Updates to PBDR and Preparing for Science Book Version II

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CMB-S4 Collaboration Meeting
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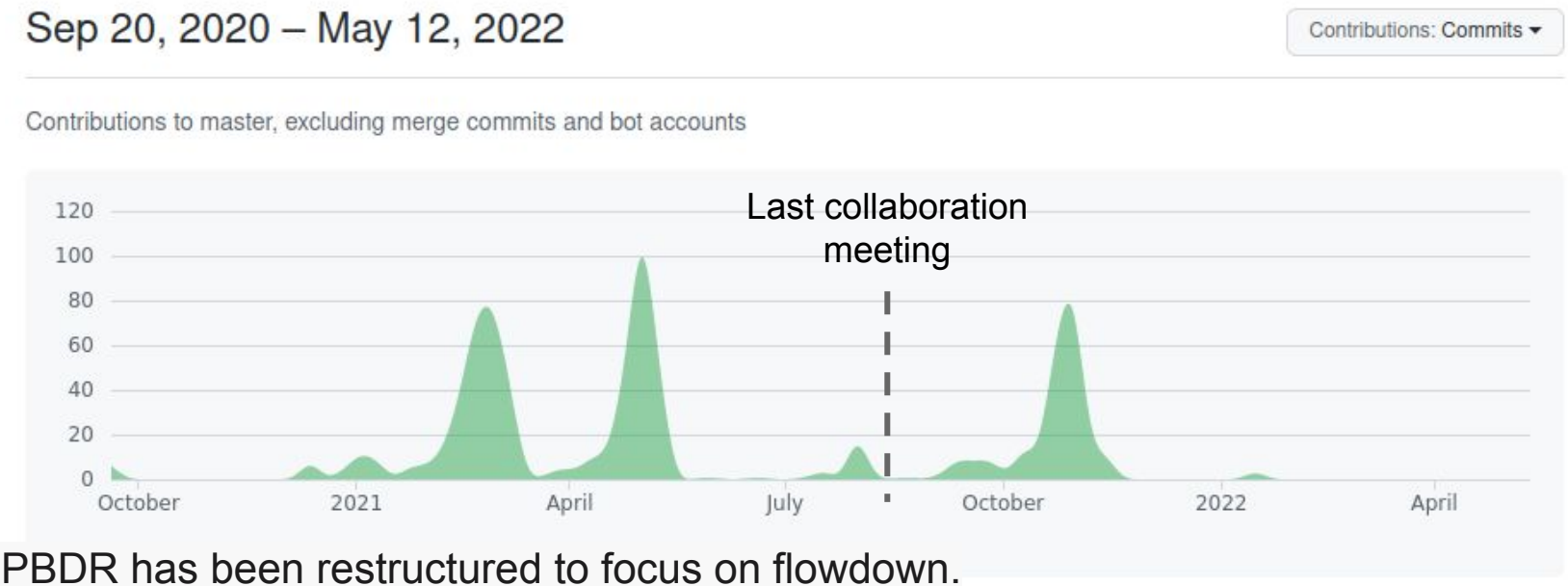
CMB-S4

Updates to PBDR



- PBDR has been restructured to focus on flowdown.
- Compared to the DSR, and especially Science Book, we do not explore the broad science case
- Documents the ways in which the Science Goals and Science Requirements lead us to a specific design

