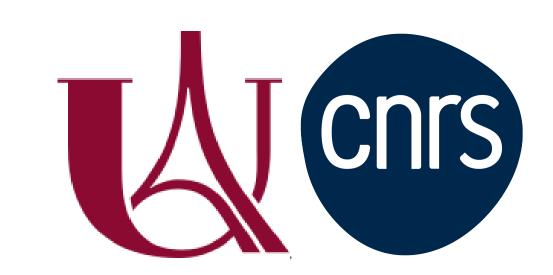


Map-making strategies for next generation CMB polarization experiments



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Introduction

Map-making is the reconstruction of the observed sky from the time-ordered data (TOD) collected by a telescope. It compresses the volume of data by many orders of magnitude, while trying to preserve cosmological information.

In the quest for B-mode polarization of the CMB, modern experiments are lining up tens, even hundreds of thousands of detectors to extract the primordial signal. As a result, the size of the TOD is increasing to an unprecedented volume, challenging our ability to analyze it correctly and efficiently.

	Polarbear	SO	CMB-S4
Data volume	100 TB	2 PB	50 PB
CPU hours	20 k	35 M	500 M

Table 1. Data volume and current CPU time needed to produce one sky map.

Quick review of map-making flavors

Data model and estimators

 $\mathbf{d} = \mathbf{P}\mathbf{s} + \mathbf{n}$

This is the usual assumed data model for the map-making problem.

- d = TOD (calibrated)
- P = pointing matrix, encodes scanning and orientation of the telescope
- s = true sky map
- n = noise vector

Map-making is just a linear operation, $\mathbf{m} = \mathbf{Ld}$, mapping the TOD to an estimator \mathbf{m} of the true sky map.

Method	Operator L	Pros	Cons
Binning	$\left(\mathbf{P}^T \mathbf{\Lambda} \mathbf{P}\right)^{-1} \mathbf{P}^T \mathbf{\Lambda}$	unbiased, cheap	complex noise
GLS	$\left(\mathbf{P}^T\mathbf{C}_\mathbf{n}^{-1}\mathbf{P}\right)^{-1}\mathbf{P}^T\mathbf{C}_\mathbf{n}^{-1}$	unbiased, min. variance	expensive
Filter-and-bin	$\left(\mathbf{P}^T \mathbf{\Lambda} \mathbf{P}\right)^{-1} \mathbf{P}^T \mathbf{F}$	easy to compute	biased
Templates	$\left(\mathbf{P}^T\mathbf{F}\mathbf{P}\right)^{-1}\mathbf{P}^T\mathbf{F}$	unbiased filtering	iterative

Table 2. Comparison of different map-making approaches. Legend: Λ = diagonal noise weights; $\mathbf{C}_{\mathbf{n}}^{-1}$ = noise covariance matrix; \mathbf{F} = filtering and weighting operator.

Observing from the ground

Ground-based experiments have to deal with two specific contaminants which are very bright compared to the CMB:

- atmospheric signal, a major source of noise correlations
- ground pickup, typically due to the far side-lobes of the beam

Those contaminants are largely unpolarized, which motivates the **pair differencing** approach, where the timestreams of two orthogonal detectors are subtracted in order to eliminate non polarized signals.

Evaluation of the pair differencing approach

I use the map-making library mappraiser[1] to process simulations produced with the TOAST software:

- instrument: SO-SAT @ 90 GHz
- schedule: one day per month during one year
- sky: CMB lensed scalar anisotropies (from Planck FFP10 simulations)
- high-resolution atmosphere simulation
- instrumental noise
- gain errors in detector pairs
- in the future: elliptical beams

Figure of merit?

Results: gain errors

Numerical advantages of pair differencing

Reduce noise correlations...

Conclusion / Discussion?

In what conditions is pair differencing reasonable to use? What do we lose? What do we gain?

References

[1] Hamza El Bouhargani, Aygul Jamal, Dominic Beck, Josquin Errard, Laura Grigori, and Radek Stompor. MAPPRAISER: A massively parallel map-making framework for multi-kilo pixel CMB experiments. Astronomy and Computing, 39:100576, April 2022.