# On the Detection of Primordial CMB B-modes from Ground at Low Frequency

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# Outline

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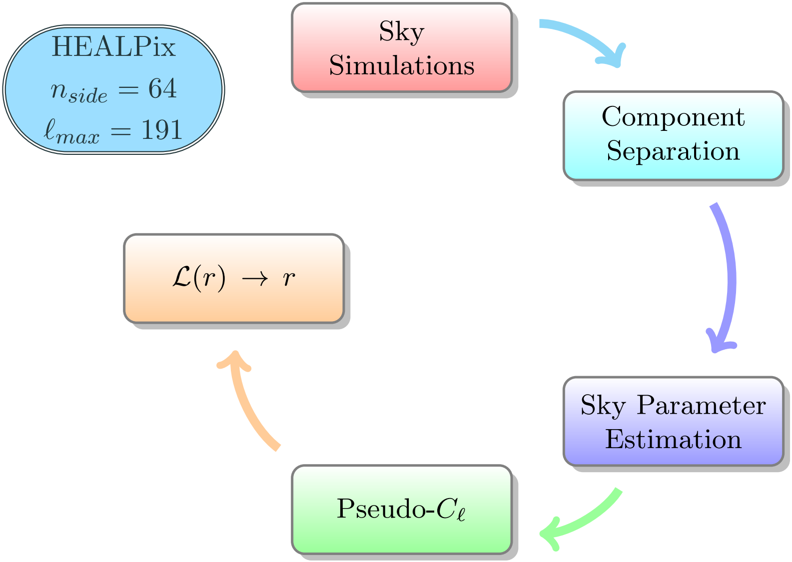
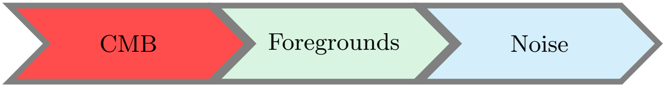
- This experiment could be a natural **complement** to other on-going and planned ones (both on-ground or satellite), which typically survey frequencies larger than the ones here considered.
- This is a **preliminary study** in the context of the European Low Frequency Survey (**ELFS**) initiative.
- As a first step we have conducted this study for an experiment located at the Teide Observatory (**Northern Hemisphere**), although the long-term purpose is to cover the full-sky from ground.

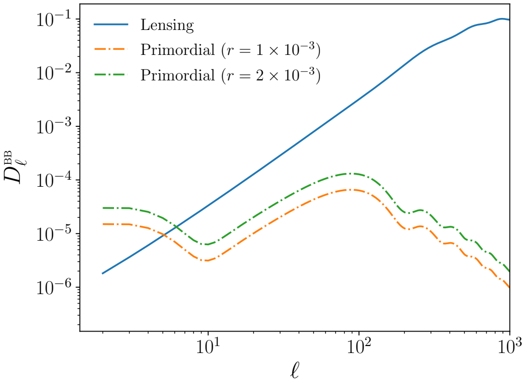
# Methodology

# Methodology Approach



# Sky Simulations




Lewis et al., astro-ph/9911177

| Parameter | TT,TE,EE+lowE +lensing+BAO |
|---|---|
| $\Omega_b$ | $0.02242 \pm 0.00014$ |
| $\Omega_c$ | $0.11933 \pm 0.00091$ |
| $100\theta_{MC}$ | $1.04101 \pm 0.00029$ |
| $\tau$ | $0.0561 \pm 0.0071$ |
| $\ln(10^{10} A_s)$ | $3.047 \pm 0.014$ |
| $n_s$ | $0.9665 \pm 0.0038$ |

Planck 2018 results. VI. Cosmological parameters, 1807.06209

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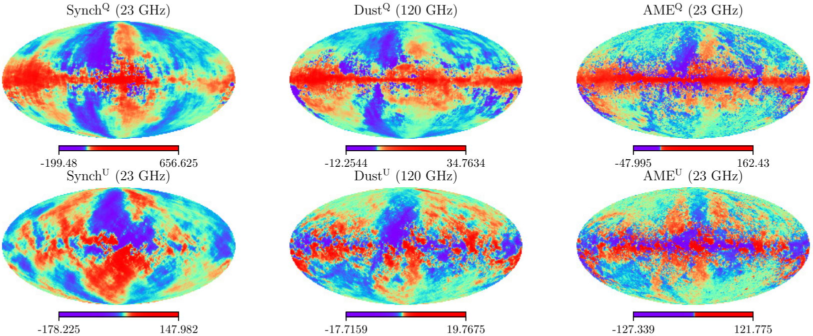


Thorne et al., 1608.02841 (PySM)

