

# Foreground Mitigation Strategies for Accurate $r$ Estimation from CMB B-Modes

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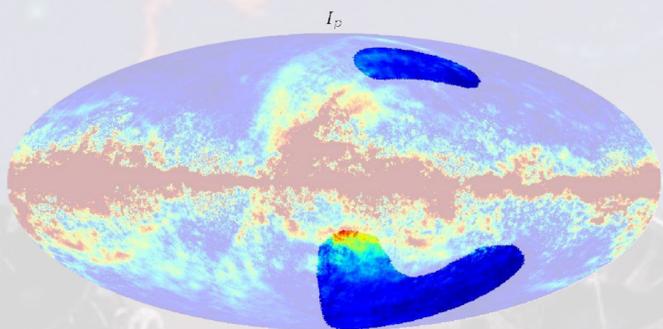
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## Introduction

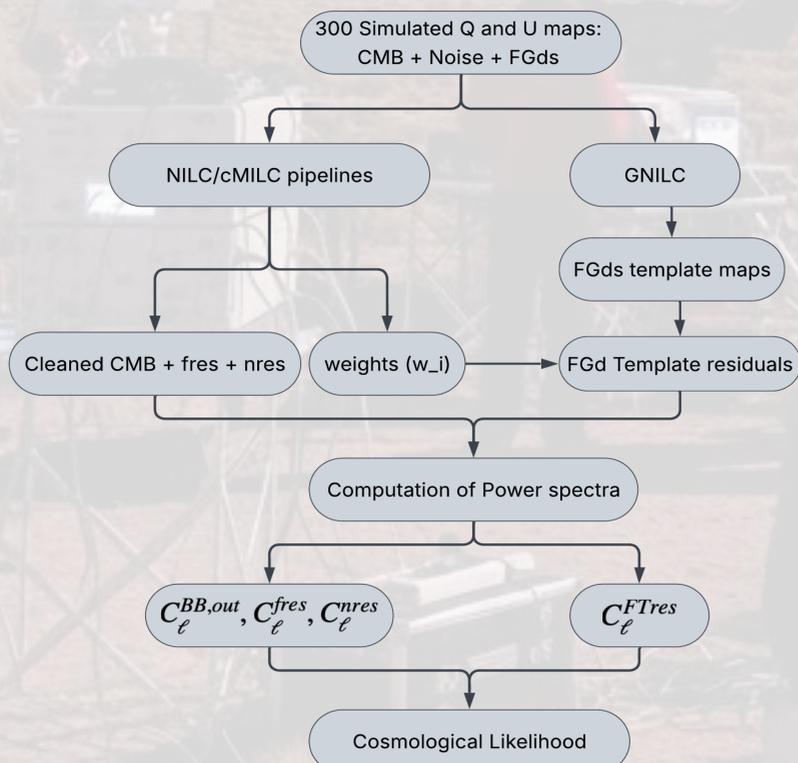
The **tensor-to-scalar ratio**  $r$  from **CMB B-mode** polarization is a key probe of cosmic inflation. Its estimation, however, is strongly challenged by Galactic foreground contamination, primarily dust and synchrotron emissions. Standard blind component separation methods, such as the **Needlet Internal Linear Combination (NILC)** [1,2,3], can leave residual foreground contamination that biases the estimate of  $r$  [4]. In this work, we present advances to NILC tailored for **Simons Observatory (SO)** data, now being collected. Our **improvements** include:

- i) Foreground marginalization using a template of foreground residuals [5].
- ii) Deprojection of specific moments of foreground emission [6].

We validate these techniques on SO-like simulations and demonstrate that they substantially reduce bias and improve the robustness of  $r$  estimation. This brings us closer to a reliable detection of primordial B-modes, the smoking gun of **inflation**.



