{All steps between sky and TOD}}$$

$$\tilde{H}^{-1} = U^{-1} \cdot T^{-1} \cdot A^{-1} \cdot F^{-1} \cdot P^{-1} \cdot Hw^{-1} \cdot L^{-1} \cdot D^{-1} \cdot I^{-1} \cdot B^{-1}$$

Leonora Kardum, postdoc (APC)

Physics-guided Machine Learning

$$H = \overbrace{B \cdot I \cdot D \cdot L \cdot Hw \cdot P \cdot F \cdot A \cdot T \cdot U}^{\text{All steps between sky and TOD}}$$

$$\tilde{H}^{-1} = U^{-1} \cdot T^{-1} \cdot A^{-1} \cdot F^{-1} \cdot P^{-1} \cdot Hw^{-1} \cdot L^{-1} \cdot D^{-1} \cdot I^{-1} \cdot B^{-1}$$

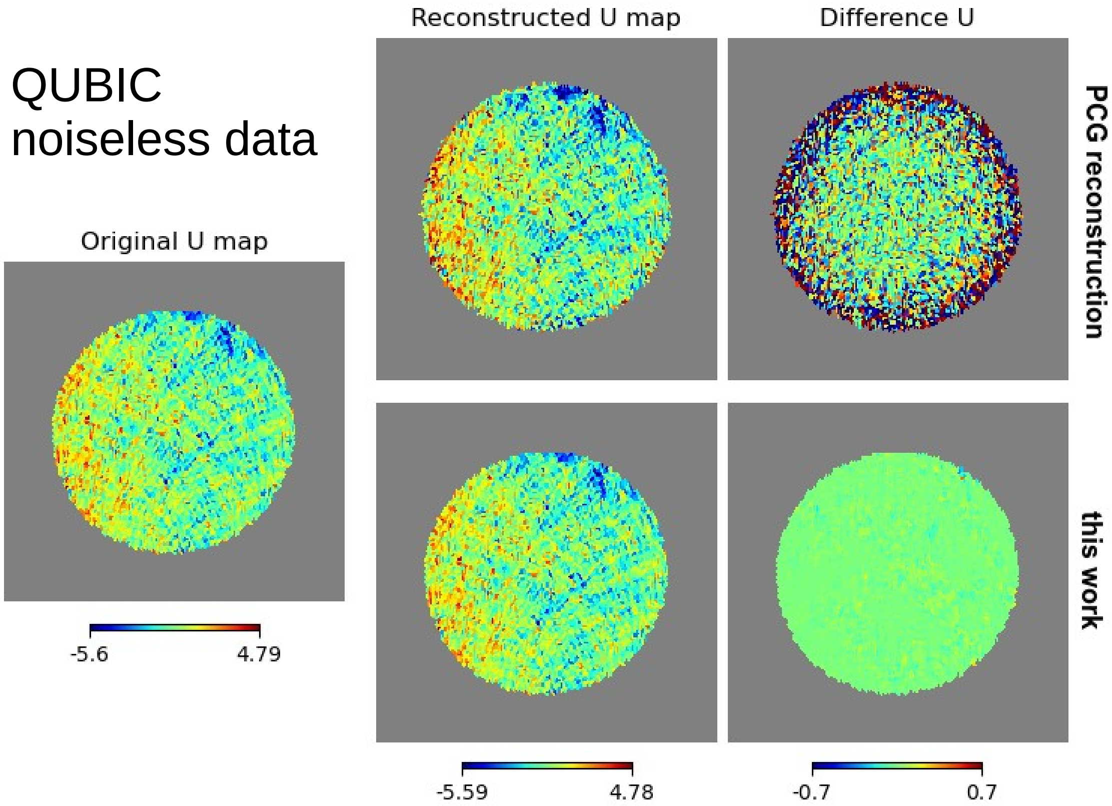
Limit free parameters based on the physics of each sub-system

→ Result is modular and interpretable

Leonora Kardum, postdoc (APC)