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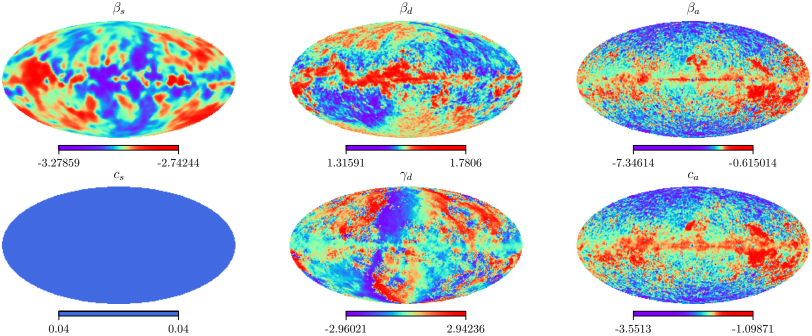


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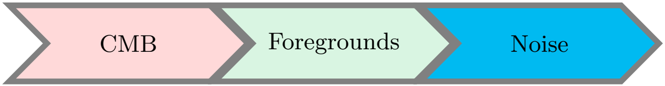


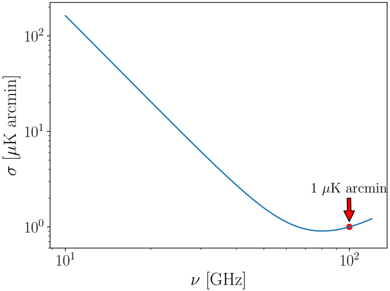


- Mimics the frequency dependence of the major contaminants: synchrotron and thermal dust
- $1\mu K$ arc min @ 100 GHz synch contribution = dust contribution @ 70 GHz

Notice that, at this stage, we are not including **atmospheric noise**.

# Component Separation Approach

- Full-parametric pixel-based maximum likelihood method.
- Affine invariant MCMC sampler.[1]
- Signal model

$$\begin{bmatrix} S^{\mathrm{Q}} \\ S^{\mathrm{U}} \end{bmatrix} = \underbrace{\begin{bmatrix} \mathbf{c}^{\mathrm{Q}} \\ \mathbf{c}^{\mathrm{U}} \end{bmatrix}}_{\text{CMB}} + \underbrace{\begin{bmatrix} \mathbf{a_s}^{\mathrm{Q}} \\ \mathbf{a_s}^{\mathrm{U}} \end{bmatrix} \left(\frac{\nu}{\nu_s}\right)^{\boldsymbol{\beta_s} + \mathbf{c_s}\left(\nu/\nu_{cs}\right)}}_{\text{Synchrotron}}$$

$$+ \underbrace{\begin{bmatrix} \mathbf{a_d}^{\mathrm{Q}} \\ \mathbf{a_d}^{\mathrm{U}} \end{bmatrix} \left(\frac{\nu}{\nu_d}\right)^{\boldsymbol{\beta_d}}}_{\text{Dust}} + \underbrace{\begin{bmatrix} \mathbf{a_a}^{\mathrm{Q}} \\ \mathbf{a_a}^{\mathrm{U}} \end{bmatrix} \left(\frac{\nu}{\nu_a}\right)^{\boldsymbol{\beta_a} + \mathbf{c_a}\left(\nu/\nu_{ca}\right)}}_{\text{AME}}$$

[1] Foreman-Mackey et al., “emcee: the MCMC hammer”.

# Results

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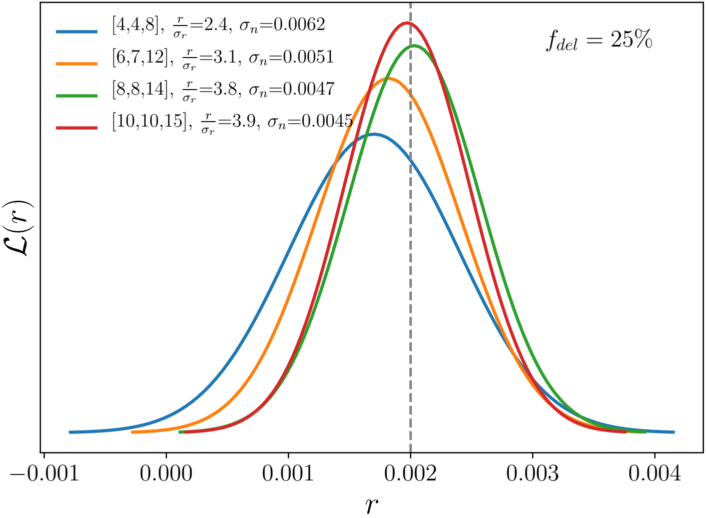
- Ground-based Telescope
  - Telescope Configurations:

| LOWBAND | MIDBAND | HIGHBAND |
|---|---|---|
| 10-20 GHz | 26-46 GHz | 75-120 GHz |

    E.g., [4,4,8].
  - Model Comparison:
    Synchrotron + Dust vs. Synchtrotron + Dust + AME
- Ground-based Telescope + LiteBIRD
  - Detectability
  - Improvements of Foreground Estimation