## Methodology



Model in Likelihood:

$$C_{\ell_b}^{\text{model}}(r, A_{\text{lens}}) = r C_{\ell_b}^{\text{prim}}(r=1) + A_{\text{lens}} C_{\ell_b}^{\text{lens}} + C_{\ell_b}^{\text{nres}}$$

$$C_{\ell_b}^{\text{model}}(r, A_{\text{lens}}, a_{\text{temp}}) = r C_{\ell_b}^{\text{prim}}(r=1) + A_{\text{lens}} C_{\ell_b}^{\text{lens}} + C_{\ell_b}^{\text{nres}} + a_{\text{temp}} C_{\ell_b}^{\text{FTres}}$$

## Results

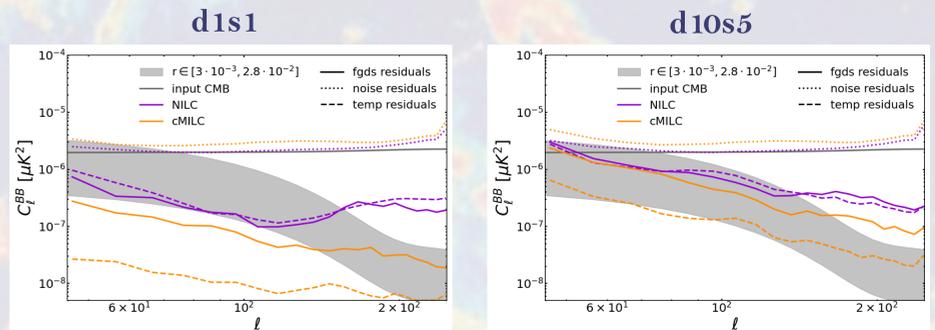


Figure 2: B-mode power spectra of noise and foreground residuals for **NILC** (violet) and **cMILC** (orange), averaged over 300 simulations with  $\Delta\ell = 10$ . The grey line shows the input CMB ( $r = 0$ ), and the shaded area marks the SO target range ( $r = 0.003\text{--}0.028$ ).

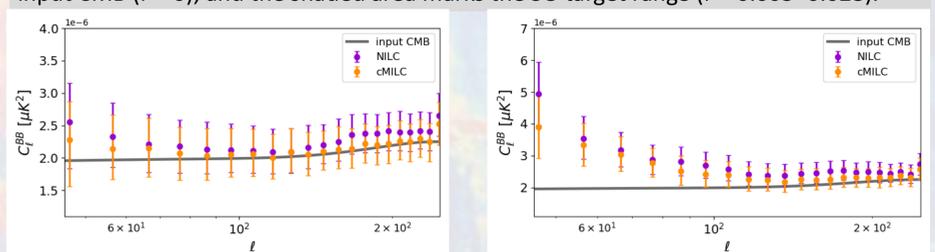


Figure 3: Averaged CMB B-mode power spectra in colored markers, and error bars show the statistical dispersion across simulations.

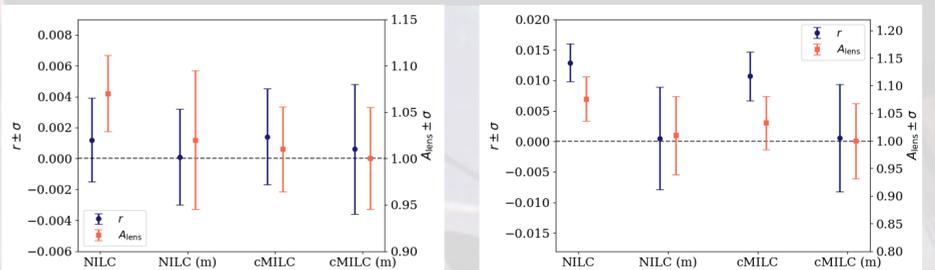


Figure 4: Mean estimates of  $r$  and lensing amplitude  $A_{\text{lens}}$  using **NILC** and **cMILC**, with and without foreground marginalization (m). Error bars represent the  $1\sigma$  credible intervals.

## Conclusion

- The **cMILC** method provides an improvement over standard **NILC** in reducing residuals, especially when marginalization is not performed, highlighting the advantage of deprojecting leading foreground moments to suppress bias, although it comes with a penalty of higher variance.
- The inclusion of spectral foreground templates in the likelihood model effectively removes these biases for **NILC** and **cMILC**, even in the challenging case of **d10s5**, providing unbiased lensing amplitude and tensor-to-scalar ratio estimates.

## References

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Background Image generated by Google's Gemini