SAT Systematics Forecasting Status & Plans

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CMB-S4

Overview

Context

- Instrumental systematics identified in Top 10 "Moderate Risks" for SATs
- Reviews (CDR, Director's Reviews) recommended deeper investigation of instrumental systematics in existing experiments and mitigation strategies

Goals for the SAT systematics forecasting project

- Extend existing *r* forecasting framework to include realistic instrumental systematics templates (after mitigation/deprojection)
    - Build/collect systematics template
    - Understand how a given effect affects constraints on *r*
- Use framework to set requirements on systematics residual levels that we can tolerate
  → quantify required improvements from achieved performance
  → requirements to achieve these improvements

CMB-S4

Previous work

- Studies in the context of stage 3 experiments (e.g. BK Beam paper, SO Bandpass requirements, BK18, LiteBIRD side lobe paper)
- Generic framework in the S4 *r* forecast paper
  → Experiment configuration, foreground models, code etc. from 2019
  → Effects grouped into categories and compared to achieved physical levels
    - Not tied to a specific instrument feature
    - No difference in requirements between frequency bands

Table 4

Map-based simulation results for dedicated simulations containing systematics (DC3). Simulations here assume the Science Book Configuration (Abazajian et al. 2016), i.e., an instrument configuration including a (low-resolution) 20-GHz channel, a survey of 3% of the sky with 1.0×10^6 150-GHz-equivalent detector-years, and $A_L = 0.1$. We report sky Model 3 and $r = 0$ **(no decorrelation)**, with additive systematic effects in varying combinations, the amplitudes of which are specified as percentages of survey noise, for the white (A) and $1/\ell$ (B) components. **The r bias columns list the bias due solely to systematic effects, i.e. the shift relative to the "None" case.**

	Uncorrelated		Correlated		ILC		Parametric	
Systematic	A [%]	B [%]	A [%]	B [%]	$\sigma(r) \times 10^{-4}$	r bias $\times 10^{-4}$	$\sigma(r) \times 10^{-4}$	r bias $\times 10^{-4}$
None	0	0	0	0	5.3	—	7.2	—
Uncorrelated white	3.3	0	0	0	6.0	0.84	8.0	0.63
Uncorrelated $1/\ell$	0	6.8	0	0	5.0	0.99	7.0	0.85
Correlated white	0	0	5.8	0	6.3	1.2	7.3	1.4
Correlated $1/\ell$	0	0	0	11	5.2	1.0	6.7	0.97
Uncorrelated white + $1/\ell$	1.6	3.5	0	0	5.6	0.89	7.5	0.76
Correlated white + $1/\ell$	0	0	2.9	5.3	5.5	0.98	6.9	1.0
Both, white + $1/\ell$	0.8	1.7	1.5	2.6	5.6	1.1	7.9	0.98

Additive/multiplicative systematics

Additive systematics

- Bias on the BB spectra - like an unmodeled noise term
- Can be modelled in map-based/power-spectrum space if we have the right templates to scale from

Examples: residual beam mismatch, crosstalk, polarisation angles, etc.

Multiplicative systematics

- Mismeasurement of existing B-modes
- May require TOD sims

Examples: bandpass

Setting requirements

Goal: "The unknown residual contamination from effect A must be controlled to better than [X_1,X_2, … X_n] % of the final map noise, corresponding to [Y_1,Y_2, … Y_n] nK at ℓ=80"

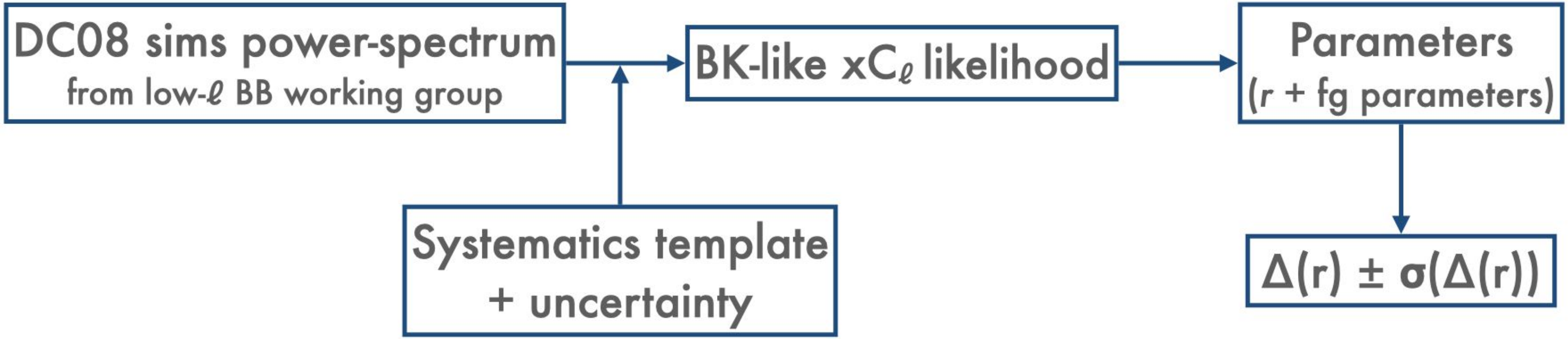
Proposed methodology

1. Inject systematics at levels that they are currently controlled or forecasted by Stage 3 experiments (BK, SO) to get a baseline
2. Scale to levels we would need in S4 so that bias on *r* doesn't exceed z% of σ (r) to **quantify required improvement** in systematics control
   → Forecasting paper used 0.2 σ(r) as goal for each systematic category
   → Trade off for how much each systematics is allowed to contribute
3. Investigate paths to achieve required improvement
   a. improved control at the instrument level → **design requirement**
   b. improved calibration measurements → **calibration requirement**
   c. improved treatment in analysis → **demonstration on Stage 3 data**