Structure of PBDR

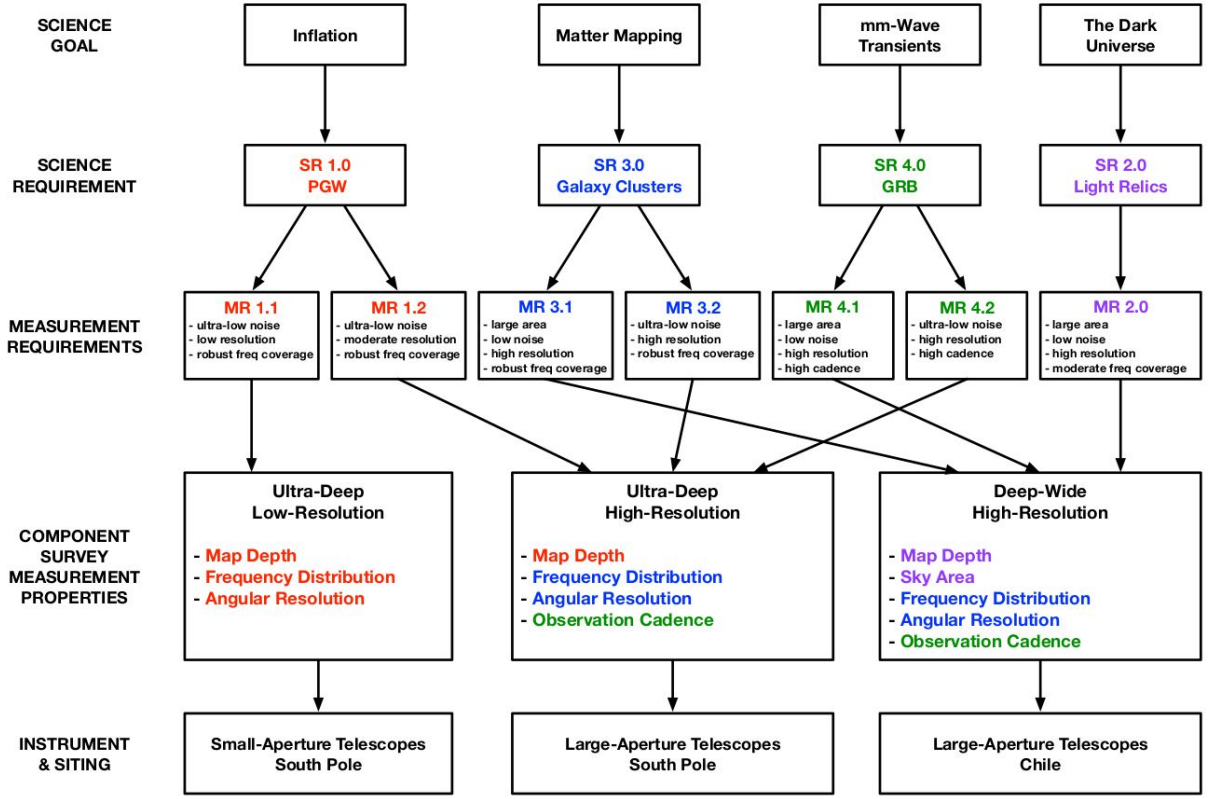
Chapter 1

Chapter 2
Appendix A.2

Chapter 2 + 3

Chapter 3

Chapter 4



PBDR Chapter 1 - Science Goals to Science Requirements

Goal 1: Test models of inflation by measuring or putting upper limits on r, the ratio of tensor fluctuations to scalar fluctuations.

Goal 2: Determine the role of light relic particles in fundamental physics, and in the structure and evolution of the Universe.

Goal 3: Measure the emergence of galaxy clusters as we know them today. Quantify the formation and evolution of the clusters and the intracluster medium during the crucial early period of galaxy formation.

Goal 4: Explore the millimeter-wave transient sky. Measure the rate of mm-transients for the first time. Use the rate of mm-wave GRBs to constrain GRB mechanisms. Provide mm-wave variability and polarization measurements for stars and active galactic nuclei.

PBDR Chapter 1 - Science Goals to Science Requirements

Science Requirement 1.0: CMB-S4 shall test models of inflation by putting an upper limit on r of $r \leq 0.001$ at 95% confidence if $r = 0$, or by measuring r at a 5σ level if $r > 0.003$.

Science Requirement 2.0: CMB-S4 shall determine $N_{\rm eff}$ with an uncertainty ≤ 0.06 at the 95% confidence level.

Science Requirement 3.1: CMB-S4 shall detect at $\geq 5\sigma$ all galaxy clusters at $z \geq 1.5$ with an integrated Compton $Y_{\rm SZ,500} \geq 2.4 \times 10^{-5}\,{\rm arcmin}^2$ over at least 50% of the sky.

