A novel pixel-based non-parametric component separation approach, the MICMAC package

2024 CMB-S4 Spring Collaboration Meeting

2024, March 27th

Magdy MORSHED
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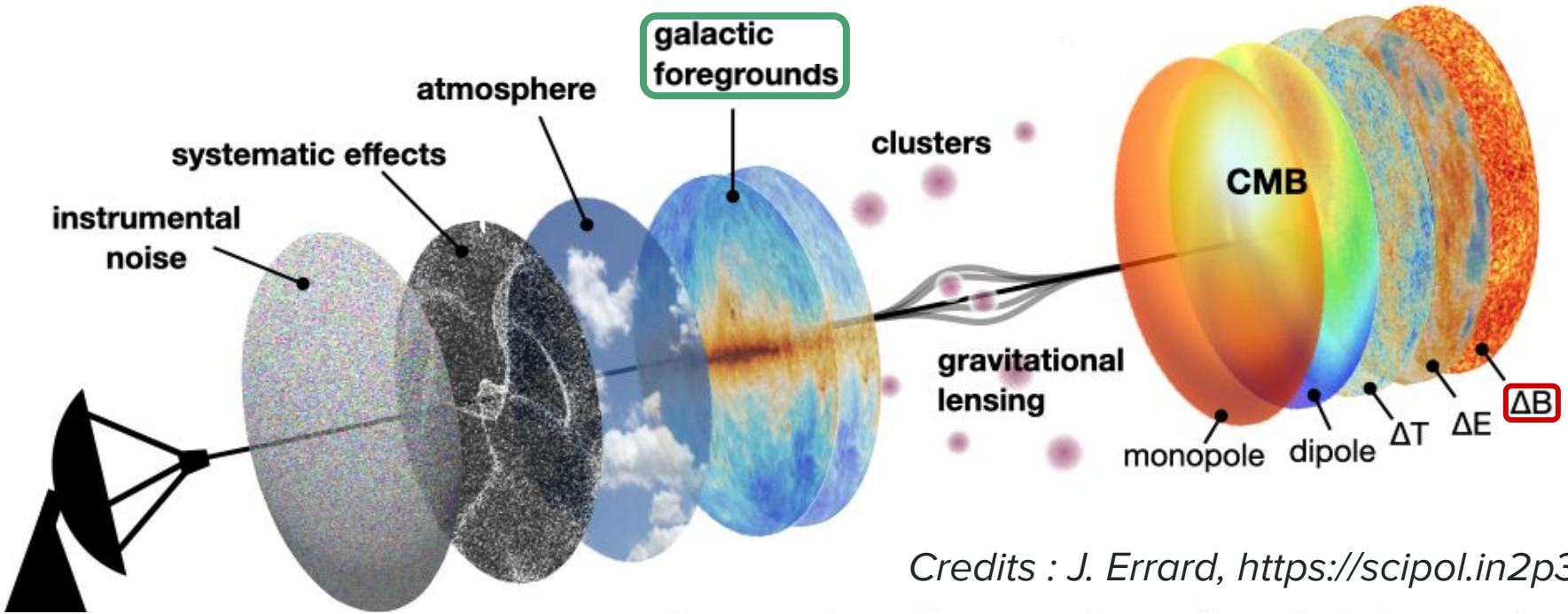
SciPol
Science from the large scale cosmic microwave background polarization structure

Component separation for CMB data analysis



Credits : J. Errard, https://scipol.in2p3.fr/

Addressing **assumptions on foreground** and **foreground spatial variability** will be **crucial** for **future CMB experiments**

➔ Minimally informed approach developed in **Leloup et al. 2023**

Basic assumptions of the method

Goal: Retrieve CMB signal with minimal assumptions on foregrounds

Context formalism:

- 2 **foreground components**
  Foreground SED not assumed !
- **CMB** is a **black body**, fluctuations described by **Gaussian prior**
- **Mixing matrix**: Fit of the amplitude for **each foreground component and each frequency**

Mixing matrix

$$\overline{\mathbf{d}} = \overline{\mathbf{B}}\,\overline{\overline{\mathbf{s}}} + \overline{\mathbf{n}}$$

noise

Observed data

***CMB** signal*
***foreground components** (**dust** and **synchrotron**)*

What is proposed:
New Maximum Likelihood method to **minimize number of assumptions**, estimating some elements of the **mixing matrix** to clean **foregrounds**

Main feature: perform **foreground cleaning** while making assumptions on **CMB**

