



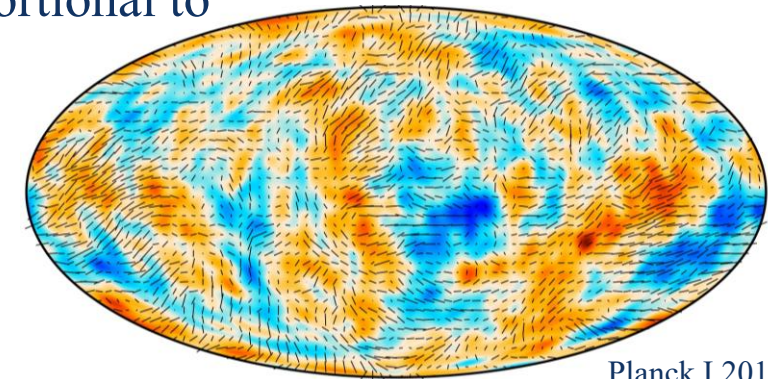
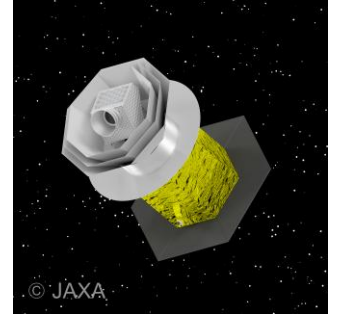
# Galactic Science with the *LiteBIRD* satellite: Spectral characterization of diffuse Galactic polarized emission at the angular power spectrum level

S. Vinzl, J. Aumont, L. Vacher, R. Génova-Santos, D. Adak, A. Rizzieri  
LiteBIRD Collaboration

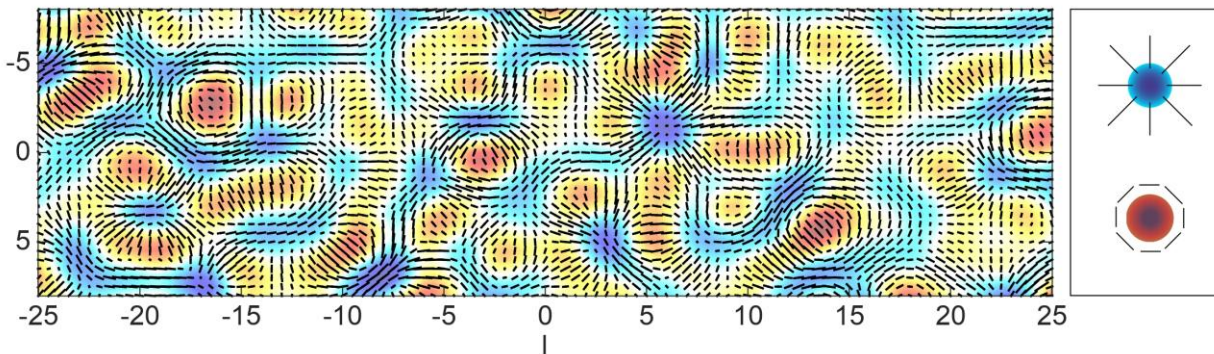
*1st year PhD Student (IRAP)*

# The *LiteBIRD* satellite

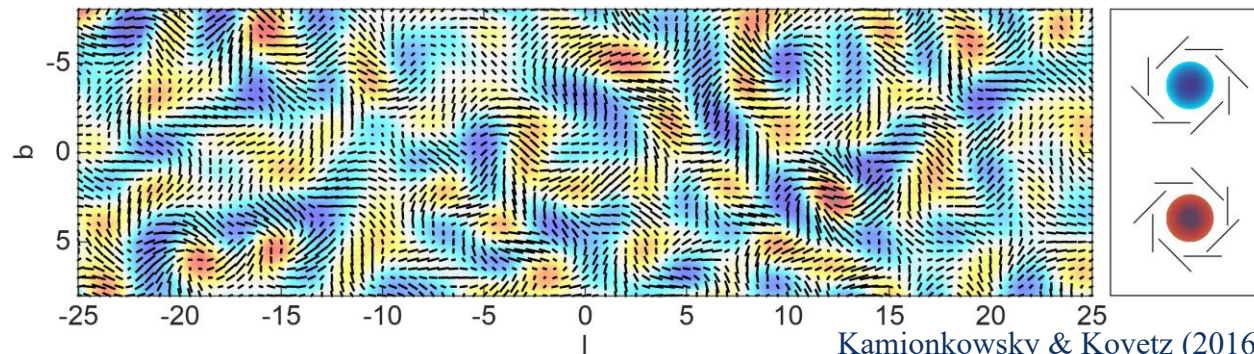
- Will scan the full sky from space in 15 frequency bands (**40-402 GHz**) at **70-18 arcmin** angular resolution (*LiteBIRD Collaboration 2023*)
- **Objectives:**
  - Measure the cosmic microwave background (CMB) **B-mode polarization** produced by primordial gravitational waves, amplitude of which is proportional to the energy level at which cosmic inflation occurred  $\sim 14$  Gyrs ago
  - Create **full-sky** ultra-sensitive **microwave polarization maps**
  - Wonderful tool for studies of the polarized interstellar medium (ISM)
- Launch planned in JFY2036



E-mode Polarization

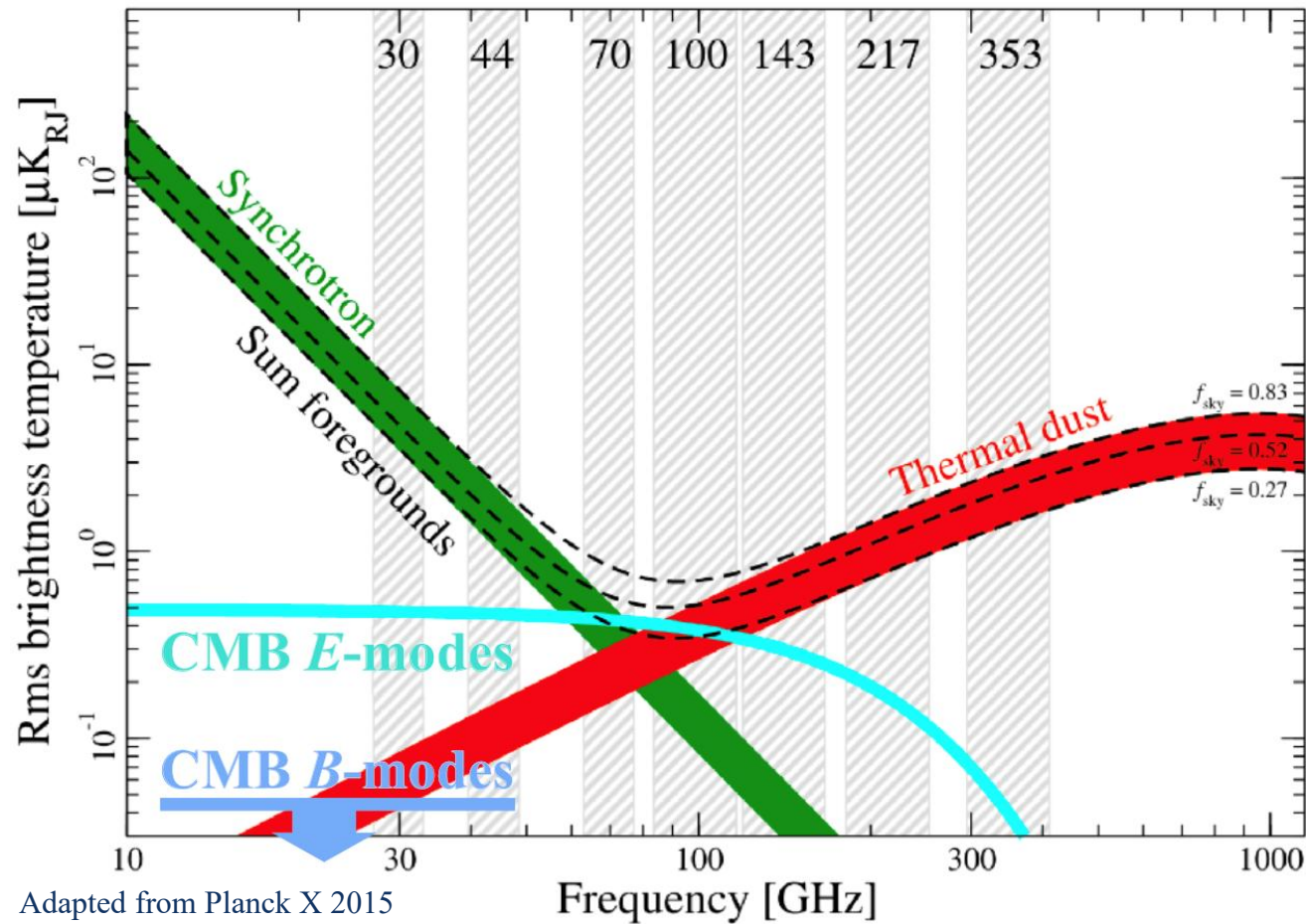


B-mode Polarization



Kamionkowsky & Kovetz (2016)

# Polarized emission from the ISM



- **Thermal dust emission**

- Frequencies  $\gtrsim 100$  GHz
- Polarization fractions up to  $\sim 20\%$  (Planck Int. XIX, Planck XII 2018)
- Spectral energy distribution (SED) usually described as a **modified black-body** (MBB)

$$S_{\nu,d} = A_d \epsilon_d(\nu, \beta_d, T_d) = A_d \frac{B_\nu(\nu, T_d)}{B_\nu(\nu_d, T_d)} \left( \frac{\nu}{\nu_d} \right)^{\beta_d}$$