Science Requirement 3.2: CMB-S4 shall detect at $\geq 5\sigma$ all galaxy clusters at $z \geq 1.5$ with an integrated Compton $Y_{\rm SZ,500} \geq 1.2 \times 10^{-5}\,{\rm arcmin}^2$ over at least 3% of the sky.

Science Requirement 4.1: CMB-S4 shall detect GRB afterglows brighter than 30 mJy at 90 and 150 GHz over at least 50% of the sky and enable followup by issuing timely alerts to the community.

Science Requirement 4.2: CMB-S4 shall detect GRB afterglows brighter than 9 mJy at 90 and 150 GHz over at least 3% of the sky and enable followup by issuing timely alerts to the community.

PBDR Chapter 2 - Science Requirements to Measurement Requirements

Measurement Requirement 1.1: CMB-S4 shall measure Stokes linear polarization parameters Q and U over 3% of the sky at frequencies of 25, 40, 85, 95, 145, 155, 230 and 280 GHz, with angular resolutions of 72.8, 72.8, 25.5, 22.7, 25.5, 22.7, 13.0, and 13.0 arcminutes, respectively and Q/U-map noise levels (including all sources of noise) $\leq$ 3.5, 4.5, 0.88, 0.78, 1.2, 1.3, 3.5, and 6.0 μK-arcmin, respectively. Maximum noise levels as a function of multipole are given in Figure 15.

Measurement Requirement 1.2: CMB-S4 shall measure Stokes Q and U over the same 3% of the sky at frequencies of 20, 25, 40, 90, 150, 230, and 280 GHz, with angular resolutions of 11.4, 8.4, 5.8, 2.5, 1.6, 1.1, and 1.0 arcminutes, respectively, and Q/U-map noise levels (including all sources of noise) $\leq$ 13.2, 6.5, 4.2, 0.63, 0.59, 1.9, and 4.4 μK-arcmin, respectively. Maximum noise levels as a function of multipole are given in Figure 16.

Measurement Requirement 2.0: CMB-S4 shall measure Stokes I, Q, and U over 60% of the sky at frequencies of 25, 40, 90, 150, 230, and 280 GHz, with angular resolutions of 7.4, 5.1, 2.2, 1.4, 1.0, and 0.9 arcminutes, respectively, with I-map noise levels $\leq$ 21.8, 12.4, 2.0, 2.0, 6.9 , and 16.7 μK-arcmin, respectively, and Q/U-map noise levels of $\leq$ 30.8, 17.6, 2.9, 2.8, 9.8, and 23.6 μK-arcmin, respectively. Maximum noise levels as a function of multipole are given in Figure 17.

Measurement Requirement 3.1: CMB-S4 shall measure I over 60% of the sky at frequencies of 25, 40, 90, 150, 230, and 280 GHz, with angular resolutions of 7.4, 5.1, 2.2, 1.4, 1.0, and 0.9 arcminutes, respectively, with I-map noise levels $\leq$ 21.8, 12.4, 2.0, 2.0, 6.9 , and 16.7 μK-arcmin, respectively. Maximum noise levels as a function of multipole are given in Figure 17.

Measurement Requirement 3.2: CMB-S4 shall measure I over 3% of the sky at frequencies of 20, 25, 40, 90, 150, 230, and 280 GHz, with angular resolutions of 11.4, 8.4, 5.8, 2.5, 1.6, 1.1, and 1.0 arcminutes, respectively, and I-map noise levels $\leq$ 9.4, 4.6, 3.0, 0.45, 0.41, 1.3, and 3.1 μK-arcmin, respectively. Maximum noise levels as a function of multipole are given in Figure 16.

Measurement Requirement 4.1: During normal operations, CMB-S4 shall measure I, Q, and U at 90 and 150 GHz, over $\geq$ 25% of the sky daily, with angular resolution $\leq$ 3.0 arcminutes and noise level $\leq$ 10 mJy/day. At least 90% of the time, the same $\geq$ 25% of the sky shall be observed for $\geq$ 5 consecutive days.

