Forecasts with LiteBIRD and a low-frequency MFI-like instrument

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RADIO FOREGROUNDS

Motivation for this talk: The importance of the low-frequency characterization

How important are the low-frequency bands in the determination of r?

- Would a deeper knowledge about the synchrotron have an impact on a possible primordial gravitational wave detection?
- How much would a hypothetical forthcoming QUIJOTE-MFI like experiment contribute as a complement to LiteBIRD?

Forecasting procedure

- Use of PySM simulations at $N_{side} = 32$ of the observations corresponding to several instrumental configurations.
- The residuals and noise level in the recovered CMB map are estimated with fgbuster (see Errard et al. JCAP03(2016)052 and D. Poletti's talk).
- Forecast on the r determination are computed assuming a Gaussian likelihood approach.

Forecasting procedure

- Gaussian likelihood for $\sigma(r)$:

$$\mathcal{L} \propto \exp\left(-\frac{1}{2}\chi^2\right), \qquad \chi^2 = \sum_{\ell} \frac{[C_\ell - (rP_\ell + L_\ell + R_\ell)]^2}{\frac{2}{2\ell+1}(r^* P_\ell + L_\ell + R_\ell)^2}$$

- Marginalized value for r:

$$\sigma(r) = (F_{\rm sky}\mathrm{F}_{11})^{-1/2}$$

$$F_{ij} = \frac{1}{2}\frac{\partial^2 \chi^2}{\partial\theta_i \partial\theta_j}$$

r^*: True value $r = 0.001$.
P_ℓ: fiducial BB primordial CMB spectrum for $r = 1$.
L_ℓ: fiducial BB lensing spectrum.
R_ℓ: BB residual + noise spectrum model.

Instrument configurations

- LiteBIRD (freqs: 40 - 400 GHz)

Frequency (GHz)	40.0	50.0	60.0	68.4	78.0	88.5	100.0
P Sens ($\mu K \cdot \mathrm{arcmin}$)	42.4	25.8	20.1	15.6	12.5	10.1	11.8

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118.9	140.0	166.0	195.0	234.9	280.0	337.4	402.1
9.5	7.6	6.7	5.1	6.3	10.1	10.1	19.1

- LiteBIRD + MFI (or "super" MFI)

Frequency (GHz)	11.0	13.0	17.0	19.0
P Sens "super" MFI ($\mu K \cdot \mathrm{arcmin}$)	21.0	21.0	21.0	21.0

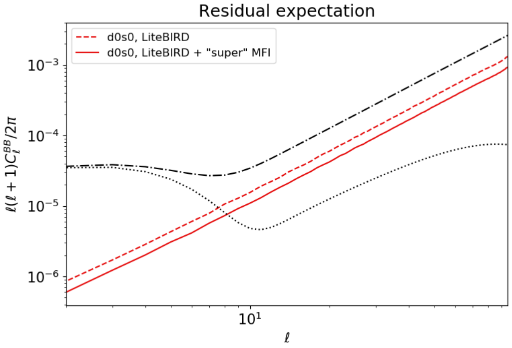
Simulated sky

- CMB with r = 0.001.
- Dust (d0 model from PySM): modified black body with $\nu_0 = 353$ GHz and fixed $T = 20$ K and $\beta_d = 1.54$.
- Synchrotron with $\nu_0 = 23$ GHz:
  - s0: power law with fixed $\beta_s = -3.0$.
  - s1: power law with varying β_s.
  - s0curv: curved power law with fixed $\beta_s = -3.0$ and curvature running C.
  - s1curv: curved power law with varying β_s and fixed curvature running C.

Homogeneous spectral parameters

Case	d0s0	
Instrument configuration	LiteBIRD	LiteBIRD + "super" MFI
$\sigma(\beta_s)$	0.00046	0.00001
$\sigma(r)$	0.00022	0.00021

5% of improvement

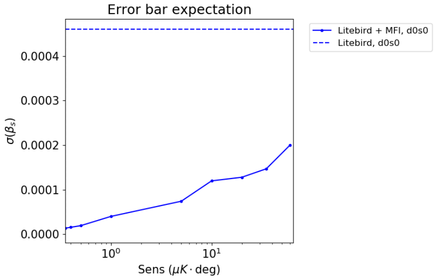


Impact of the MFI sensitivity

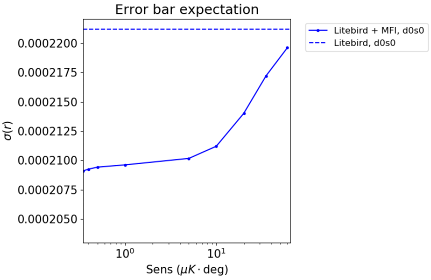
Different MFI sensitivity for a LiteBIRD + MFI configuration:

- Homogeneous spectral parameters.

