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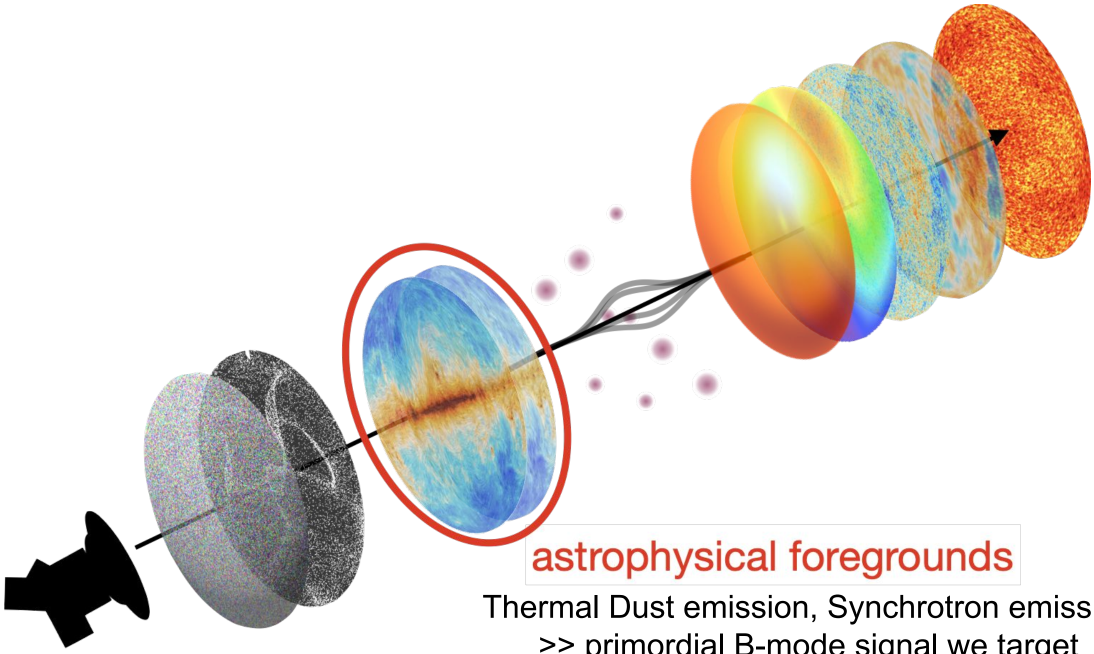
Component separation for LiteBIRD

Arianna Rizzieri,
on behalf of the LiteBIRD collaboration

LB Day @ APC

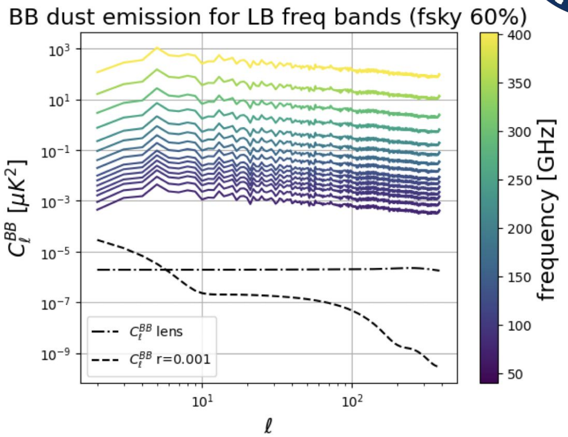
Need for component separation



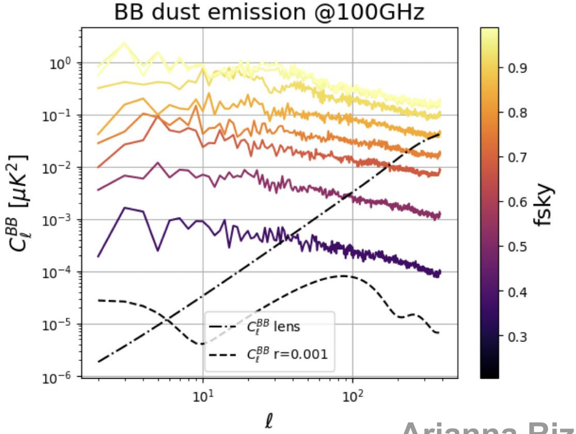
astrophysical foregrounds

Thermal Dust emission, Synchrotron emission
>> primordial B-mode signal we target