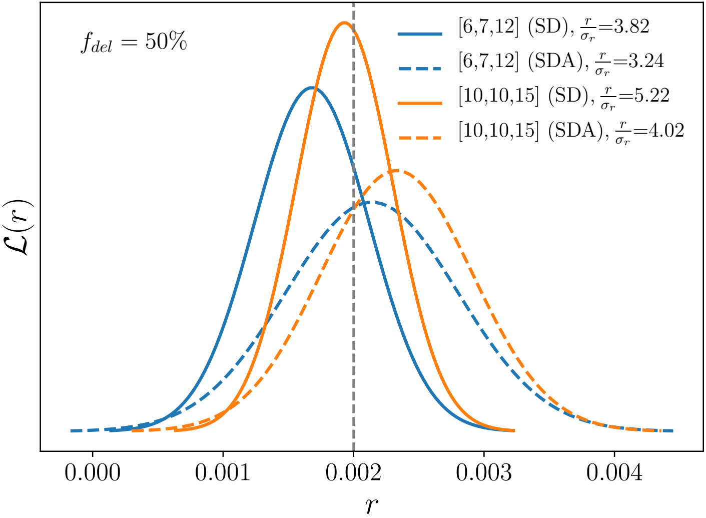
# Ground-based Telescope

**Telescope Configurations**



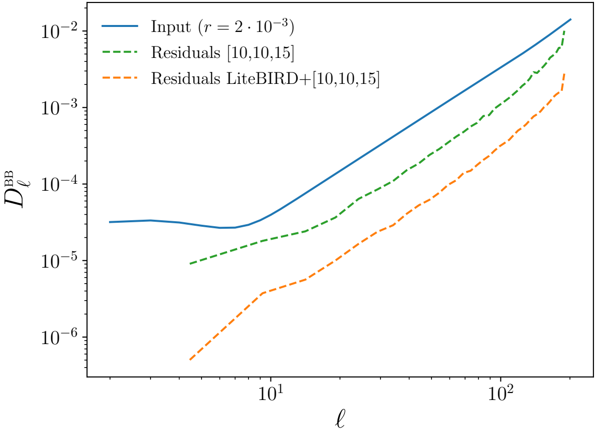
# Ground-based Telescope

**Model Comparison**



# LiteBIRD + Ground-Based Telescope

**Detectability**

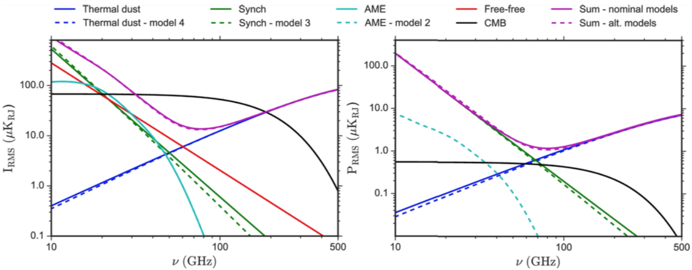


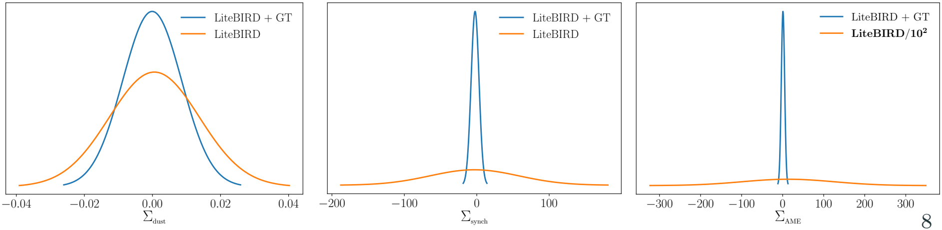

| $r_{in} \times 10^3$ | model | configuration | $f_{del}(\%)$ | $r \times 10^3$ | $\sigma_r \times 10^3$ | $(r/\sigma_r)$ |
|---|---|---|---|---|---|---|
| 2 | SD | [10,10,15] | 0 | 2.28 | 0.68 | 3.36 |
| 2 | SD | LB + [10,10,15] | 0 | 2.31 | 0.50 | 4.63 |

# LiteBIRD + Ground-Based Telescope

## Inprovements on the Foreground Estimation

Thorne et al., 1608.02841



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- This instrument is a helpful **complementary tool** for satellite experiments such as **LiteBIRD** due to:
  - **Detectability improvement**.
  - **Foreground characterization**.

# Conclusions

- CMB **B-modes** are **detectable** with an experiment of this sort for $r \sim 2 \times 10^{-3}$.
- This instrument is a helpful **complementary tool** for satellite experiments such as **LiteBIRD** due to:
  - **Detectability improvement**.
  - **Foreground characterization**.
- The **low-frequency** range covered presents several **advantages**:
  - Opens a **frequency range** with **sensitivities** never achieved before.
  - **Synchrotron and AME** well-characterized to reduce their contribution at $\sim 100$ GHz.