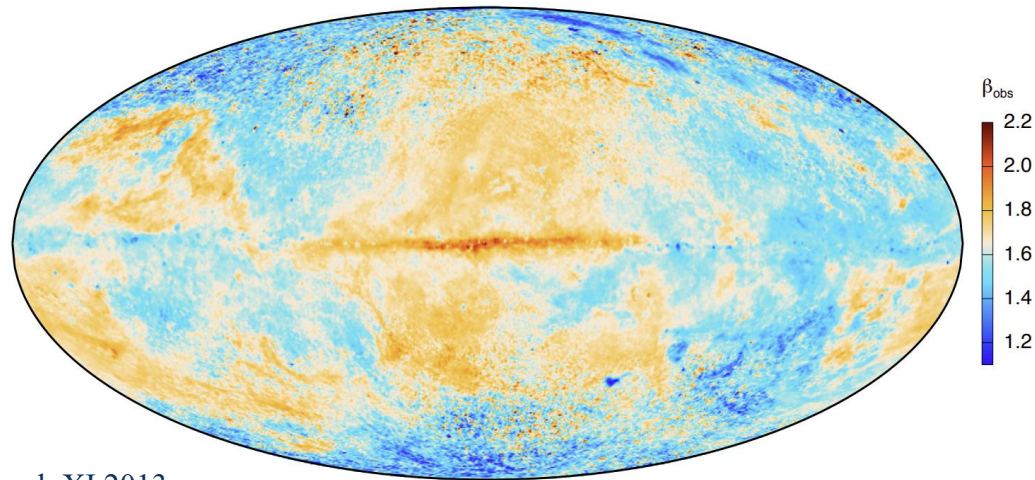
- **Synchrotron radiation**

- Frequencies  $\lesssim 100$  GHz
- Polarization fractions up to  $\sim 10\%$  (Kogut et al. 2007)
- Canonical SED: **power law** (PL)

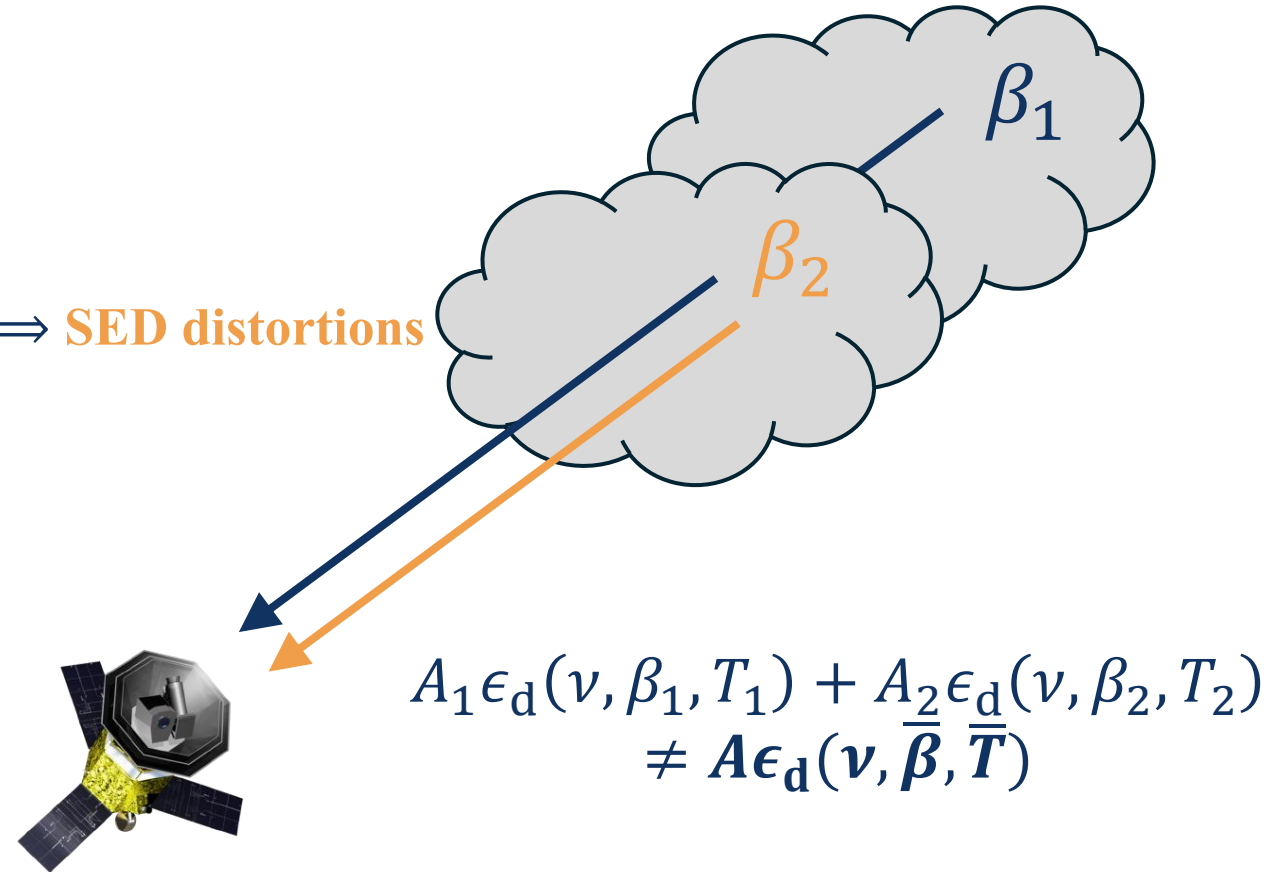
$$S_{\nu,s} = A_s \epsilon_s(\nu, \beta_s) = A_s \left( \frac{\nu}{\nu_s} \right)^{\beta_s}$$

# Polarized emission from the ISM

- The **spectral properties** of Galactic emission are expected to **vary with the physical conditions** governing the ISM
- What one observes is an **averaged emission**
  - along the line of sight
  - within the beam
- Dust and synchrotron emission laws are non-linear  $\Rightarrow$  **SED distortions**



Planck XI 2013



- The last CMB experiment observing the microwave sky from space, *Planck*, has revolutionized our understanding of the early universe but also of the ISM of the Milky Way (**~30 % of the papers related to Galactic science**)
- All millimeter measurements were **consistent with the canonical SEDs** of thermal dust and synchrotron emission (e.g., Planck XI 2018), **both in intensity and polarization**
- In polarization, *Planck* was **dominated by systematics** while *LiteBIRD* is designed to accurately control them

## Objective of this work (Vinzi et al. 2026, soon on arXiv):

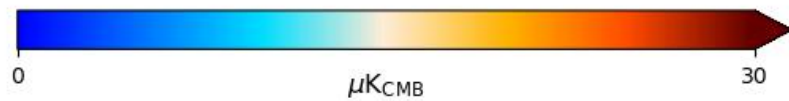
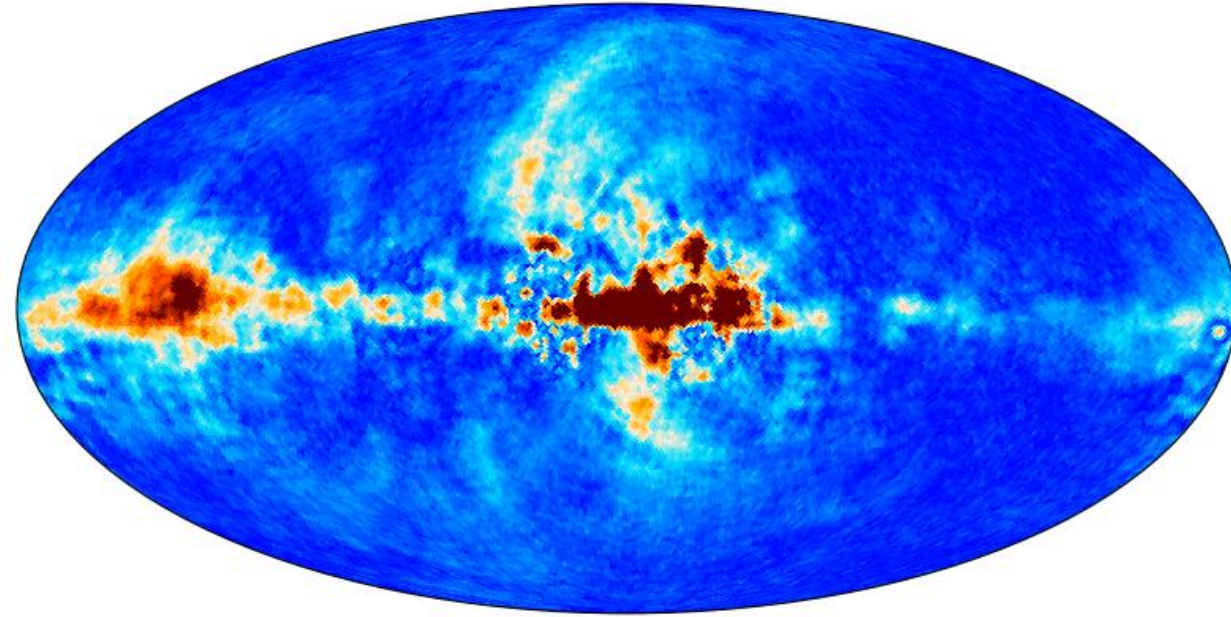
Assess *LiteBIRD*'s ability to

- improve our current constraints on the dust and synchrotron **polarized SEDs**
- detect and model **variations of the emission properties** across the three dimensions of the Galaxy
- We perform a **power spectrum analysis** to focus on **statistical properties** of the emission in the **diffuse ISM** (excluding the Galactic plane)