Credits: J. Errard



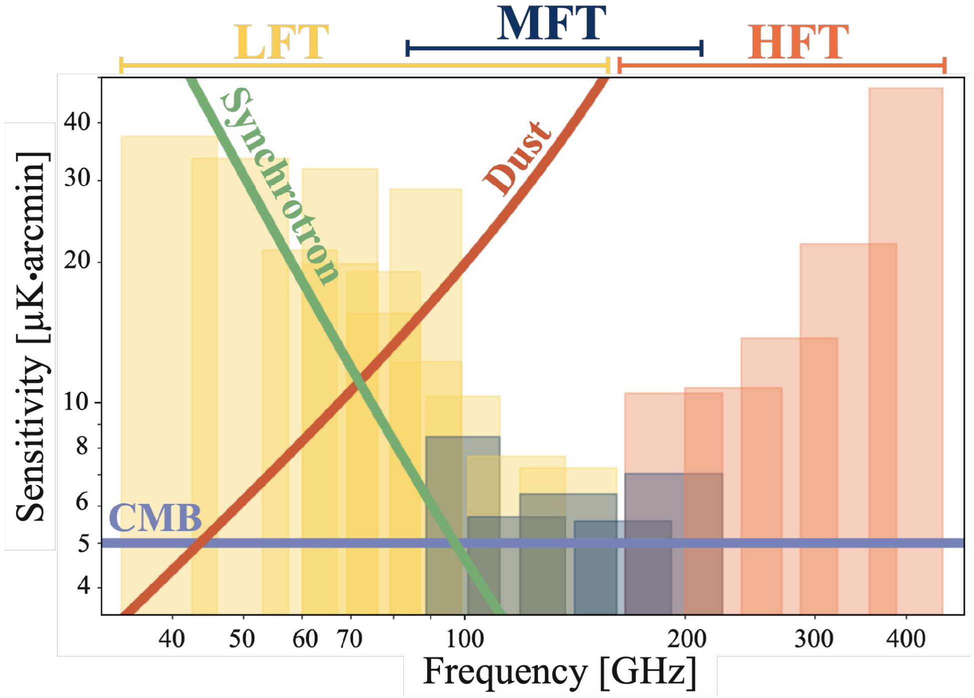
BB dust emission for LB freq bands (fsky 60%)



BB dust emission @100GHz

Need for component separation

Projected polarization sensitivities for a 3-year full-sky survey:



- **Sensitivity**:
  both in CMB and foreground dominated frequency bands
  - 4.3 μK·arcmin @ 119 GHz
  - combined sensitivity: 2.2 μK·arcmin

`Hazumi+ 2020`

- **Robust component separation techniques**:
  to deal with complex foreground models

↓

many component separation techniques explored

Parametric component separation

LiteBIRD Collaboration, PTEP, 2023

Component separation model

$$\begin{bmatrix} d^{Q,U}_{\nu_0} \\ \vdots \\ d^{Q,U}_{\nu_n} \end{bmatrix} = \begin{bmatrix} a^{cmb}_{\nu_0} & a^{dust}_{\nu_0} & a^{synch}_{\nu_0} \\ \vdots & \vdots & \vdots \\ a^{cmb}_{\nu_n} & a^{dust}_{\nu_n} & a^{synch}_{\nu_n} \end{bmatrix} \begin{bmatrix} s^{Q,U}_{cmb} \\ s^{Q,U}_{dust} \\ s^{Q,U}_{synch} \end{bmatrix} + \begin{bmatrix} n^{Q,U}_{\nu_0} \\ \vdots \\ n^{Q,U}_{\nu_n} \end{bmatrix}$$

- **d** : data vector of the measured signal for all the frequencies and Stokes parameters
- **A** : component Mixing Matrix unknown → parametrized by spectral parameters ***β***: **A**(***β***)
- **s** : true values signals for each component unknown
- **n** : instrumental noise

Component separation method

Solving by maximum likelihood: (`FGBuster`)