Main results in harmonic domain

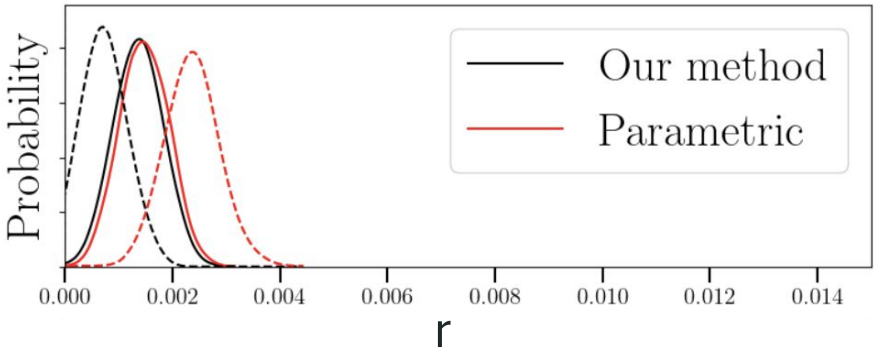
What is retrieved:

- Cosmological parameter and mixing matrix elements

Development of the method on **Simons Observatory**, **LiteBIRD** in harmonic domain

What is shown:

- With **parametric scaling for foregrounds**, performs as good as **parametric component separation method**
- With **non-parametric scaling**, seems better and promising



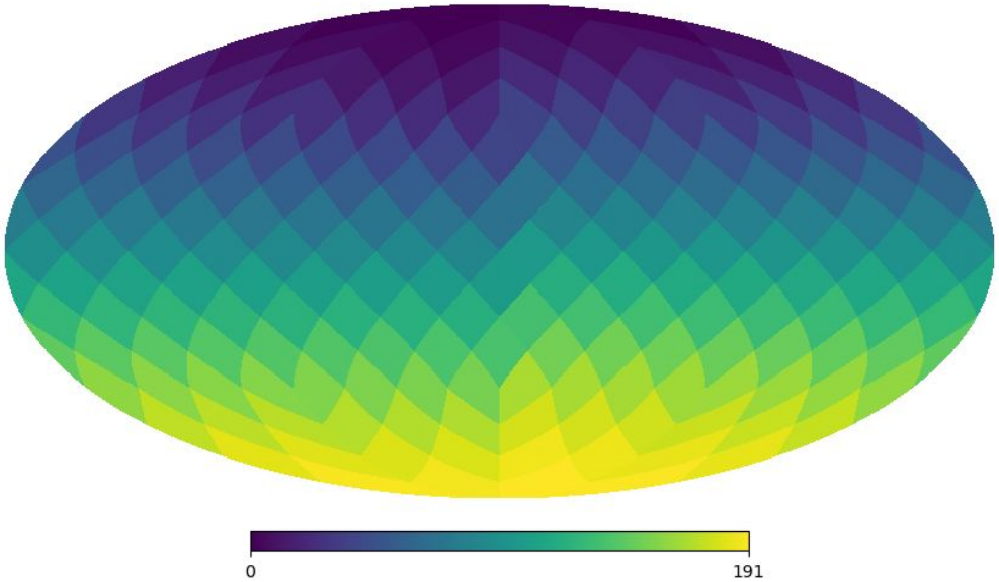
Both methods fail when **foreground spatial variability** involved

➜ Calls for a **pixel domain implementation**

Pixel domain implementation

Goal: Perform component separation with minimal assumptions on foregrounds, as a follow-up of **Leloup et al. (2023)**

➔ Pixel domain implementation, and extension to **multipatch approach**



Multipatch approach:
Perform component separation in patches instead of the full sky

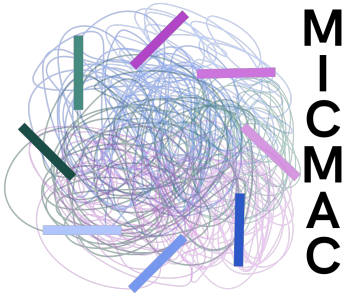
➔ Necessary for large patches survey as LiteBIRD and CMB-S4

Minimally Informed CMB MAp foreground Cleaning: MICMAC

We developed a new package in pixel domain !