Measurement Requirement 4.2: During normal operations, CMB-S4 shall measure I, Q, and U at 90 and 150 GHz, over 3% of the sky daily, with angular resolution $\leq$ 3.0 arcminutes and noise level $\leq$ 3 mJy/day.

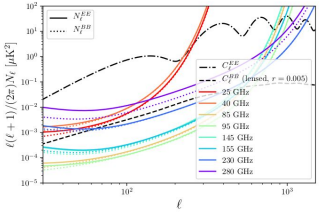


Figure 15: Required noise as a function of multipole for each frequency in polarization for the low-resolution, ultra-deep survey of 3% of the sky.

Frequency (GHz)	25	40	85	95	145	155	230	280
$\theta_{\rm FWHM}$ (arcmin)	72.8	72.8	25.5	22.7	25.5	22.7	13.0	13.0
Δ_E (μK-arcmin)	3.7	4.7	0.93	0.82	1.3	1.33	3.5	8.1
$\ell^E_{\rm knee}$	60	60	60	60	65	65	65	65
α_E	2.2	2.2	2.2	2.2	3.1	3.1	3.1	3.1
Δ_B (μK-arcmin)	3.5	4.5	0.88	0.78	1.2	1.3	3.5	6.0
$\ell^B_{\rm knee}$	60	60	60	60	60	60	60	60
α_B	1.7	1.7	1.7	1.7	3.0	3.0	3.0	3.0

Table 2-1: Parameters describing the required noise for the low-resolution, ultra-deep survey of 3% of the sky.

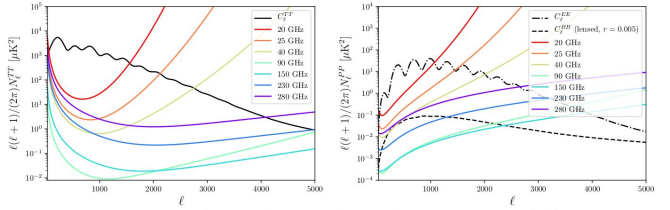


Figure 16: Required noise as a function of multipole for each frequency in intensity (left) and polarization (right) for the high-resolution, ultra-deep survey of 3% of the sky.

Frequency (GHz)	20	25	40	90	150	230	280
$\theta_{\rm FWHM}$ (arcmin)	11.4	8.4	5.8	2.5	1.6	1.1	1.0
Δ_T (μK-arcmin)	9.4	4.6	3.0	0.45	0.41	1.3	3.1
$\ell^T_{\rm knee}$	1200	1200	1200	1200	1900	2100	2100
α_T	4.2	4.2	4.2	4.2	4.1	4.1	3.9
Δ_P (μK-arcmin)	13.16	6.5	4.15	0.63	0.59	1.83	4.34
$\ell^P_{\rm knee}$	150	150	150	150	200	200	200
α_P	2.7	2.7	2.7	2.6	2.2	2.2	2.2

Table 2-2: Parameters describing the required noise for the high-resolution, ultra-deep survey of 3% of the sky.

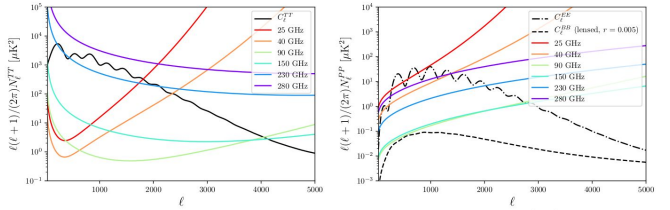
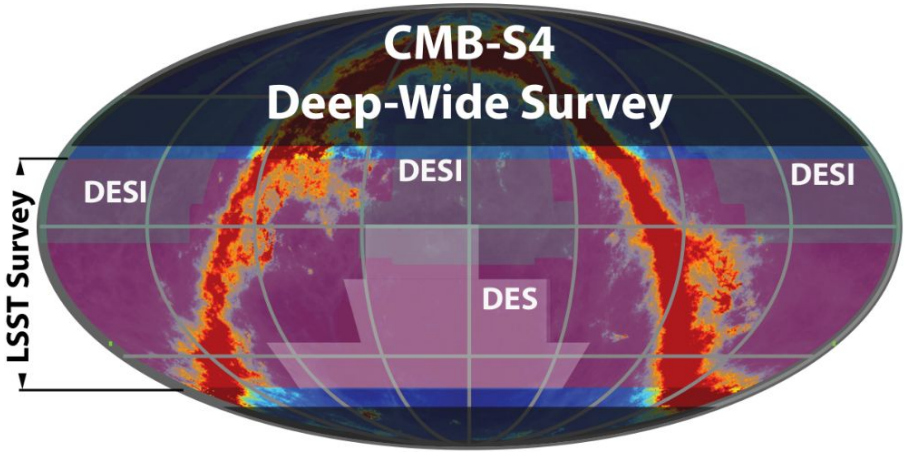