Physics-guided Machine Learning

QUBIC
noiseless data



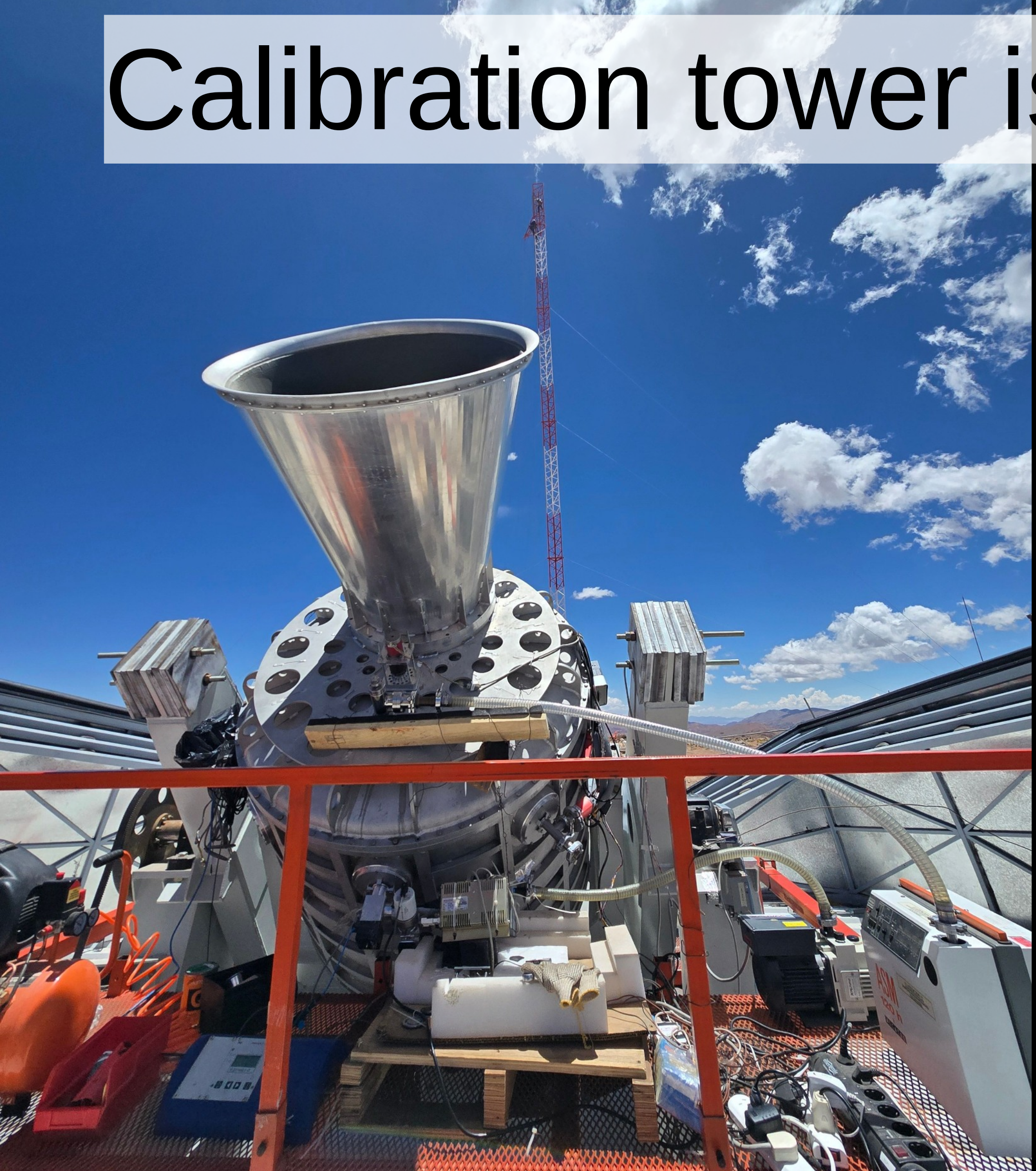
PCG has trouble with edge effect