$\sigma(\beta_s)$ vs MFI sensitivity

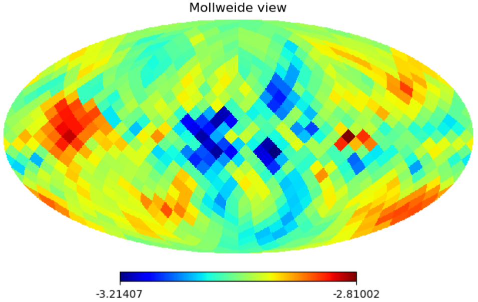


$\sigma(r)$ vs MFI sensitivity



Varying synchrotron spectral index

- The β_s PySM template degraded to $N_{side} = 8$ is used to generate the simulations at $N_{side} = 32$.

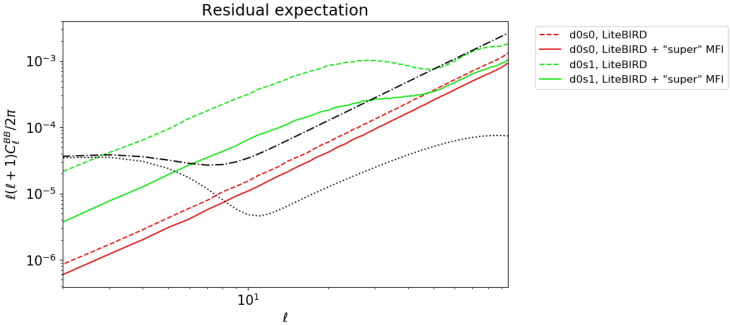


- The component separation is done with fgbuster independently in pixels of $N_{side} = 8$.

Varying synchrotron spectral index

Case	d0s1	
Instrument configuration	LiteBIRD	LiteBIRD + "super" MFI
$\sigma(\beta_s)$	0.17862	0.00333
$\sigma(r)$	0.00045	0.00027
$\sigma(r)$ up to $\ell = 23$	0.00065	0.00035

40% of improvement (47% up to $\ell = 23$)

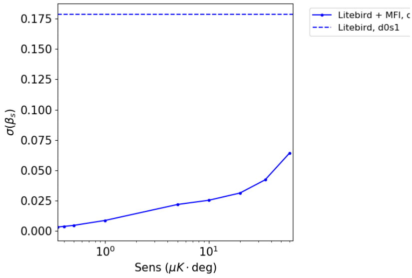


Impact of the MFI sensitivity

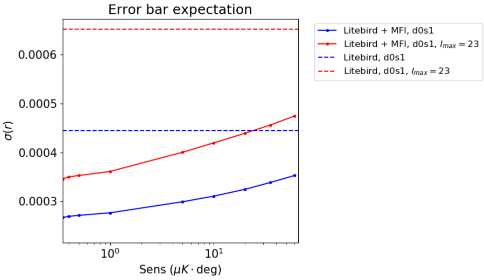
Different MFI sensitivity for a LiteBIRD + MFI configuration:

- Varying synchrotron spectral index.

$\sigma(\beta_s)$ vs MFI sensitivity

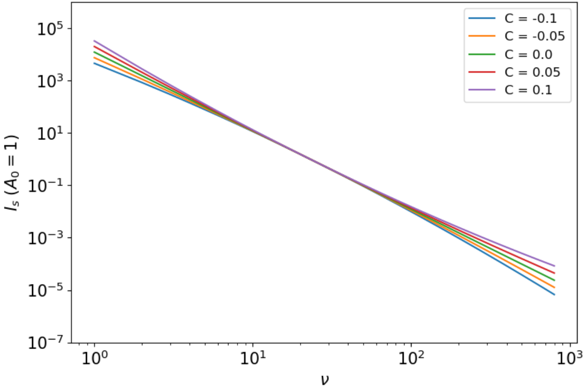


$\sigma(r)$ vs MFI sensitivity



Including synchrotron curvature

$$I_s = A_0 \left(\frac{\nu}{\nu_0} \right)^{\beta_s + C \log \frac{\nu}{\nu_0}}, \ \nu_0 = 23.0$$



Forecast for different curvatures

- Homogeneous spectral parameters.