Step 1 spectral parameter estimates ***β***
Step 2 sky components **s**

Foreground modeling

Synchrotron: power law

$$[Q_s, U_s](\hat{n}, \nu) = [Q_s, U_s](\hat{n}, \nu_\star) \cdot \left(\frac{\nu}{\nu_\star}\right)^{\beta_s(\hat{n})}$$

Dust: modified blackbody

$$[Q_d, U_d](\hat{n}, \nu) = [Q_d, U_d](\hat{n}, \nu_\star) \cdot \left(\frac{\nu}{\nu_\star}\right)^{\beta_d(\hat{n})-2} \frac{B_\nu(T_d(\hat{n}))}{B_{\nu_\star}(T_d(\hat{n}))}$$

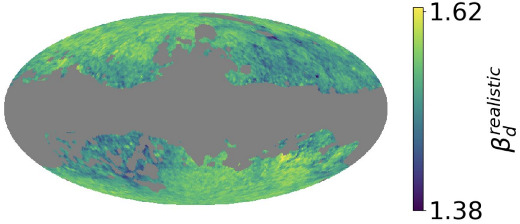
→ 3 spectral parameters
+ amplitudes

Parametric component separation

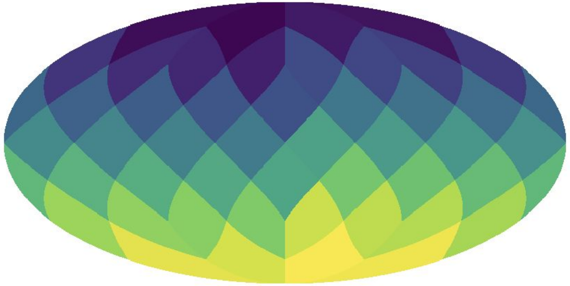
Adaptive multi-resolution technique to account for spatial variability of the spectral parameters

→ 12x$(\text{Nside})^2$ patches + amplitudes ($O(10^4)$ parameters)

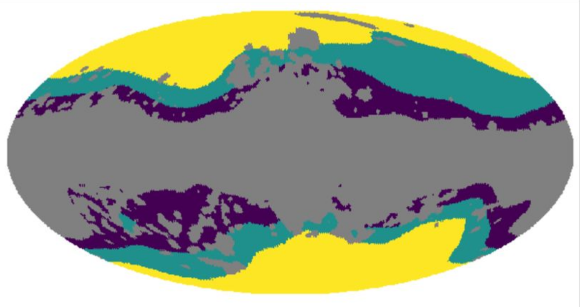
LiteBIRD Collaboration, PTEP, 2023



Many ways to choose the patches (for each spectral parameter):



patches shape



patches distribution

Patches from healpix nsides:

