Map-making strategies for next generation CMB polarization experiments

Simon Biquard

AstroParticule et Cosmologie, Paris, France

Introduction

The quest for B-mode polarization of the cosmic microwave background (CMB) is leading modern experiments to line up tens, even hundreds of thousands of detectors in order to distinguish the primordial signal from numerous foregrounds. As a result, their time-ordered data (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.

Map-making, i.e. the reconstruction of the observed sky from the TOD, compresses the volume of the data by many orders of magnitude, while trying to preserve relevant cosmological information as much as possible.

Map-making basics

Data model and GLS solution

Let's assume that the TOD is calibrated and collected in a vector $\mathbf{d}$. For polarization sensitive detectors, each measured sample d_t contains a sky signal contribution from the observed pixel p_t, and some noise:

$$d_t = I_{p_t} + \cos(2\phi_t) Q_{p_t} + \sin(2\phi_t) U_{p_t} + n_t$$

The angle ϕ_t is the orientation of the detector projected on the sky. This model is written in matrix form using the *pointing matrix* $\mathbf{P}$ which encodes the scanning and orientation of the telescope.

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

In this form, map-making is simply a linear problem for which the GLS solution is an unbiased estimator for any choice of a positive definite *weight matrix* $\mathbf{M}$.

$$\hat{\mathbf{m}} = \left(\mathbf{P}^\intercal \mathbf{M} \mathbf{P}\right)^{-1} \mathbf{P}^\intercal \mathbf{M} \mathbf{d}$$

If $\mathbf{M} = \mathbf{N}^{-1}$ the time domain noise covariance matrix, and if the noise is Gaussian, then $\hat{\mathbf{m}}$ is the minimum variance and maximum likelihood solution.

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, which makes the estimation and inversion of $\mathbf{N}$ difficult
- *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.

biquard@apc.in2p3.fr