Configuration	LiteBIRD	LiteBIRD + "super" MFI
Case	C=-0.052	
$\sigma(\beta_s)$	0.00892	0.00014
$\sigma(C)$	0.00595	0.00013
$\sigma(r)$	0.00022	0.00021
Case	C=0.0	
$\sigma(\beta_s)$	0.00239	0.00003
$\sigma(C)$	0.00167	0.00003
$\sigma(r)$	0.00022	0.00021
Case	C=0.052	
$\sigma(\beta_s)$	0.00950	0.00014
$\sigma(C)$	0.00698	0.00012
$\sigma(r)$	0.00023	0.00021

Forecast for different curvatures

If $C_{sky} = 0.0$, fitting curvature increases the error bar of the synchrotron parameters with respect the d0s0 case but it has a neglected impact on r.

With respect to the LiteBIRD case, including a "super" MFI implies:

- Almost two orders of magnitude improvement in the determination of the synchrotron parameters.
- 5% improvement in the determination of r.

In the homogeneous spectral index case, the estimation of the synchrotron parameters is already sufficiently good such that the improvement in the determination of r by including a QUIJOTE-MFI like experiment is limited.

Forecast for different curvatures

- Homogeneous spectral parameters adding the 30 GHz band with $0.1\mu K \cdot \mathrm{deg}$.

Configuration	LiteBIRD + "super" MFI + 30 GHz
Case	C=-0.052
$\sigma(\beta_s)$	0.00006
$\sigma(C)$	0.00006
$\sigma(r)$	0.00020
Case	C=0.0
$\sigma(\beta_s)$	0.00002
$\sigma(C)$	0.00002
$\sigma(r)$	0.00021
Case	C=0.052
$\sigma(\beta_s)$	0.00006
$\sigma(C)$	0.00006
$\sigma(r)$	0.00020

Forecast for different curvatures

Advantages of including the 30 GHz band with $0.1\mu K \cdot \mathrm{deg}$:

With respect to the LiteBIRD + "super" MFI case:

- $50\% - 60\%$ improvement in the determination of the synchrotron parameters when $C_{sky} = \pm 0.052$.
- $20\% - 30\%$ improvement in the determination of the synchrotron parameters when $C_{sky} = 0.0$.
- 2% improvement in the determination of r.

With homogeneous spectral parameters, even including a 30 GHz channel does not make a significant difference on r.

Forecast for different curvatures

- Varying synchrotron spectral index.

Configuration	LiteBIRD + “super” MFI	
Case		C=-0.052
$\sigma(\beta_s)$	-	0.01633
$\sigma(C)$	-	0.01480
$\sigma(r)$	-	0.00029
$\sigma(r)$ up to $\ell = 23$	-	0.00039
Case	Without curvature	C=0.0
$\sigma(\beta_s)$	0.00333	0.01626
$\sigma(C)$	-	0.01471
$\sigma(r)$	0.00027	0.00029
$\sigma(r)$ up to $\ell = 23$	0.00035	0.00040
Case		C=0.052
$\sigma(\beta_s)$	-	0.01629
$\sigma(C)$	-	0.01462
$\sigma(r)$	-	0.00030
$\sigma(r)$ up to $\ell = 23$	-	0.00040

Forecast for different curvatures

In this case, fitting the curvature running when $C_{sky} = 0.0$, implies a worsening of the determination of the synchrotron spectral index of one order of magnitude and a negative impact on the r determination at a 10% level.

For non-null curvature, positive values of C implies slighty greater error bars than the negative ones. This is expected because the synchrotron emission is greater when the curvature is positive.

Forecast for different curvatures

Including the 30 GHz band involves a 50% − 60% improvement in the determination of the synchrotron parameters and ∼ 20% in the r estimation with respect to the LiteBIRD + "super" MFI case.

Configuration	LiteBIRD + "super" MFI + 30 GHz
Case	C=-0.052
$\sigma(\beta_s)$	0.00675
$\sigma(C)$	0.00734
$\sigma(r)$	0.00025
$\sigma(r)$ up to $\ell = 23$	0.00033
Case	C=0.052
$\sigma(\beta_s)$	0.00704
$\sigma(C)$	0.00751
$\sigma(r)$	0.00026
$\sigma(r)$ up to $\ell = 23$	0.00034

Conclusions

- This is a preliminary study of the effect of including low-frequency bands in the determination of r.
  - More foreground models and instrumental configurations should be considered, and specially biased cases in which the sky emission is not exactly described by the model.
- Including a QUIJOTE-MFI like experiment involves an improvement about $40\% - 50\%$ in the determination of r when considering a realistic case (varying index model without curvature).
- The case including curvature should be further explored.
- For more complex sky emission, it is expected that the role of the low-frequency bands is more important.