Moment expansion: a new path towards capturing the CMB B-modes with LiteBIRD

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Context and introduction

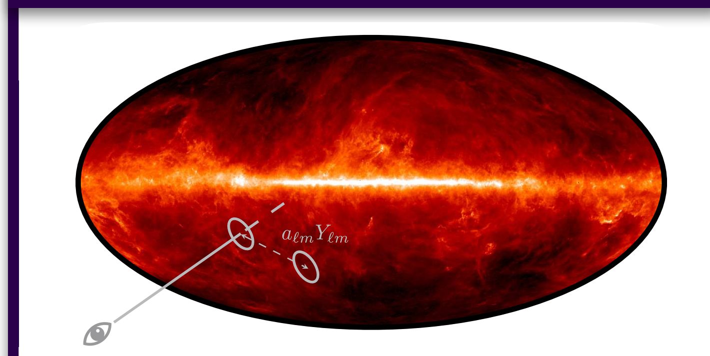
- LiteBIRD is designed to reach the scalar to tensor ratio r , smoking gun for cosmic inflation, with strong limit $\sigma(r) \approx 10^{-4}$
- Polarized foregrounds must be characterized with very high accuracy, otherwise they induce a biais on r

- We propose to apply a method to characterize the complexity of the high frequency polarized SED (spectral distortions) of thermal galactic dust emission.
- This method is an extent of the Moment expansion (Chluba et al 2017) in harmonic space (done in Mangilli et al 2019)
- Application to simulated LiteBIRD observation in order to reach an unbiased value for r

SED distortions

Unavoidable SED averages :
- Along the Line of sight (depth)
- Between lines of sights (in instrumental beams)
- Over whole sky regions (spherical harmonics)

Dust, synchrotron etc … SED are non linear → SED spectral distortions



Moment expansion of the SED to catch spectral distortions

Standard way to characterize thermal dust emission : modified black-body (MBB)
New idea : Taylor like expansion of the SED in β around the modified black body

Spectral index Black body Moment of order i

$$I_D(\nu,\vec{n}) = \left(\frac{\nu}{\nu_0}\right)^{\beta} \frac{B_\nu(T)}{B_{\nu_0}(T)} A(\vec{n}) = \frac{I_\nu(\beta,T)}{I_{\nu_0}(\beta,T)} A(\vec{n}) \longrightarrow I_D(\nu,\vec{n}) = \frac{I_\nu(\beta_0,T_0)}{I_{\nu_0}(\beta_0,T_0)} \left[A(\vec{n}) + \sum_{i=1}^{\infty} \frac{1}{i!}\omega_i(\vec{n}) \ln^i\left(\frac{\nu}{\nu_0}\right)\right]$$

Intensity map

Generalization of the above formula in harmonic space and cross-power spectra :

$$\mathcal{D}_{\ell,\text{moments}}^{\nu_1\times\nu_2} = \frac{I_\nu\left(\beta_0(\ell),T_0\right) I_\nu\left(\beta_0(\ell),T_0\right)}{I_{\nu_0}^2\left(\beta_0(\ell),T_0\right)} \Bigg\{ \mathcal{D}_\ell^{A_d\times A_d} + \sum_{k=1}^{\infty} \frac{1}{k!} \mathcal{D}_\ell^{A_d\times\omega_k} \left[\ln^k\left(\frac{\nu_1}{\nu_0}\right) + \ln^k\left(\frac{\nu_2}{\nu_0}\right)\right] + \sum_{i,j=1}^{\infty} \frac{1}{i!j!} \mathcal{D}_\ell^{\omega_i\times\omega_j} \left[\ln^i\left(\frac{\nu_1}{\nu_0}\right) \ln^j\left(\frac{\nu_2}{\nu_0}\right)\right] \Bigg\}$$

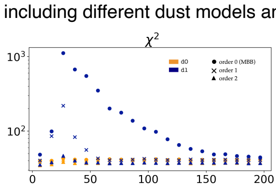
Cross-frequency spectra

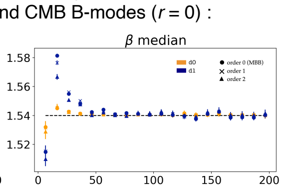
« Going to order N » => stopping the sums at k,i,j = N