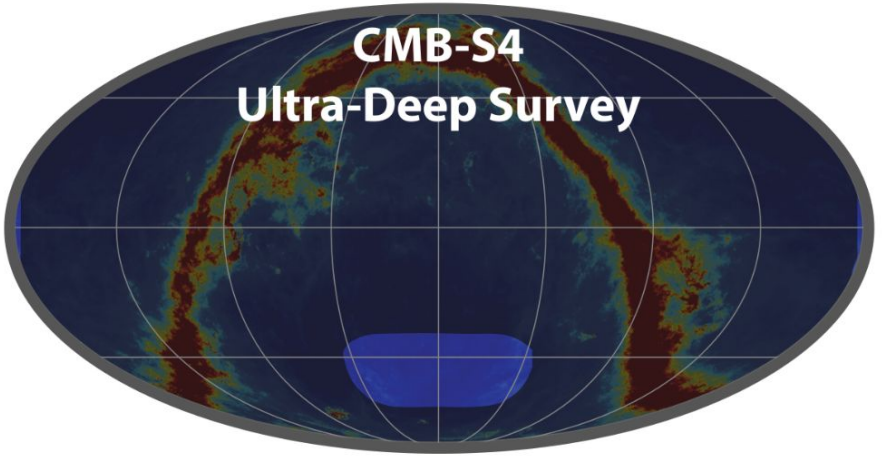
Figure 17: Required noise as a function of multipole for each frequency in intensity (left) and polarization (right) for the high-resolution, wide and deep survey of 60% of the sky.

Frequency (GHz)	25	40	90	150	230	280
$\theta_{\rm FWHM}$ (arcmin)	7.4	5.1	2.2	1.4	1.0	0.9
Δ_T (μK-arcmin)	21.8	12.4	2.0	2.0	6.9	16.7
$\ell^T_{\rm knee}$	415	391	1932	3917	6740	6792
α_T	3.5	3.5	3.5	3.5	3.5	3.5
Δ_P (μK-arcmin)	30.23	16.53	2.68	2.96	9.78	23.93
$\ell^P_{\rm knee}$	700	700	700	700	700	700
α_P	1.4	1.4	1.4	1.4	1.4	1.4

Table 2-3: Parameters describing the required noise for the high-resolution, wide and deep survey of 60% of the sky.

PBDR Chapter 3 - Sites and Surveys





PBDR Appendix A.2 - Measurement Requirements to Science Requirements

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Science Book, First Edition

1. Exhortations
2. Inflation
3. Neutrinos
4. Light Relics
5. Dark Matter
6. Dark Energy
7. CMB Lensing
8. Data Analysis, Simulations, and Forecasting

Science Book, Second Edition

- The science case has evolved and expanded since 2016. Science Book I has:
  - No transients
  - No galactic science
  - Only a little on galaxy clusters
- Science Book II should be a reference for everything you can think to do with CMB-S4
- CMB-S4 concept has evolved since 2016, and is more mature
  - We now have a Preliminary Baseline Design
  - We will soon have data challenge products
  - However, we may need to wait for the Analysis of Alternatives to settle down
- People may start preparing to run a forecast of your favorite science cases on one or more instrumental configurations. The meeting later this year will be key in organizing this.
- We will want unified, version-controlled (e.g. tagged branches and versions) instrumental concepts taken to N_l, coverage maps, effective areas, etc. that can plug into forecasts.