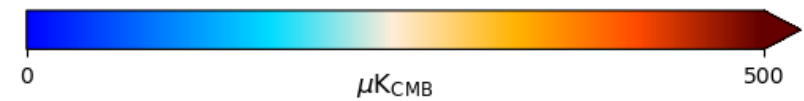
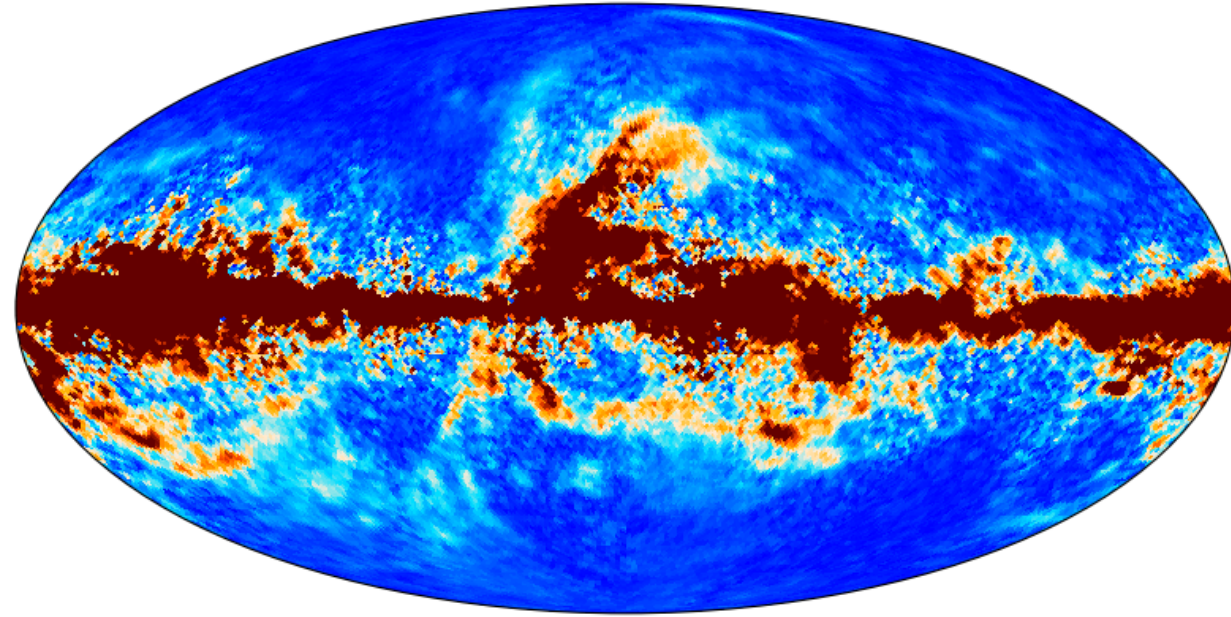
# Simulating *LiteBIRD* full-sky maps



40 GHz



402 GHz

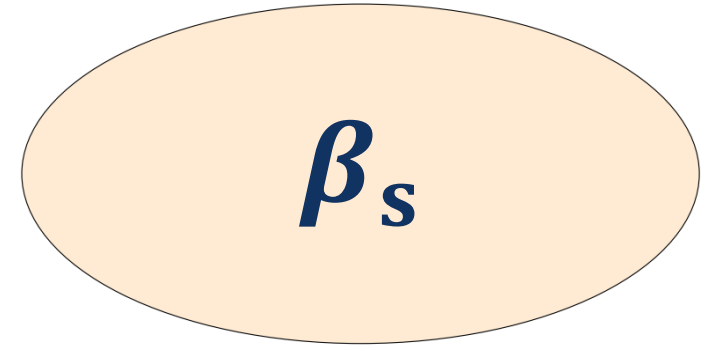
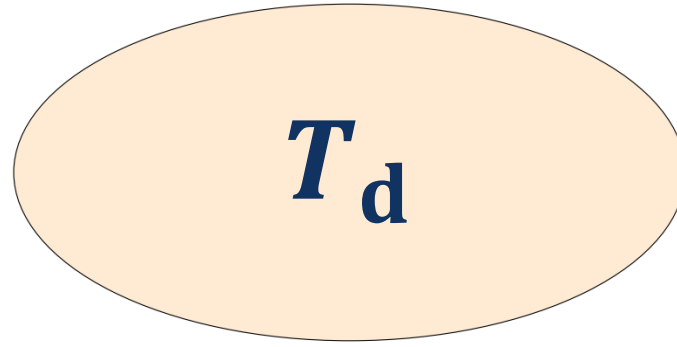
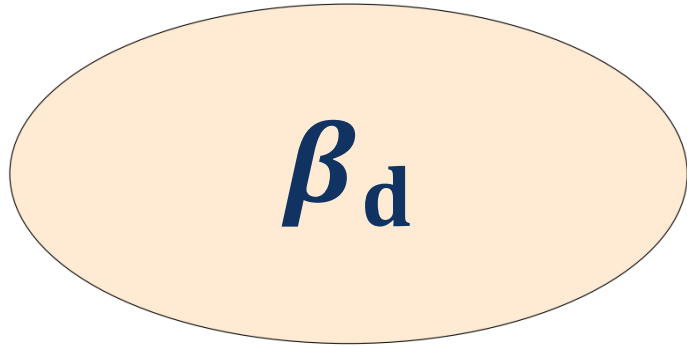


Maps contain **dust, synchrotron, CMB** and realistic *LiteBIRD* noise simulations

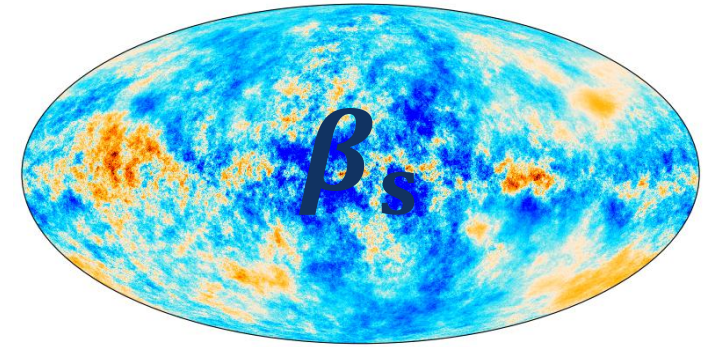
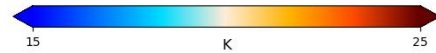
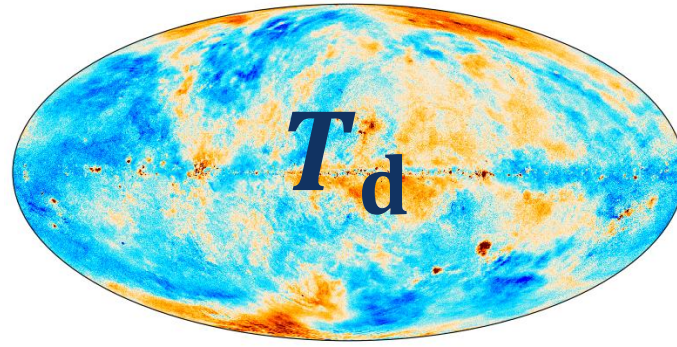
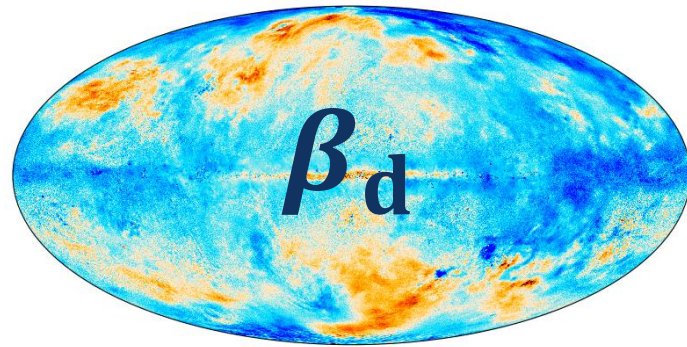
# Simulating *LiteBIRD* full-sky maps

- We simulate **different sky complexities** using the Python Sky Model (PySM; Thorne et al. 2017, Zonca et al. 2021, PanEx GS Group 2025)

**Low**  
(d9s4)



**Medium**  
(d10s5)



**High**  
(d12s7)

6 layers of spatially varying  $\beta_d, T_d \Rightarrow$  **line of sight integration**

Synchrotron **curvature**

# Angular power spectrum analysis



- **250 data sets** from Monte-Carlo realizations of CMB and noise, composed of **253 cross-frequency angular power spectra** in **12 multipole bins** of width  $\Delta\ell = 10$
- Spectral model:

$$C_\ell(\nu_i \times \nu_j) = C_\ell^{\text{CMB}}(\nu_i \times \nu_j) + \underbrace{C_\ell^{\text{dust}}(\nu_i \times \nu_j)}_{A_{\ell,d}, \beta_d(\ell), T_d(\ell)} + \underbrace{C_\ell^{\text{sync}}(\nu_i \times \nu_j)}_{A_{\ell,s}, \beta_s(\ell)} + \underbrace{C_\ell^{\text{dust} \times \text{sync}}(\nu_i \times \nu_j)}_{\rho_\ell}$$

- The **CMB component is fixed** during the fitting process, only included in the covariance
- *Planck* data are consistent with a **power-law scaling** of the dust and synchrotron amplitudes (Planck Int. XXX)