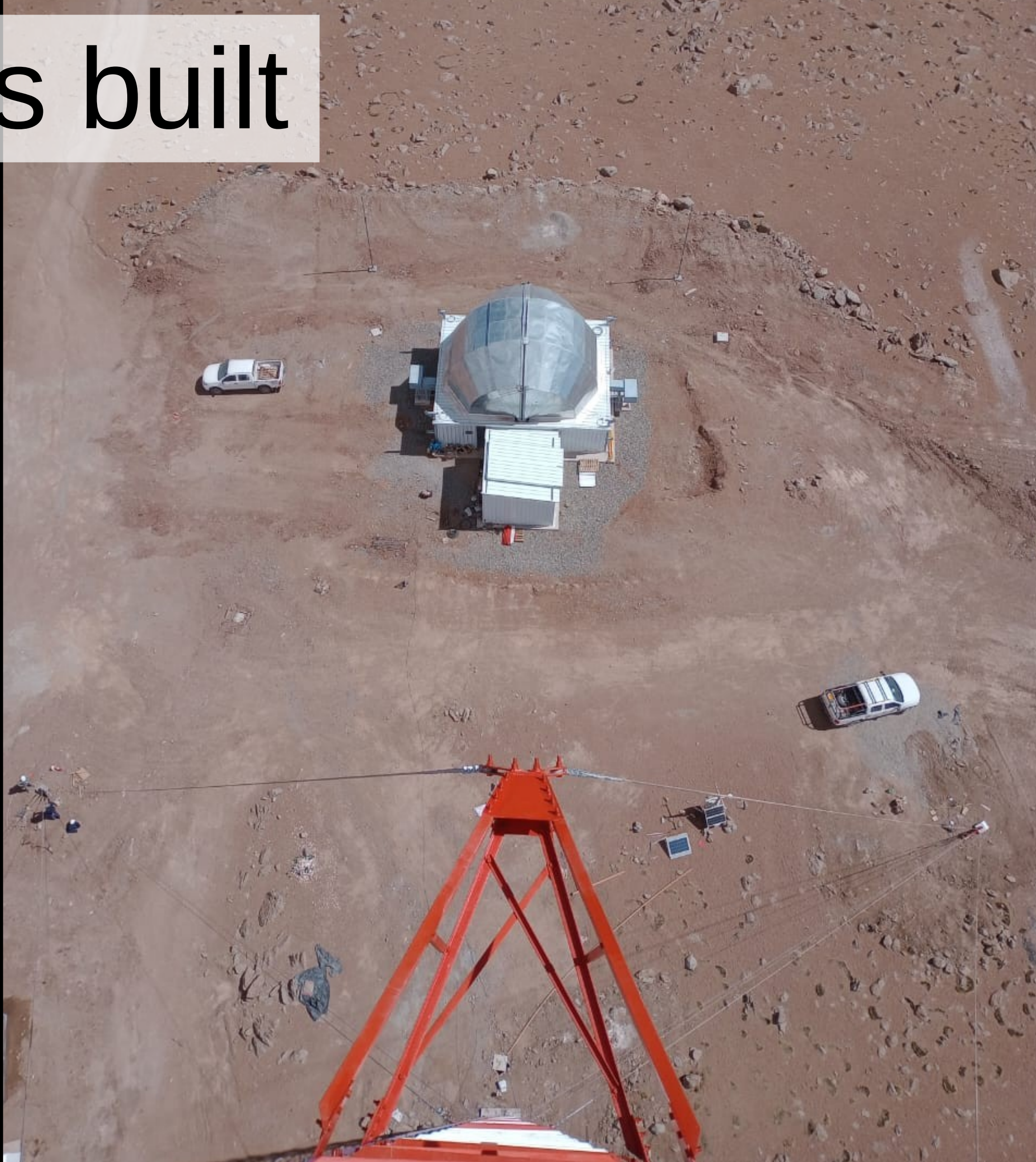
Neural Network handles it well

Leonora Kardum, postdoc (APC)