Framework overview

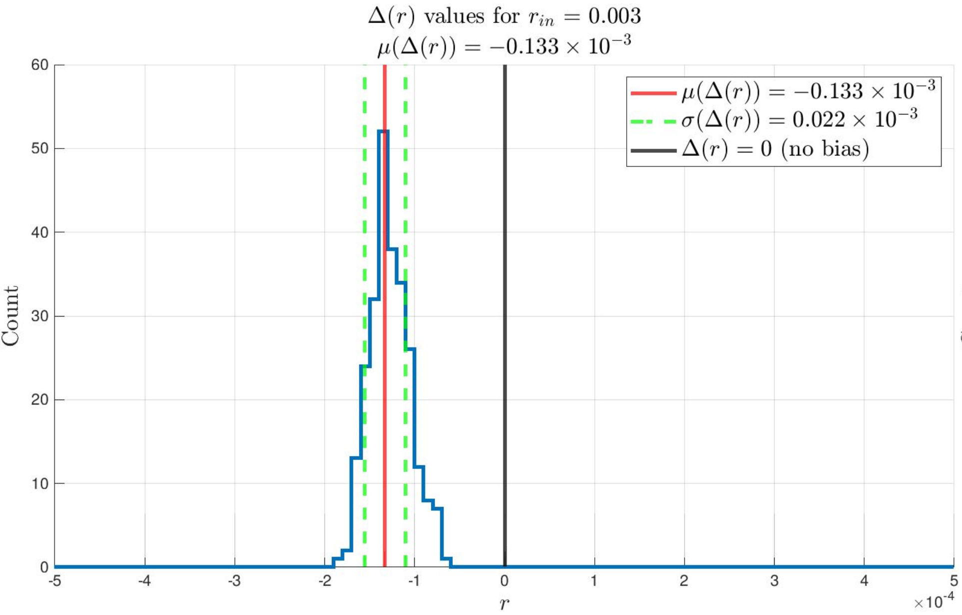
New compared to forecasting paper

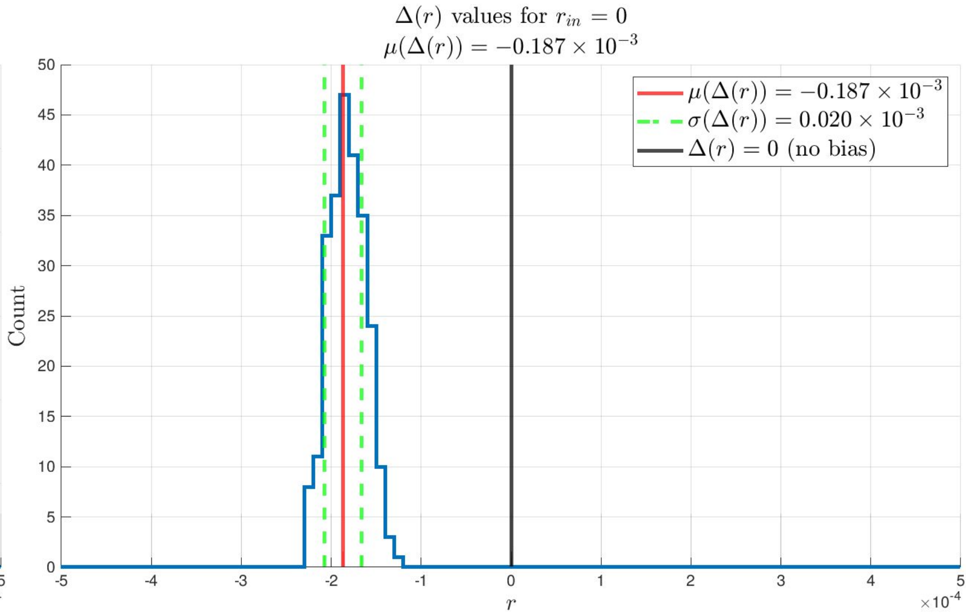
→ updated instrument configuration (bands, sensitivity, etc.)
→ new foreground models
→ delensing using lensing template in the likelihood
→ systematics template from stage 3 experiments (calibration data / forecasting)



Simple demonstration

Demonstrated here: uncorrelated 1/ℓ noise ~3.7 nK$_{CMB}$ @ ℓ = 80 across all bands
Realisation-to-realisation difference on best-fit *r* values between baseline and baseline + contamination





Examples of application

T→P leakage for LF horn layout

→ how well do we need to control T→P leakage in LF/HF bands compared to MF bands? how does that impact requirements on e.g. edge taper/beam mismatch for these bands?

SAT optics design to mitigate mid sidelobe response

→ which amount of side lobe response to the sky (CMB) can we tolerate?

Polarisation angles

→ what level of detector-to-detector variation is acceptable?

Bandpass

→ how well do we need to characterise bandpass parameters and features in different bands?

Next steps

Build confidence in the framework

- Reproduce results from the *r* forecasting paper (generic templates)
- First test case: BK T→P leakage from beam mismatch residuals

→ how can we best plug-in stage 3 templates into this framework?

→ reproduce BK18 results in terms of bias on *r*

T→P leakage investigation

- Scale the template to quantify improvement necessary for S4
- Look into specific questions, e.g. level of leakage per frequency band

Build other templates

- Systematics that have already been well studied for stage 3 experiments
- Systematics which haven't previously been thoroughly investigated