In practice:

- **No major assumptions on the foregrounds**, few “tuning” parameters
- Start from frequency maps to estimate:
  - **CMB power spectrum/cosmological parameters (harmonic)** $\mathbf{C}$
  - **Redefined mixing matrix elements (pixel)** $\mathbf{B_f}$



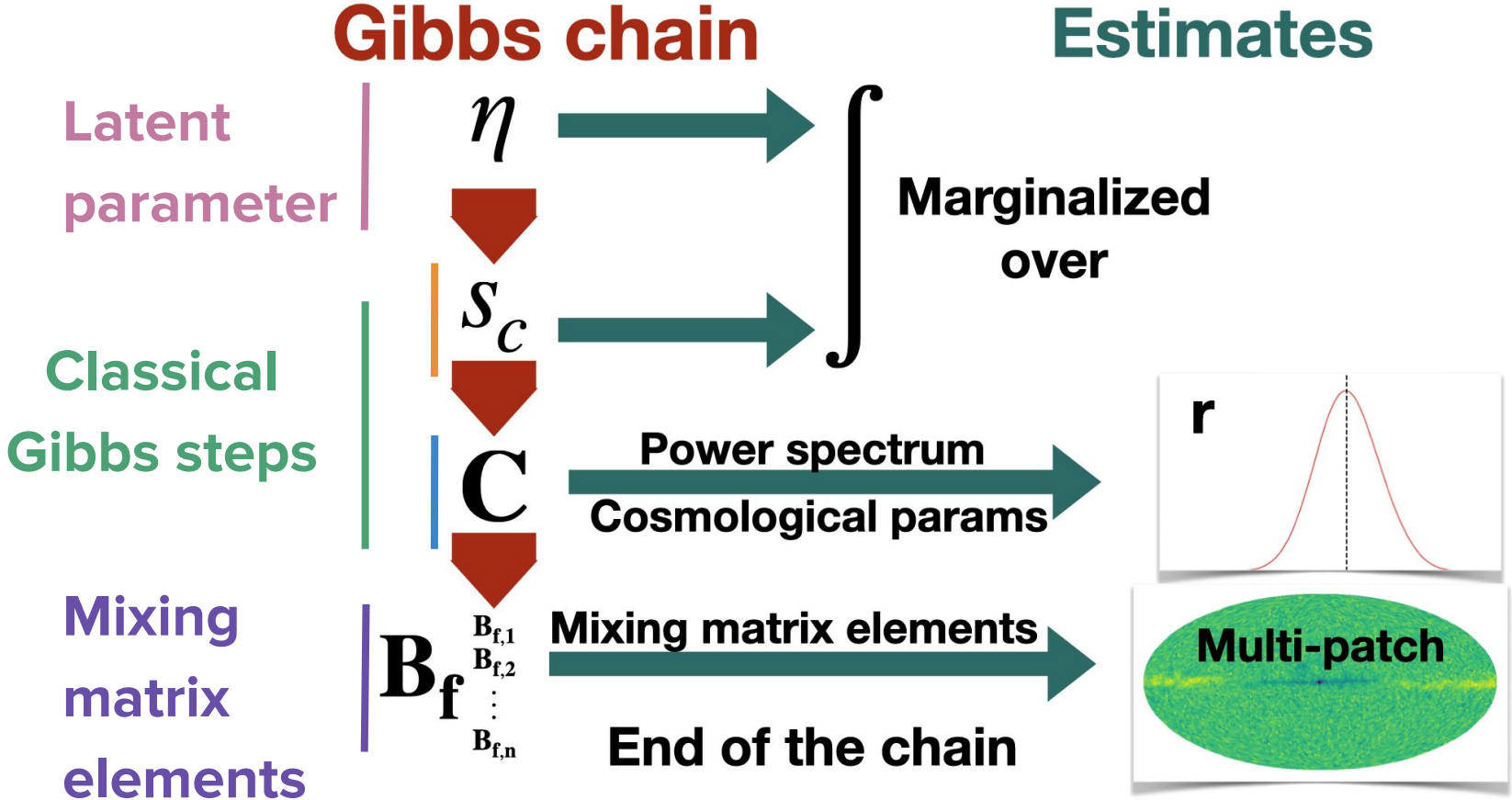
Credits: Ema Tsang King Sang

Currently in final stage, but release very soon with article ***MM et al.*** *(2024) [in prep]* !