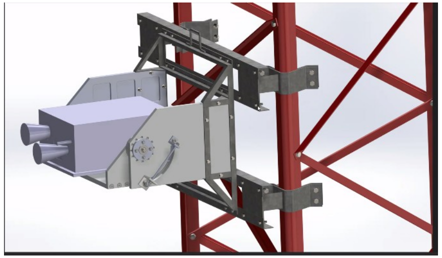
Current status of the instrument

Calibration tower is built



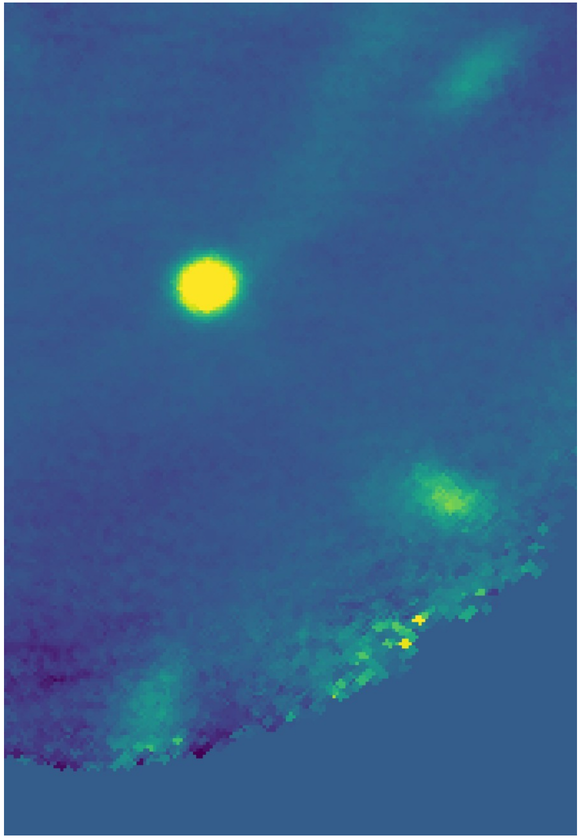


Calibration box: in 2025



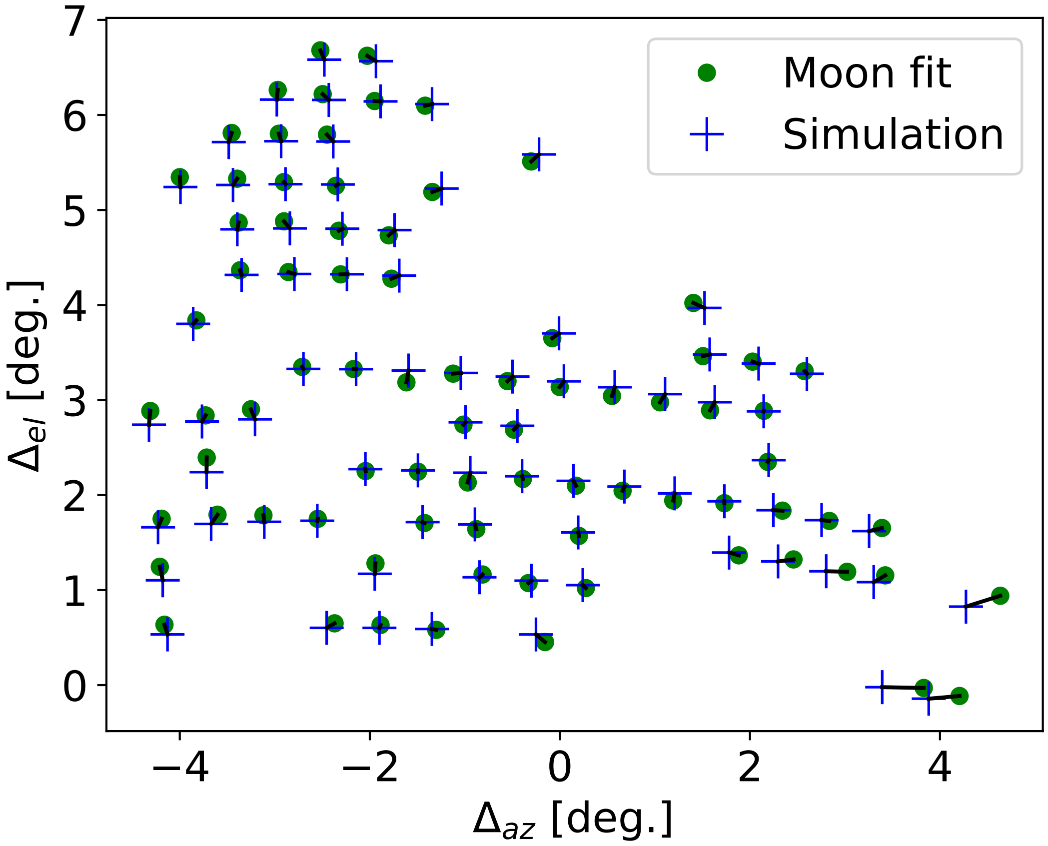
Cable carrier: this week

Moon maps



- 81 TES maps stacked
- 3.5 hours of observation in suboptimal conditions

Test calibration



Delta with the l.o.s. of the instrument for 81 TES

Thank you for your attention

Backup slides

Three snow storms, leak

Generators drown

Ground shield: after cable carrier