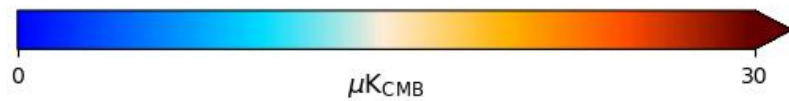
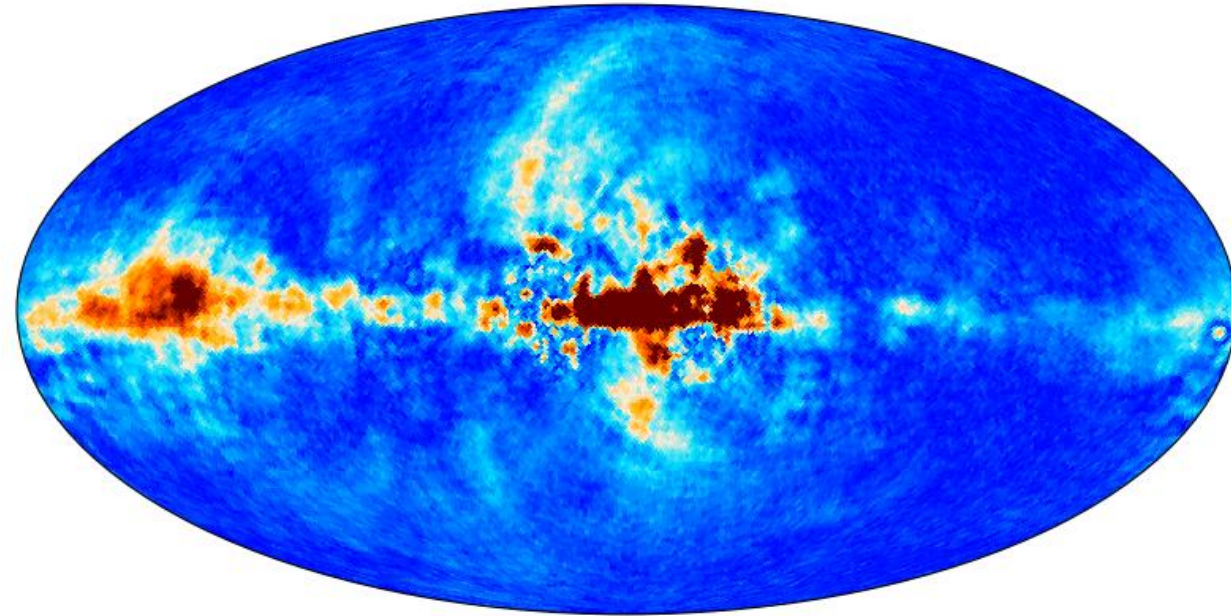
$$A_{\ell,d,s} = A_{0,d,s} \left( \frac{\ell}{\ell_0} \right)^{\alpha_{d,s}}$$

- First step: check this assumption for *LiteBIRD*!

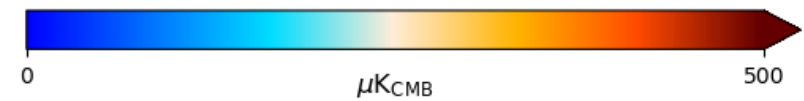
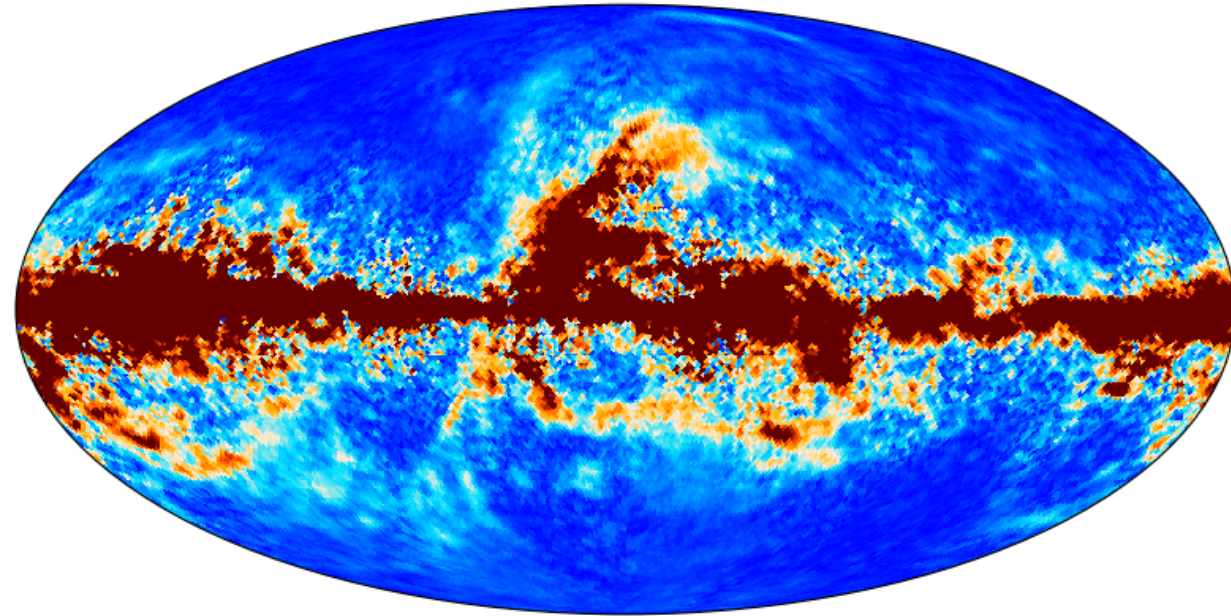
# Angular power spectrum analysis



40 GHz



402 GHz

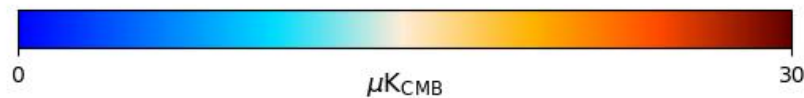
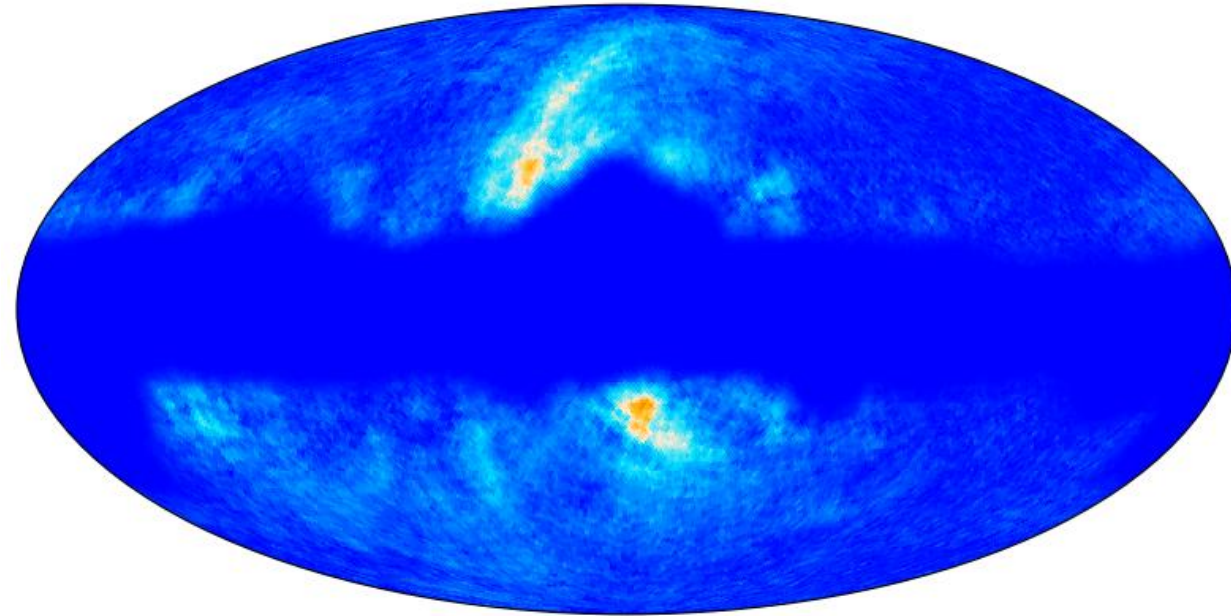


- We restrict our analysis to **diffuse ISM regions**, considering 70 % of the sky, masking the Galactic plane

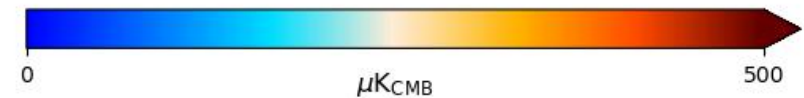
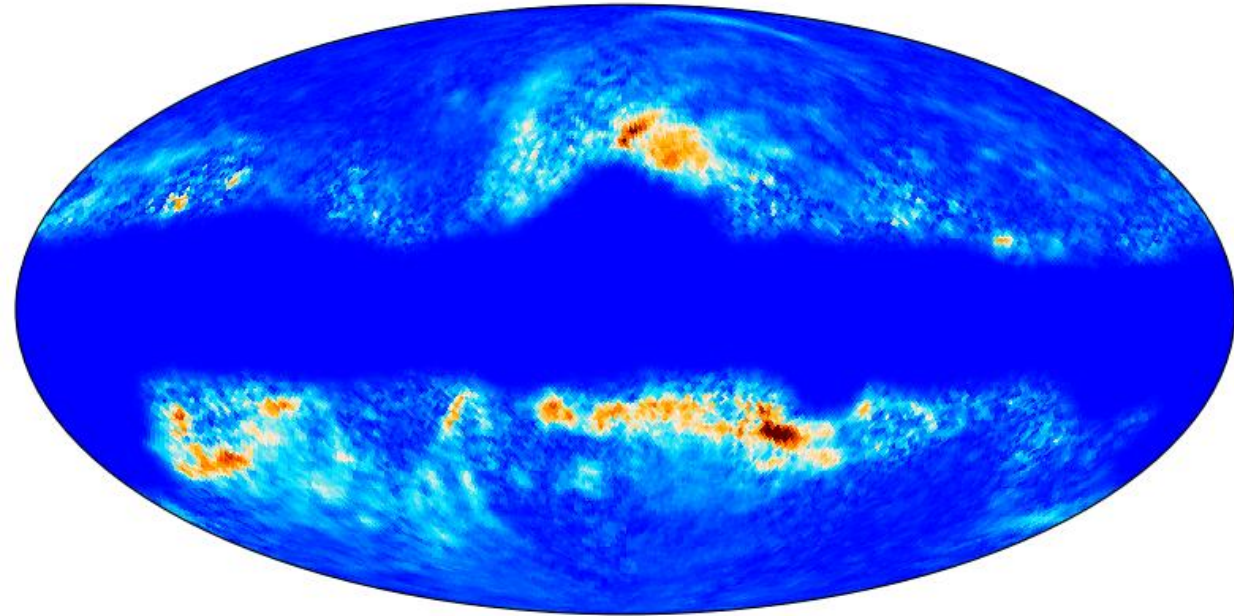
# Angular power spectrum analysis