CMBSciPol / MICMAC

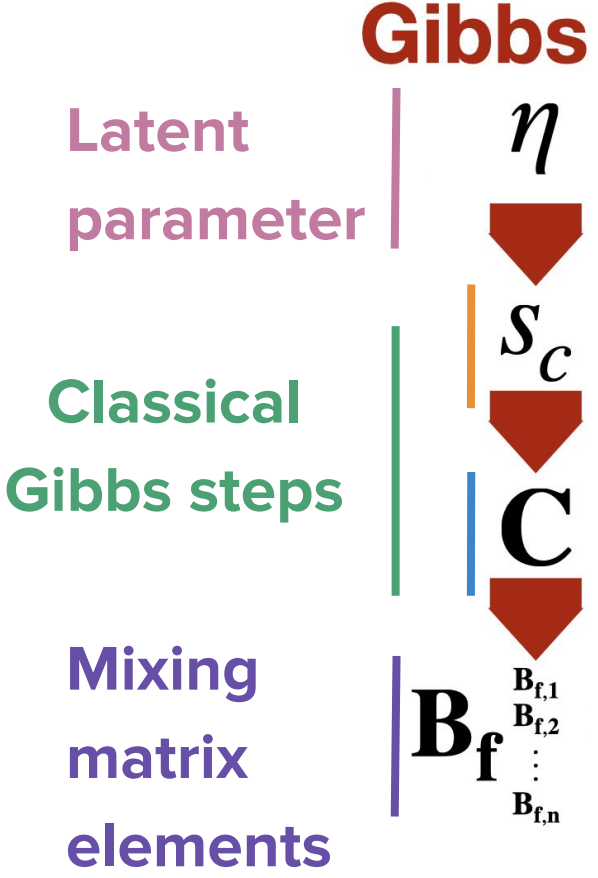
Minimally Informed CMB MAp foreground Cleaning: MICMAC

Gibbs Sampling divided in 4 steps:



Minimally Informed CMB MAp foreground Cleaning: MICMAC

Gibbs Sampling divided in 4 steps:



- **Latent parameter** (see paper !) as **Gaussian**
- **CMB maps** sampled as **Gaussian**
- **Power spectrum** as **Inverse Wishart** (or r through **MwG**)
- **Mixing matrix elements** sampled through **Metropolis-within-Gibbs**

Minimally Informed CMB MAp foreground Cleaning: MICMAC

harmonic ↔ pixel

(harmonic + pixel)$^{-1}$ with **CG**

Lot of work on optimisation
➜ Very intensive code

Gaussian

$$\mathcal{P}(\eta|....) \propto \eta^t \, \tilde{\mathbf{C}}^{-1/2} \, (\tilde{\mathbf{C}}^{-1} + \mathbf{N_c}^{-1})^{-1} \tilde{\mathbf{C}}^{-1/2} \, \eta$$

Gaussian

$$\mathcal{P}(\mathbf{s_c}|....) \propto (\mathbf{s_c} - \mathbf{s_{c,WF}})^t \, (\mathbf{C}^{-1} + \mathbf{N_c}^{-1}) \, (\mathbf{s_c} - \mathbf{s_{c,WF}})$$

Inverse Wishart (or r through MwG)

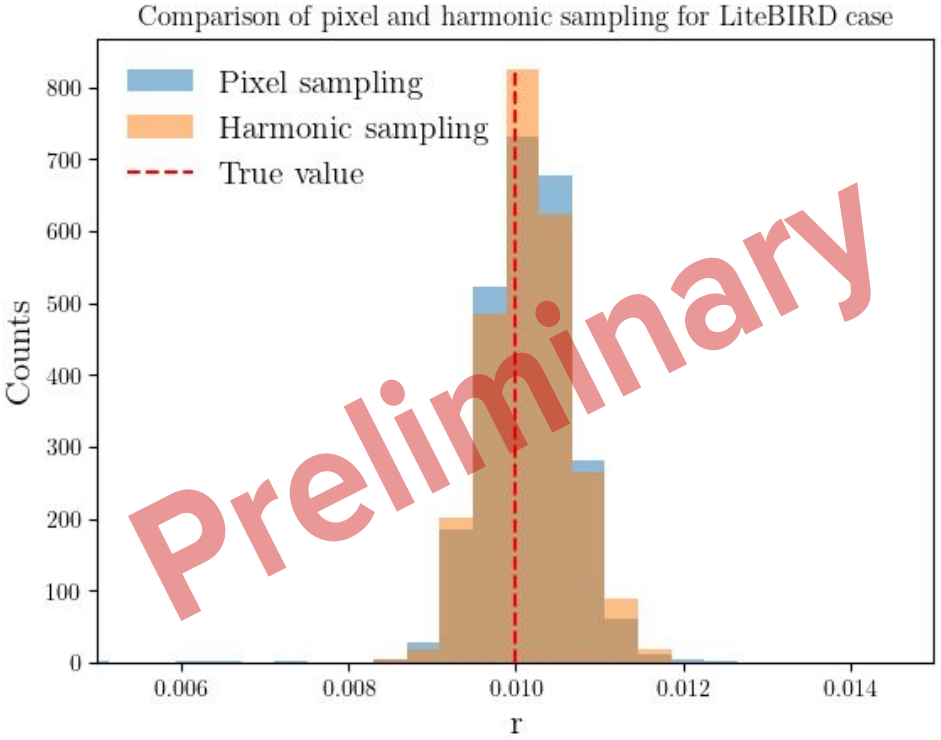
$$\mathcal{P}(\mathbf{C}|....) \propto \mathbf{s_c}^t \mathbf{C}^{-1} \mathbf{s_c} + \ln|\mathbf{C}|$$