	Galactic latitude		
	Low	Medium	High
β_d	64	64	64
T_d	8	4	0
β_s	4	2	2

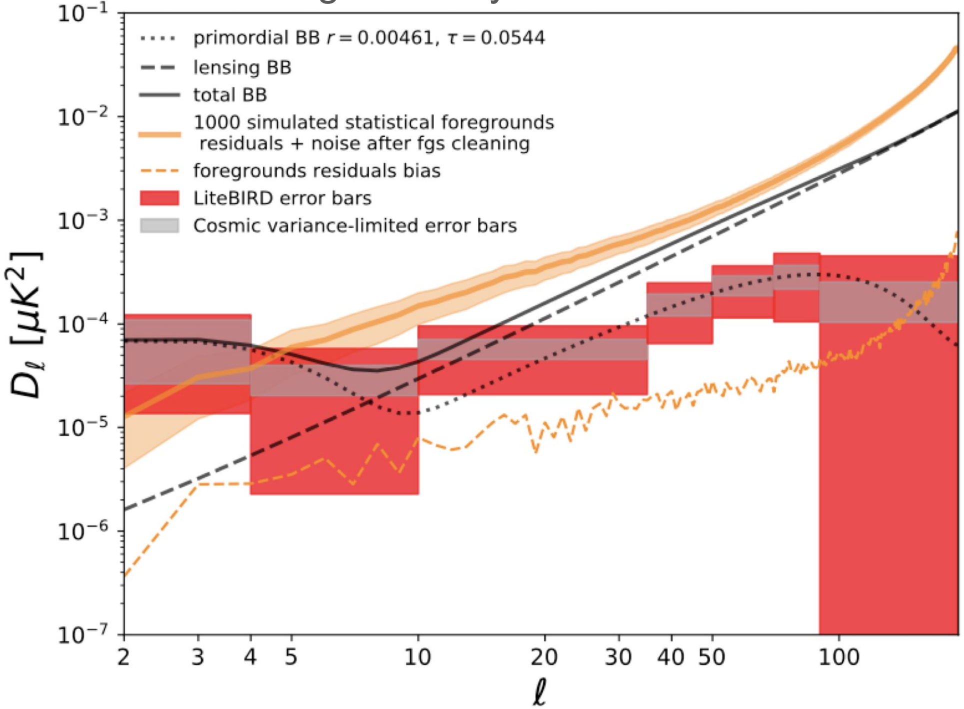
our choice

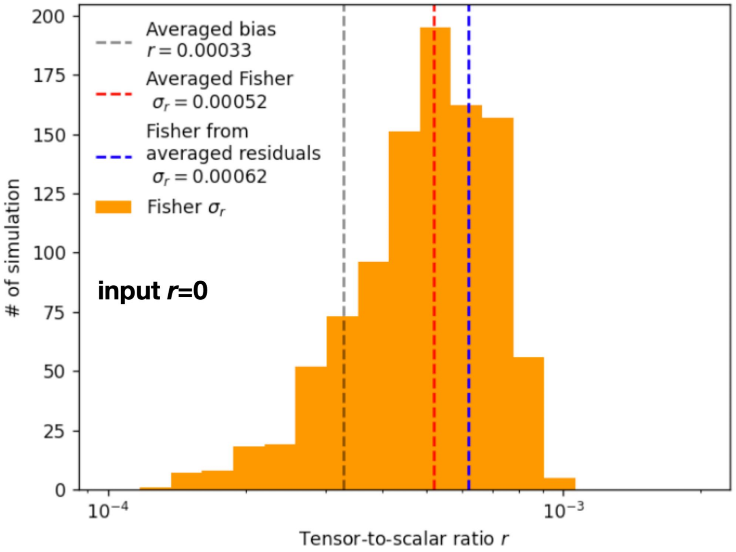
Parametric component separation

Impact of foreground residuals

LiteBIRD Collaboration, PTEP, 2023

Fgs from PySM model *d1s1*





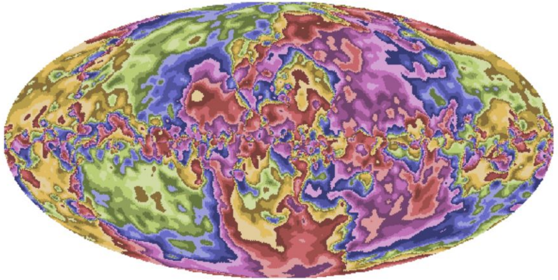
Distribution of the recovered r in 1000 simulations with input r = 0, with and without foreground residuals

Other components separation studies

- Partition of the full sky in patches for the spectral parameter from a clustering algorithm, resulting in a more physically motivated choice of patches

`Puglisi+ 2022`

`Carones+ 2023`



- More robust modeling of the foregrounds: moment expansion `Vacher+ 2022`

Current studies: E-modes project paper

Characterization of CMB E Modes from LiteBIRD

Goal: complement and extend the B modes analysis of `LiteBIRD Collaboration, PTEP, 2023` to E, for achieving a rendering of the entire polarization tensor from LiteBIRD

component separation residuals from instrumental noise + **foregrounds**

Various component separation techniques applied:

- Parametric (FGBuster, Moment Expansion, …)
- Blind (HILC, NILC, …)

PySM foreground models considered:

- simple models (*d1s1*)
- medium complexity *(d10,s5,f1,a1,co3)*
- high complexity *(d12,s7,f1,a2,co3)*

\+ galactic plane masking
\+ power spectrum estimation
\+ likelihood → **reionization optical depth**