Results : SED parameters and moments

χ^2 minimization on the cross-spectra extracted from LiteBIRD 9 highest frequency channels sky simulations including different dust models and CMB B-modes ($r = 0$) :

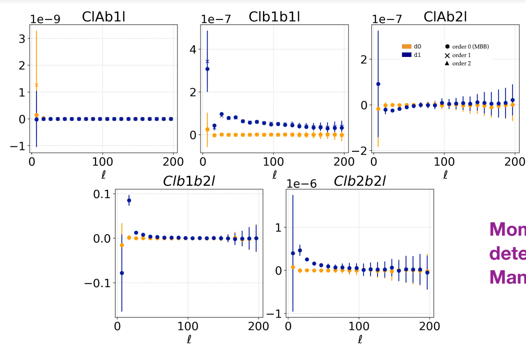
- **d0 :** MBB with constant SED parameters $\beta_{d0} = 1.54$
- **d1** : spatial variation of SED parameters





1. We are able to retrieve $\beta_{d0} = 1.54$ for d0
2. Significantly varying β_{d1} implying spectral distortions
3. χ^2_{d0} small for MBB and unaffected by moment expansion
4. χ^2_{d1} large for MBB and improving with moment expansion until order 2

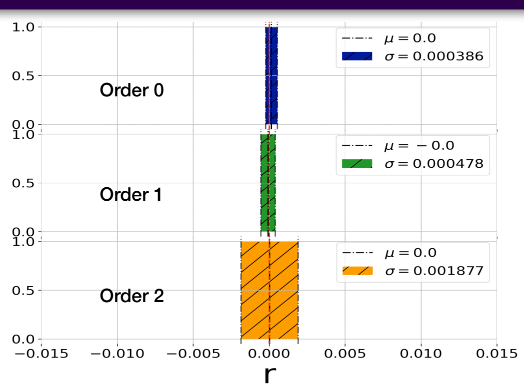
Spectral distortions are present for d1 and captured by moment expansion

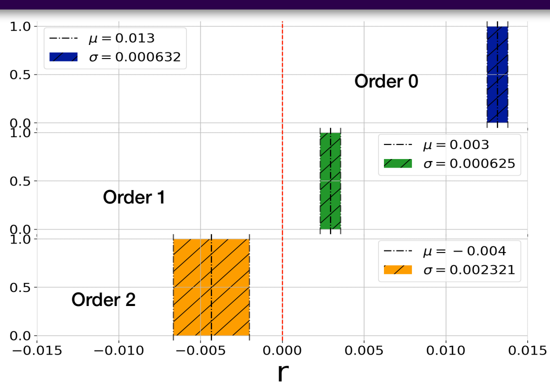


Moments remains undetected for d0, confirming that MBB is already a good model

Moments significantly detected for d1 as in Mangilli et al (2019)

Results : tensor to scalar ratio





d0 : MBB is a good fit, no biais on r at any time. Moment expansion leads to no biais but increasing standard deviation

d1 : MBB flawed inducing large biais on *r.* The biais is significantly reduced thanks to moment expansion up to order 2.

Wha to do next ?

- Trying new implementations to find the best tradeoff biais/std on r (incoming paper)
- Test the robustness of this results with an input r greater than zero (incoming paper)
- find a way to include other polarized foregrounds like synchrotron and look at all the frequency bands.
- Couple moment expansion with other methods
- Moments already used successfully for other instruments like Simon's observatory (See S. Azzoni's poster and paper **(Azzoni et al 2020)**. Could be applied in the same spirit to LiteBIRD systematic effects

Conclusion and take-away

- Applying moment expansion in harmonic space significantly reduced the biais on r due to spatial variation of dust's SED parameters
- This methods (coupled with others) could help reaching LiteBIRD's foregrounds high precision objectives