40 GHz

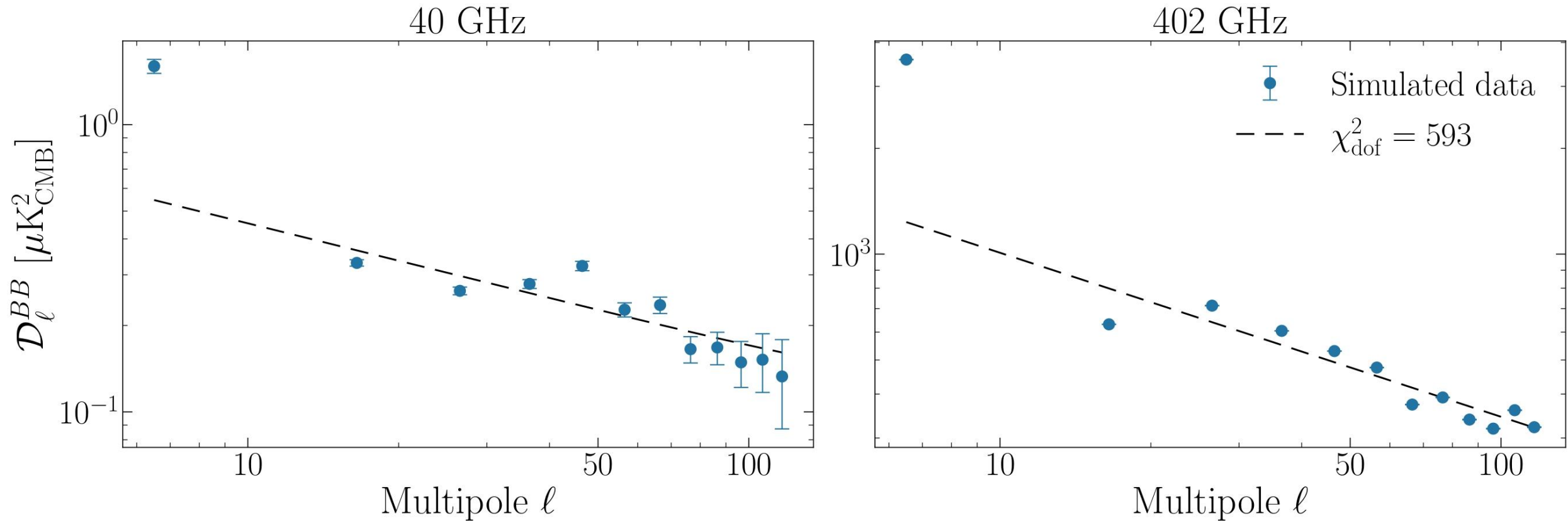


402 GHz



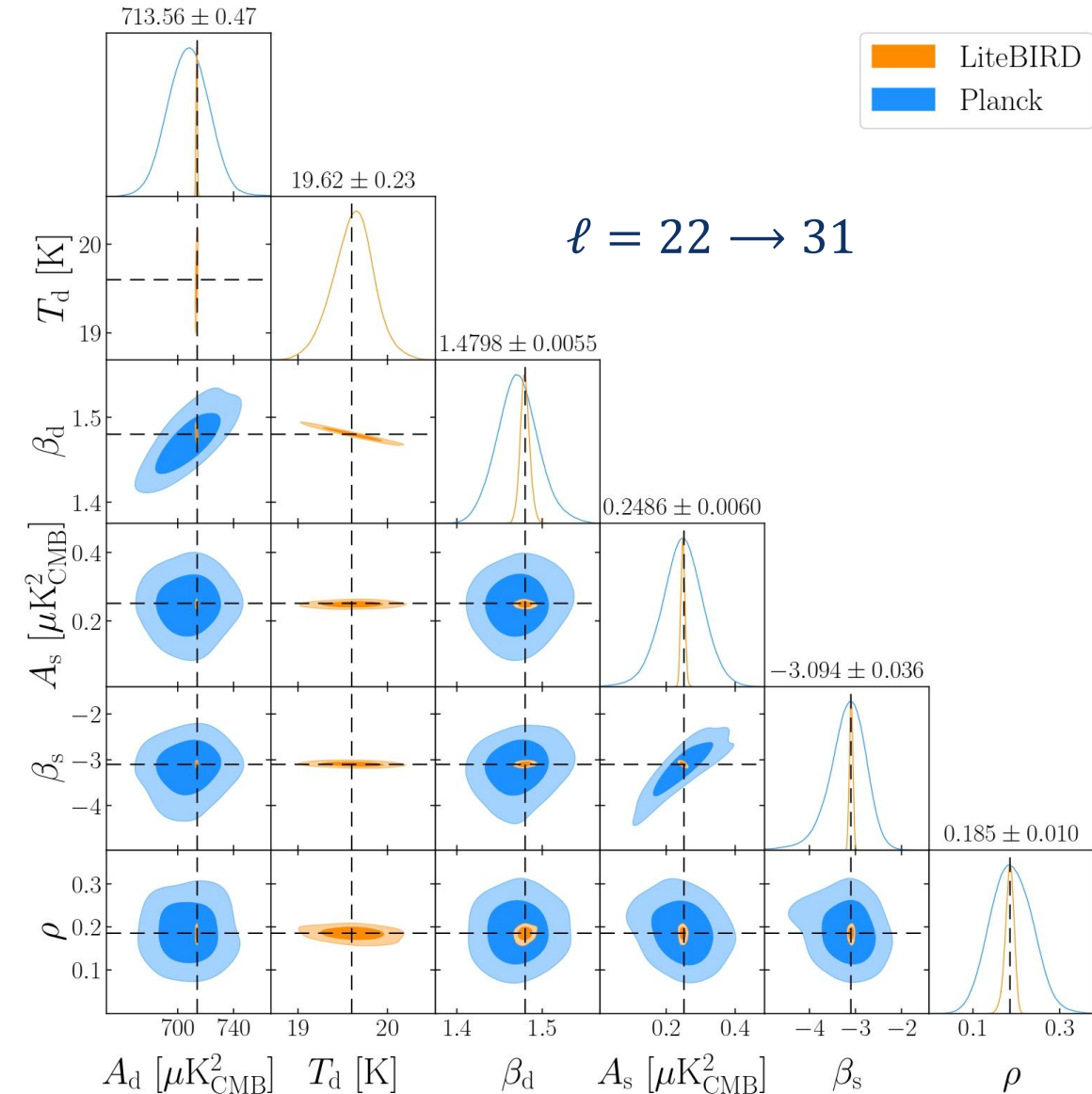
- We restrict our analysis to **diffuse ISM regions**, considering 70 % of the sky, masking the Galactic plane
- Let's start from the **low complexity** Galactic emission model (d9s4, spatially constant spectral parameters)

# Angular power spectrum analysis



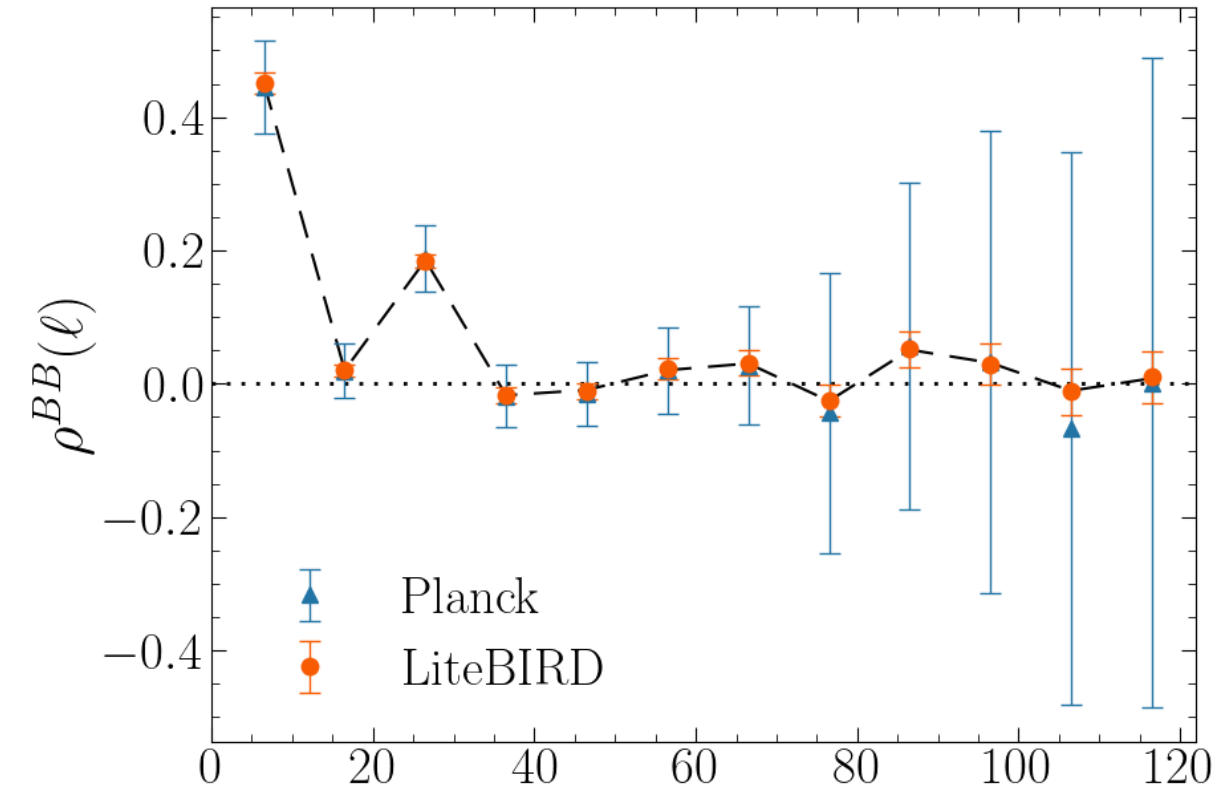
⇒ In the following, we fit **independent amplitudes** in each multipole bin

