Flowdown

(from science goals to requirements)

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(Representing the work of many many others, including the "Flowdown group" and all the AWG's…)

What is "flowdown"?

Quantitative Science Goals
(r, Neff, Clusters, transient)

(Sufficient set of)

Quantitative Measurement Requirements
(Frequencies, Map depths, Beams, Sky coverage, Cadence)

(Sufficient set of)

Quantitative Instrument (Technical) Requirements
(# of detectors, NETs, Aperture sizes, Calibration, etc etc)

Where does *this* "flowdown" stop?

Quantitative Instrument (Technical) Requirements
(# of detectors, NETs, Aperture sizes, Data volume, Calibration, etc etc)

- Optics efficiency, loading…
- Detector NEP, responsivity, efficiency...
- Readout NEI
- ...

We want to give concrete requirements to each WBS group… so they can do their work.
We don't want to unnecessarily constrain them by getting too specific.

Detectors	Readout	SATs	LATs	DAQ	DM	Chile	Pole

"Design Validation"

Quantitative Science Goals
(r, Neff, Clusters, transient)

AWG || sessions Wed/Thurs

Quantitative Measurement Requirements
(Frequencies, Map depths, Beams, Sky coverage, Cadence)

T2M || session Thurs

Quantitative Instrument (Technical) Requirements
(# of detectors, NETs, Aperture sizes, Calibration, etc etc)

From the PBDR *(copied from an official project document, the "PLR")*

Quantitative Science Requirements
(r, Neff, Clusters, transient)

SR1.0: 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 $r > 0.003$.

-> SAT and SPLAT Surveys

SR2.0: CMB-S4 shall determine $N_{\rm eff}$ with an uncertainty ≤ 0.06 at the 95% confidence level.

-> CHLAT Survey

SR3.1: CMB-S4 shall detect at $\geq 5\sigma$ all galaxy clusters at $z \geq 1.5$ with an integrated Compton $Y_{\rm SZ,500} \geq 10^{-12}$ over 50% of the sky.

-> CHLAT Survey

SR3.2: CMB-S4 shall detect at $\geq 5\sigma$ all galaxy clusters at $z \geq 1.5$ with an integrated Compton $Y_{\rm SZ,500} \geq 5 \times 10^{-13}$ over 2.8% of the sky.

-> SPLAT Survey

SR4.0: CMB-S4 shall detect γ-ray-burst afterglows brighter than 30 mJy at 93 and 145 GHz.

-> LAT Surveys

From the PBDR

Quantitative Science Goals
(r, Neff, Clusters, transient)

↓

Quantitative Measurement Requirements
(Frequencies, Map depths, Beams, Sky coverage, Cadence)