Current studies: B-modes project paper

B Modes from LiteBIRD

Goal: robustness of the expected precision of the measurements on the tensor-to-scalar ratio *r* against variations in the diffuse foreground modelling and component separation techniques

1) **component separation** residuals from instrumental noise + **foregrounds**

	Parametric methods			Blind methods			Under development			
	COMMANDER	FGBuster	B-SeCRET	HILC	NILC	SMICA	Moment expansion	Minimally Informed	Moment PILC	Delta-map
Simple fgs models										
Medium complexity fgs models										
High complexity fgs models										

FoM: r

In progress

Current studies: B-modes project paper

B Modes from LiteBIRD

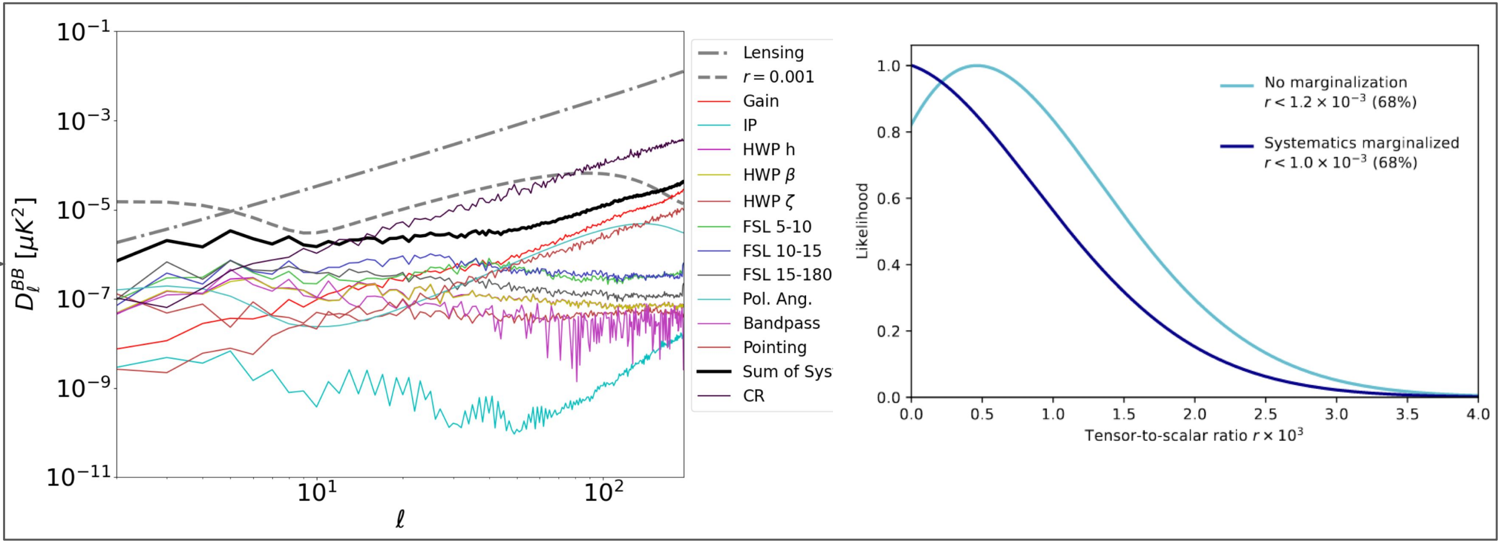
Goal: robustness of the expected precision of the measurements on the tensor-to-scalar ratio *r* against variations in the diffuse foreground modelling and component separation techniques

2) **component separation** residuals from instrumental noise + **foregrounds** + **systematic effects**

Similarly to what was done in

`LiteBIRD Collaboration, PTEP, 2023`

but with updated studies of systematic effects



Conclusion

- We need robust component separation for LiteBIRD to achieve its scientific goal

  (**$\delta r < 0.001$ (r=0)** including statistical noise, systematic effects and component separation residuals)

- Main challenge: dealing with **spatial variability** of the foreground frequency scaling

- Some work published already: `LiteBIRD Collaboration, PTEP, 2023` `Puglisi+ 2022` `Vacher+ 2022` `Carones+ 2023`

- More to come: ***E-mode project paper***, ***B-mode project paper***

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