# LiteBIRD's constraining power in $B$ modes



- *LiteBIRD* will considerably **tighten the constraints** on all the parameters with respect to *Planck*
- Constraints on the dust temperature from the polarized SED were **not reachable by *Planck*** (worse frequency coverage in polarization, spectral resolution and sensitivity)
  - *LiteBIRD*: 15 bands (40-402 GHz)
  - *Planck*: 7 bands (30-353 GHz)
- Similar improvements in  $E$  modes

# LiteBIRD's constraining power in $B$ modes

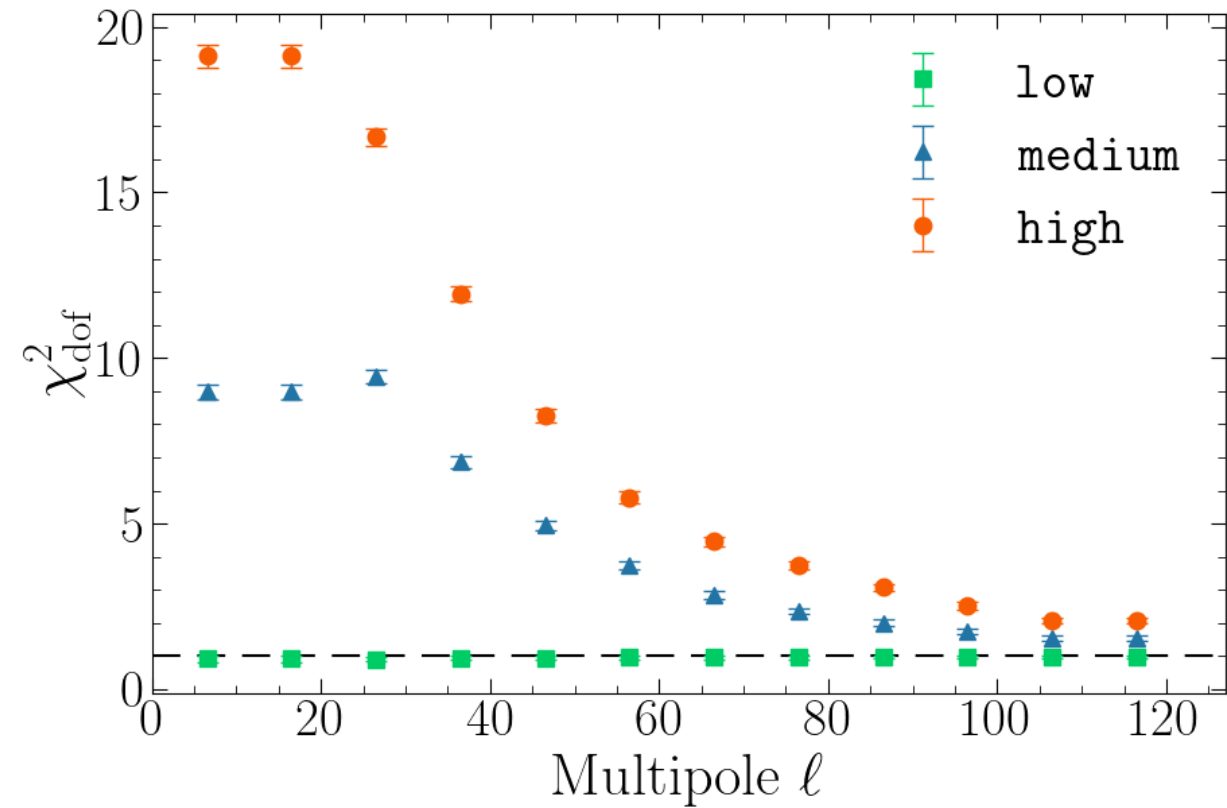
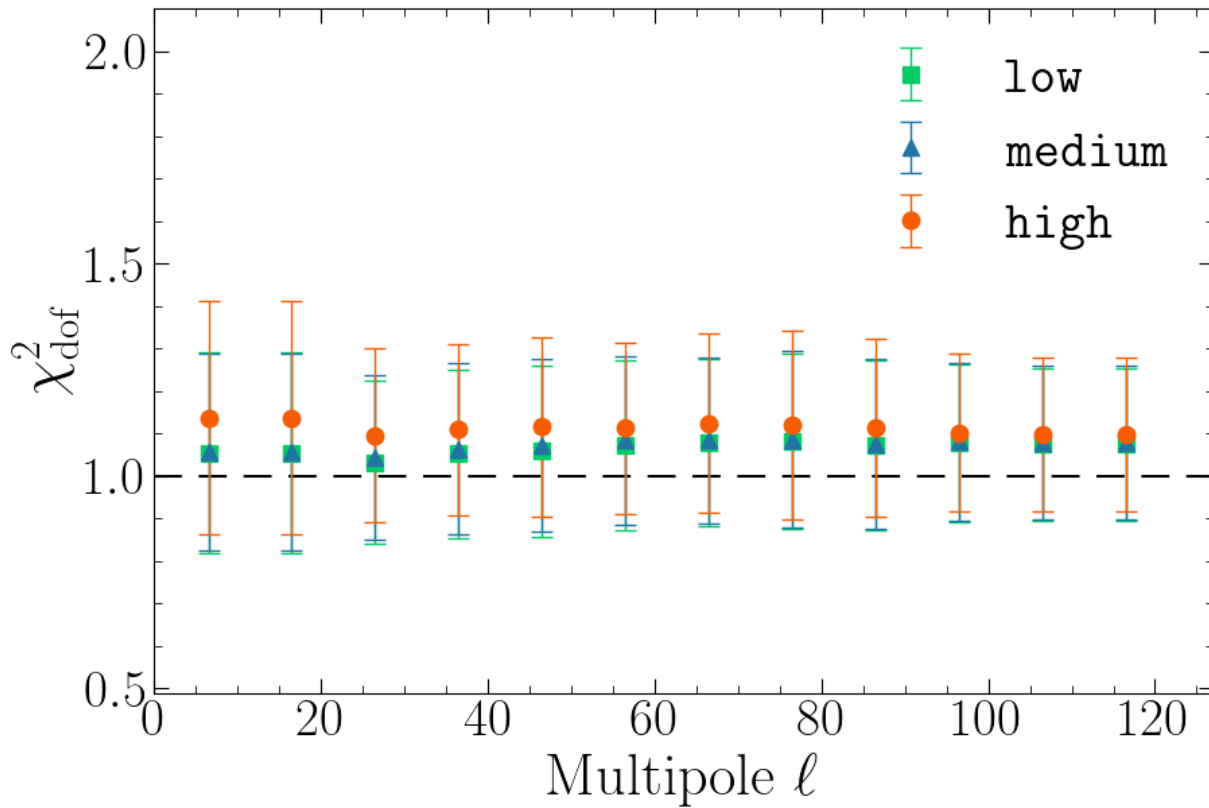


- **Spatial correlation** of dust and synchrotron emission as a function of angular scale
- These two processes **trace the same magnetic field structure**  $\Rightarrow$  highly correlated on large scales (Planck XI 2018)
- **Poorly constrained by Planck** at multipoles  $\ell \gtrsim 50$ , as synchrotron amplitude was measured to be consistent with zero
- Tight constraints **at all scales** with *LiteBIRD*