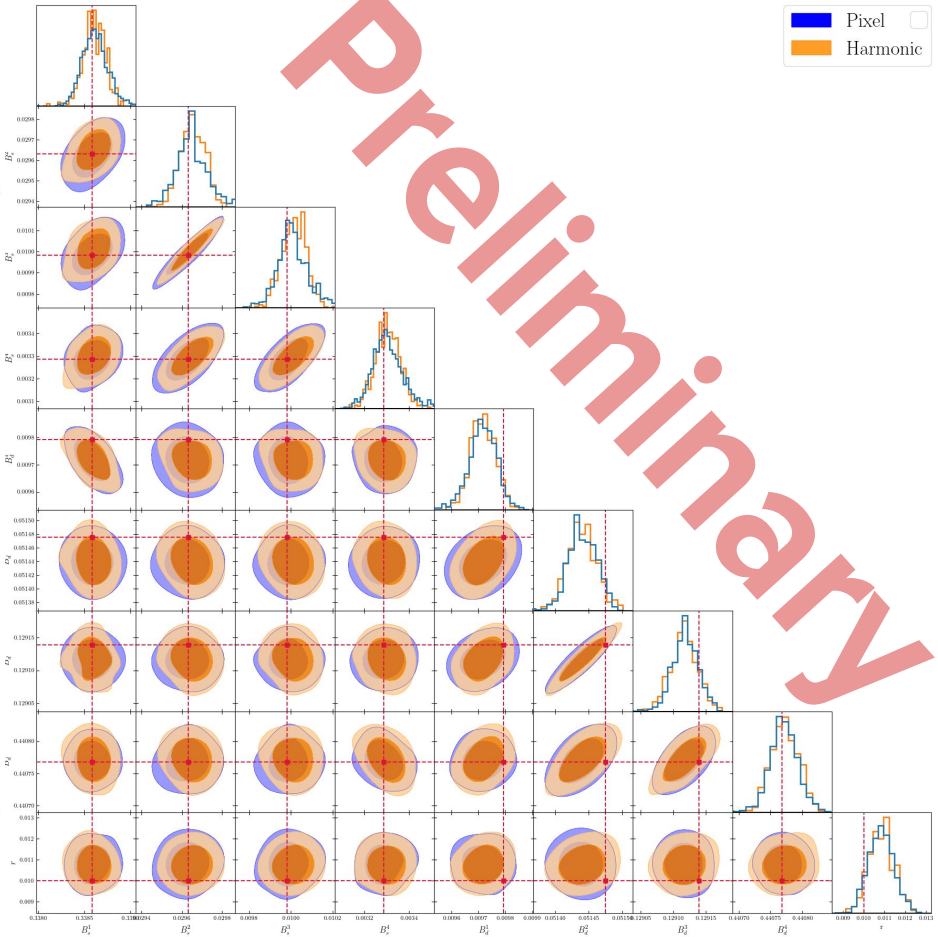
Metropolis-within-Gibbs

$$\mathcal{P}(\mathbf{B_f}|....) \propto -(\mathbf{d} - \mathbf{B_c s_c})^{\mathbf{t}} \mathbf{N}^{-1} \mathbf{B_f} (\mathbf{B_f^t N}^{-1} \mathbf{B_f})^{-1} \mathbf{B_f^t N}^{-1} (\mathbf{d} - \mathbf{B_c s_c}) + \eta^t \, \tilde{\mathbf{C}}^{-1/2} \, (\tilde{\mathbf{C}}^{-1} + \mathbf{N_c}^{-1})^{-1} \tilde{\mathbf{C}}^{-1/2} \, \eta$$

Minimally Informed CMB MAp foreground Cleaning: MICMAC

Validation of **MICMAC** vs **Leloup et al. 2023** in harmonic domain for ***d0s0***





Preliminary

MM et al. *(2024) [in prep]*

Conclusion

Main ideas:

- Novel minimally informed component separation method
  - **Performs** as **good** as **parametric component separation method** on **parametric scaling of the foreground**
  - **Outperforms parametric method** for **non-parametric scaling of the foregrounds**
- Pixel implementation (**MICMAC**) capable of handling **spatial variability of the foregrounds** and inhomogeneous noise

Prospects:

- Extension with more instrumental effects such as beams, correlated noise
- More applications on actual realistic CMB-S4 survey
- Release of the package and methodology paper (***MM et al.***) *soon*

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