# Distortions of the SED

*Planck*

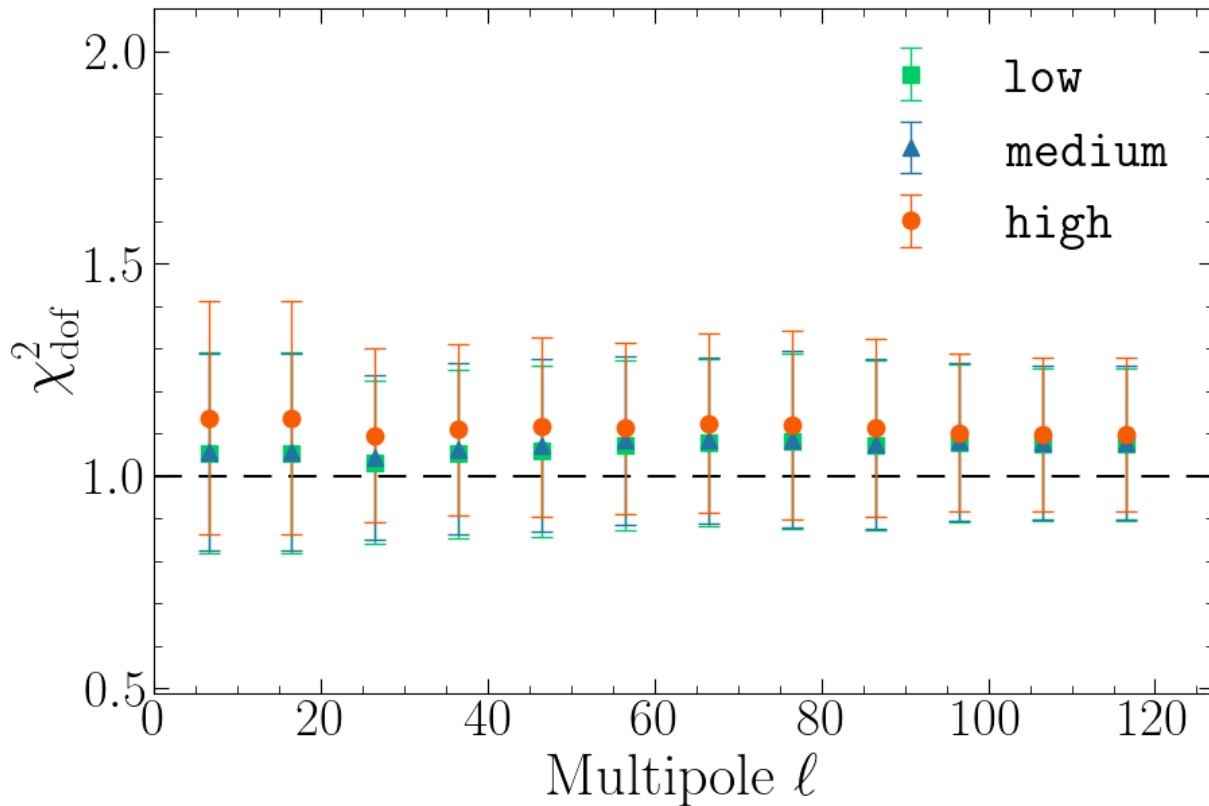
*LiteBIRD*



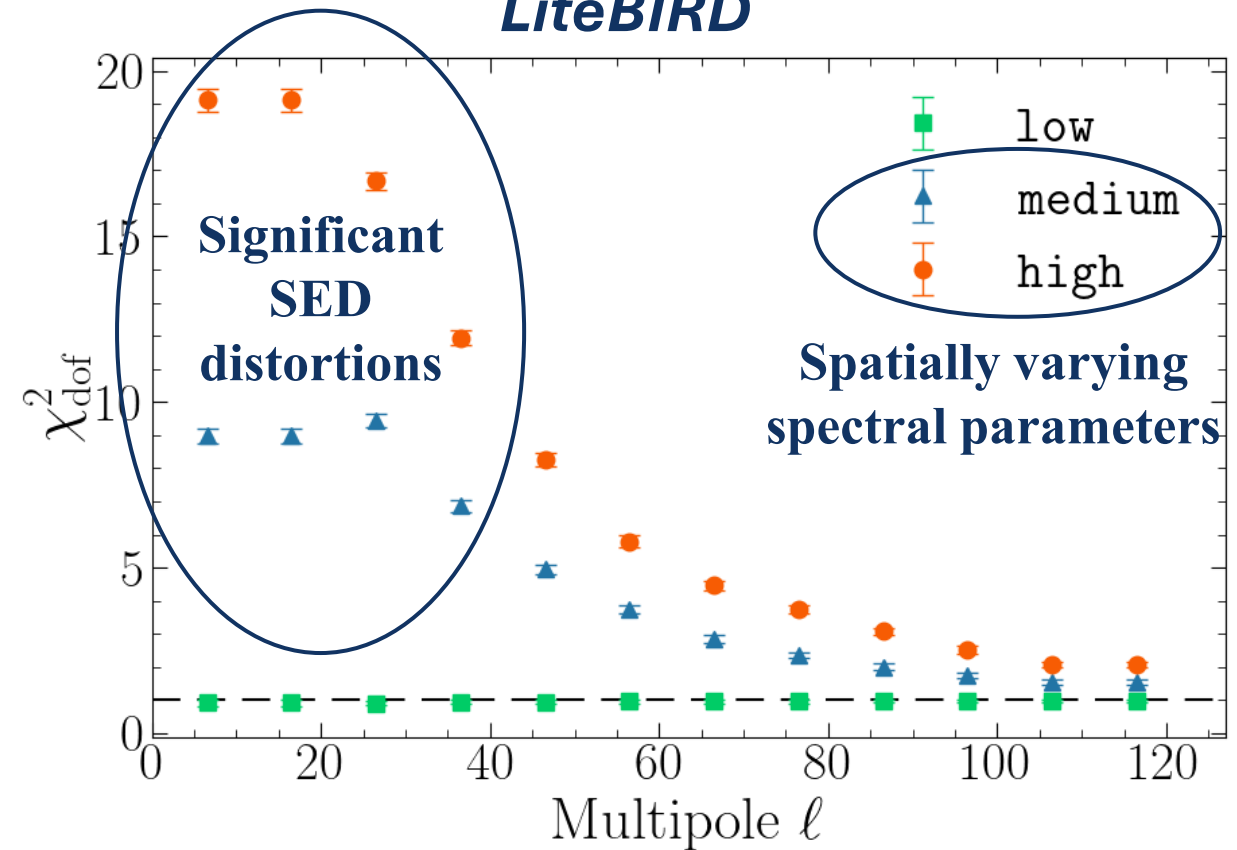
- *LiteBIRD* data **may not be compatible with the MBB+PL parametrization**, even if individual clouds emit as a perfect MBB
- SED distortions due to **spectral mixing** along and across lines of sight (within pixels, beam, harmonic space)

# Distortions of the SED

*Planck*



*LiteBIRD*

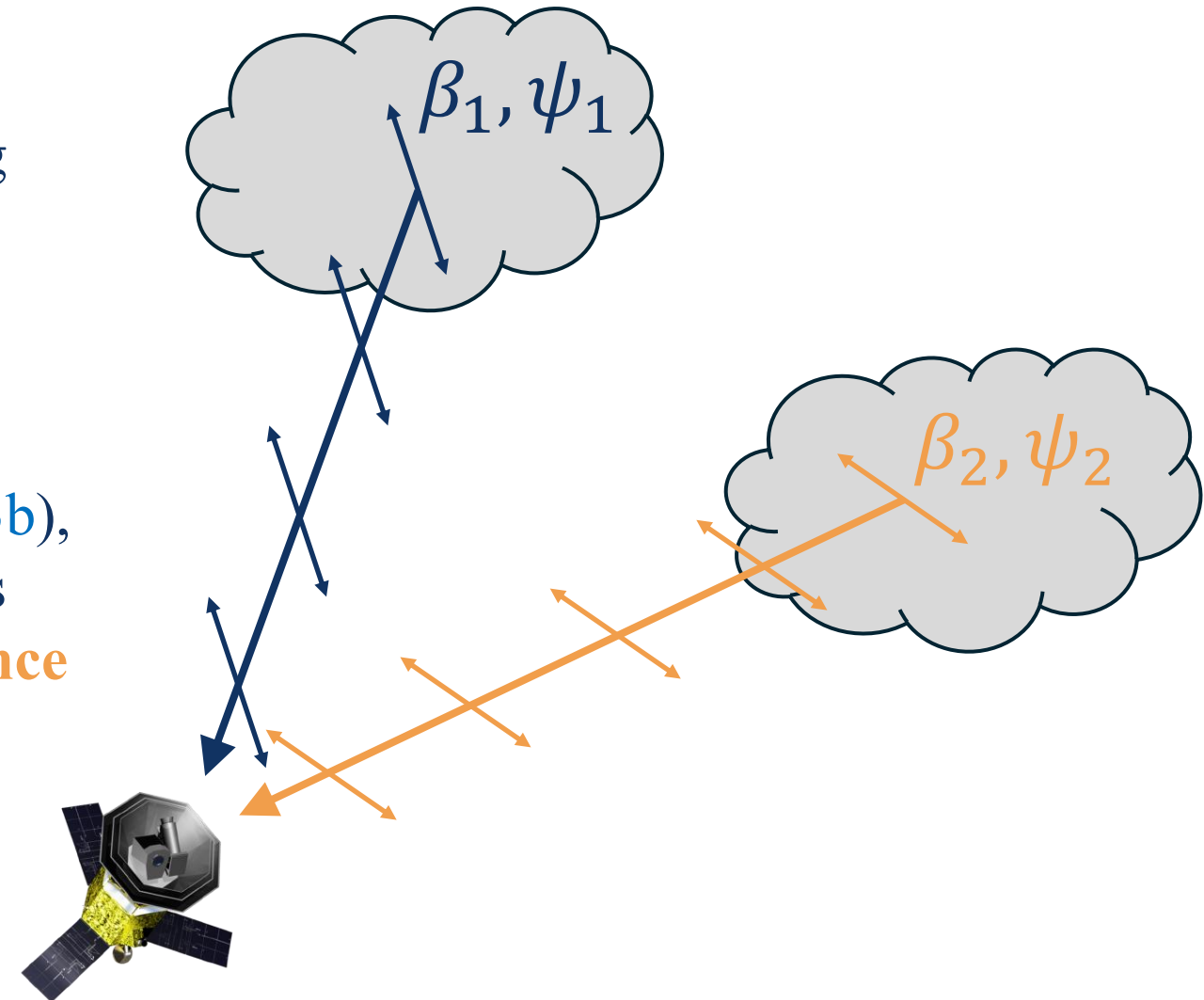


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# Polarized mixing and $E/B$ -discrepancies

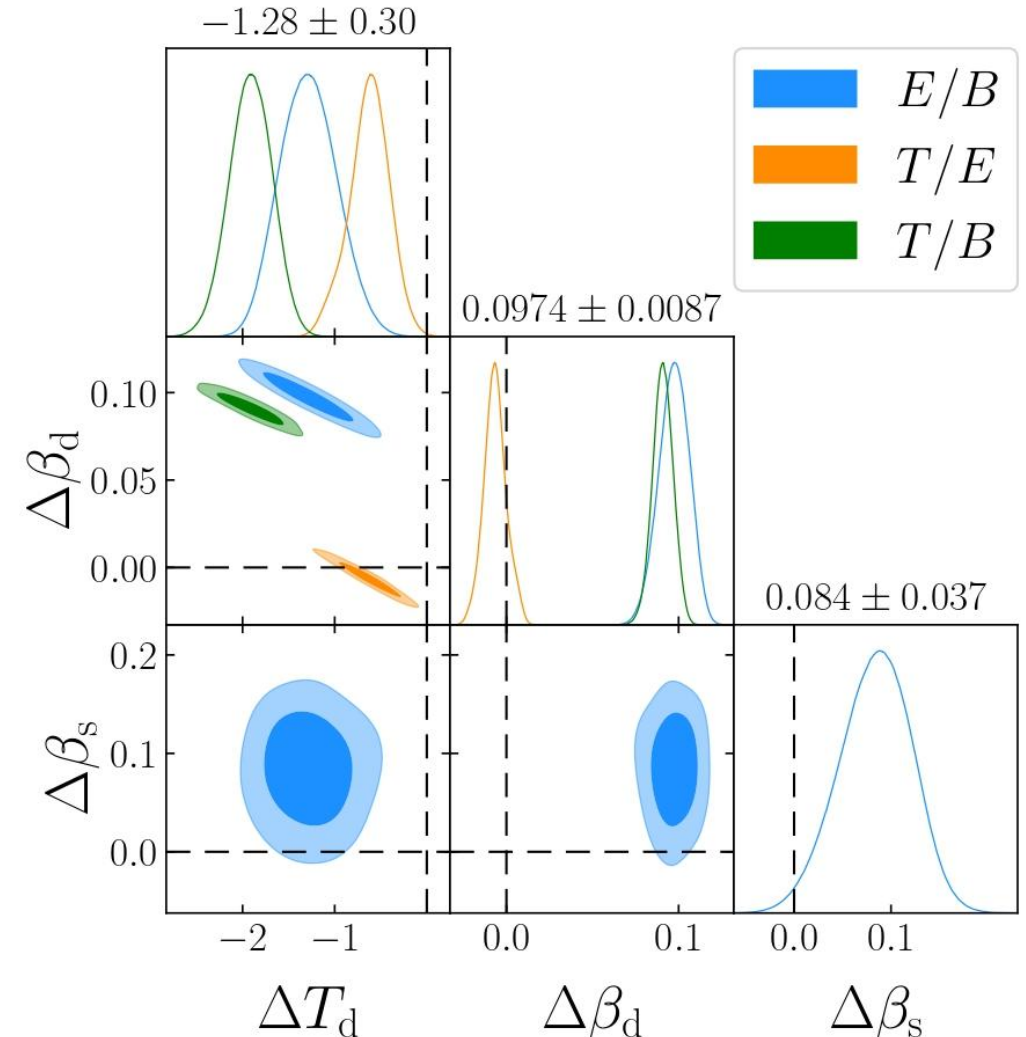


- When computing angular power spectra, we average several regions of the sky presenting **different spectral properties and polarization angles**
- The spectral behavior may therefore **differ between  $E$  and  $B$  modes** (Vacher et al. 2023b), especially at large scales where the mixing is the most important  $\Rightarrow$  **Frequency dependence of the  $E/B$  ratio**



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- Differences are also expected with  $TT$  power spectra ( **$T/E$ - and  $T/B$ -discrepancies**)



# Moment expansion to model SED distortions



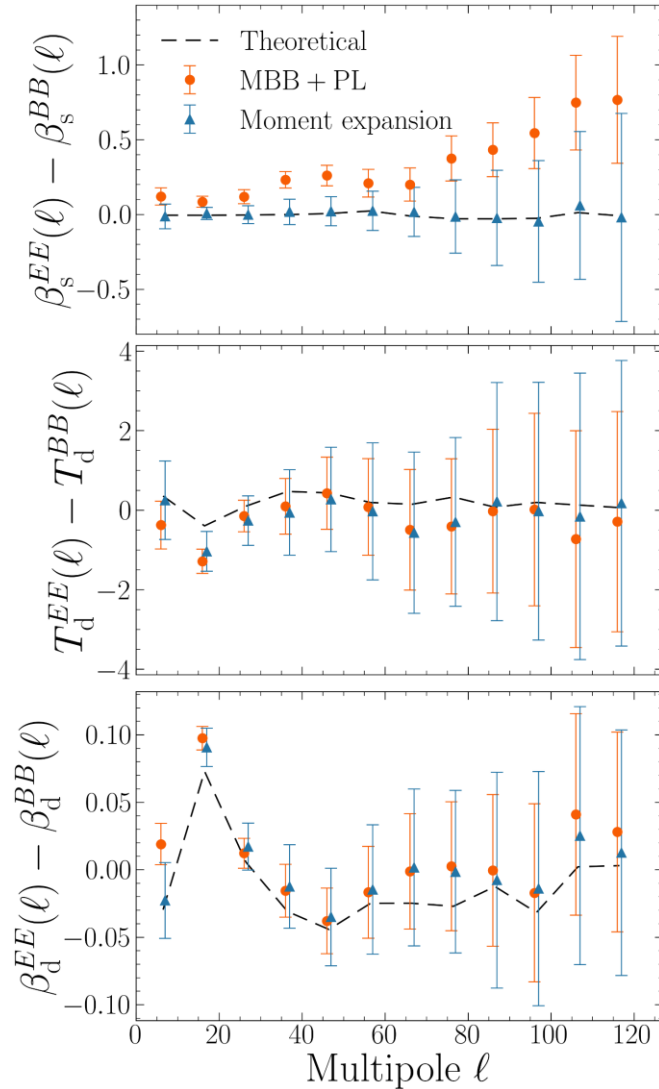
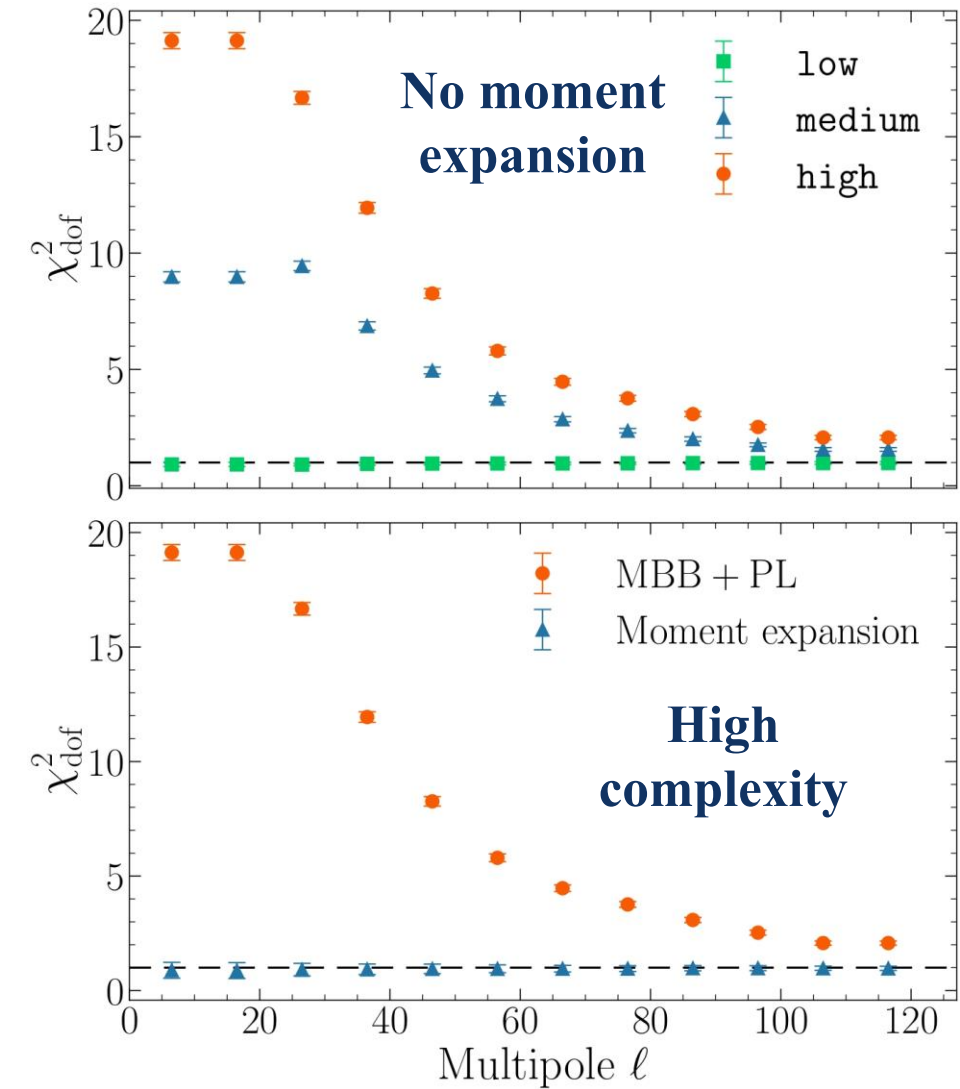
- Idea: model the SED distortions by **Taylor-expanding the SED** around pivot values of the spectral parameters (Chluba et al. 2017, generalized to polarization in Vacher et al. 2023a, applied to cross- $C_\ell$  by Mangilli et al. 2021, Azzoni et al. 2021, Vacher et al. 2022)

$$S_{\nu,d}(\overline{\beta}_d, \overline{T}_d) = A_d \epsilon_d(\nu, \overline{\beta}_d, \overline{T}_d) + \omega_1^{\beta_d} \left. \frac{\partial \epsilon_d}{\partial \beta_d} \right|_{\overline{\beta}_d, \overline{T}_d} + \omega_1^{1/T_d} \left. \frac{\partial \epsilon_d}{\partial (1/T_d)} \right|_{\overline{\beta}_d, \overline{T}_d} + \dots$$

First order moments

- Using this formalism, one can compute **theoretical expectations** for the  $\ell$ -dependence of the spectral parameters from the maps of  $\beta_d$ ,  $T_d$  and  $\beta_s$  input in the simulations
- One can also **extend our spectral model** with moments to account for the spectral mixing

# Moment expansion to model SED distortions



- Moment expansion allows the reduced  $\chi^2$  to be **compatible with one** at all angular scales
- It also allows to **predict and model the discrepancies** in the spectral parameters due to polarized mixing
- This effect has only been **marginally detected in *Planck* data** when keeping in the analysis a **large fraction of the Galactic plane**, where the mixing is more important (Ritacco et al. 2023).  
With *LiteBIRD*: **extend to high Galactic latitudes!**

- With its increased frequency coverage, number of bands and sensitivity with respect to *Planck*, *LiteBIRD* will be able **to accurately constrain the SED of polarized thermal dust and synchrotron emission in the diffuse ISM**
- It will be able to **detect and quantify variations of the spectral parameters across the three dimensions of the Milky Way**, by detecting deviations from the widely used dust MBB and synchrotron PL emission laws
- *LiteBIRD* will also be able to **detect discrepancies** between the SEDs in intensity, *E* modes and *B* modes, **for the first time in the diffuse ISM**
- Moment expansion is the **proper framework** to model these effects, and will play a key role in the data analysis of future high sensitivity CMB experiments