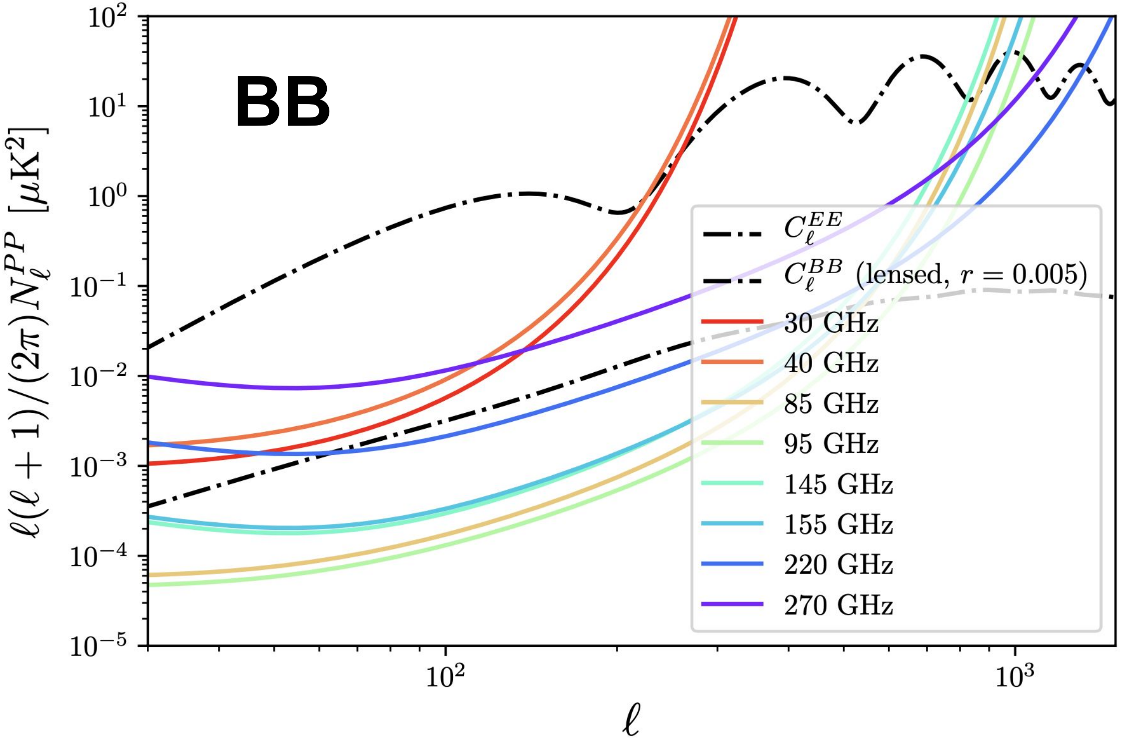
Example: SAT survey

MR1.1: CMB-S4 shall measure Q and U over 2.8% of the sky at frequencies of 30, 40, 85, 95, 145, 155, 220 and 270 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 28.

(Easier and more informative: tables and plots…)

South Pole Surveys (2.8% of sky)

SAT Survey: low-ell BB



SPLAT Survey: Delensing, Clusters (2.8% of sky)

$$N_\ell = \Delta^2 \exp\left(\ell(\ell+1)\frac{\theta^2_{\mathrm{FWHM}}}{8\ln 2}\right)\left(1+\left(\frac{\ell_{\mathrm{knee}}}{\ell}\right)^{\alpha}\right)$$

Map Depth

Beam size

Sky coverage

Things we control

Things we get from S3

Frequency (GHz)	20	27	39	93	145	225	278
θ_{FWHM} (arcmin)	11.0	8.4	5.8	2.5	1.6	1.1	1.0
Δ_T (μK-arcmin)	9.31	4.6	2.94	0.45	0.41	1.29	3.07
ℓ^T_{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
ℓ^P_{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 2.8% of the sky.

South Pole Surveys (2.8% of sky)

SPLAT Survey: Delensing, Clusters

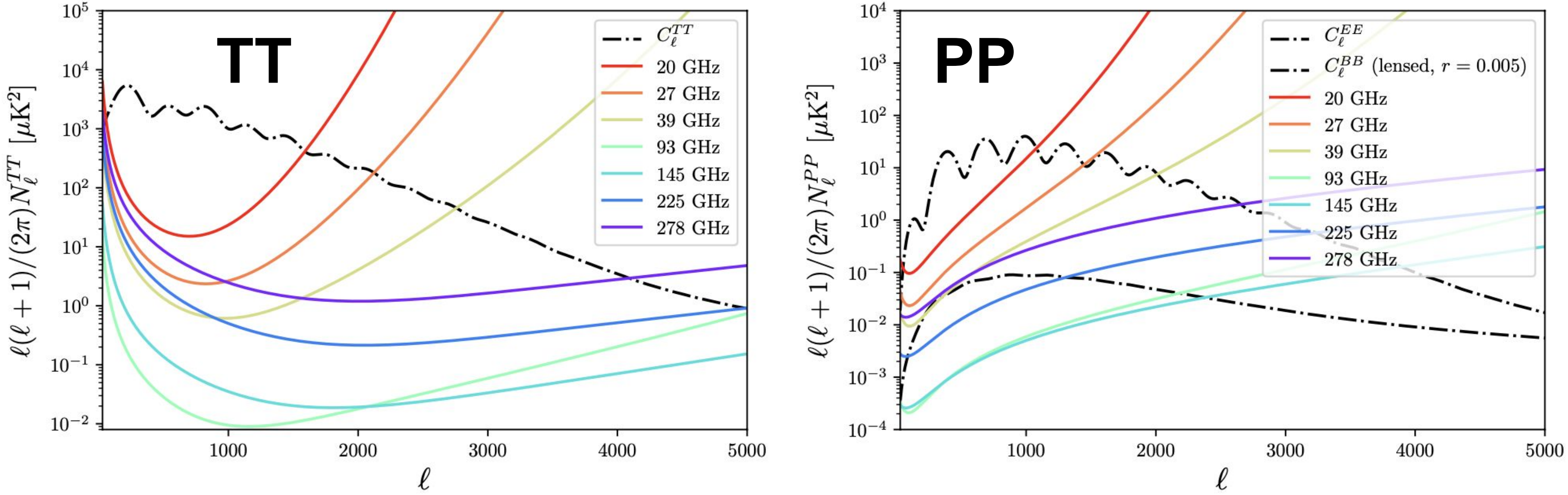


Figure 29: Required noise as a function of multipole for each frequency in intensity (left) and polarization (right) for the high-resolution, ultra-deep survey of 2.8% of the sky.

Chile Survey (68% of sky)

CHLAT Survey: Delensing, Clusters, Transients

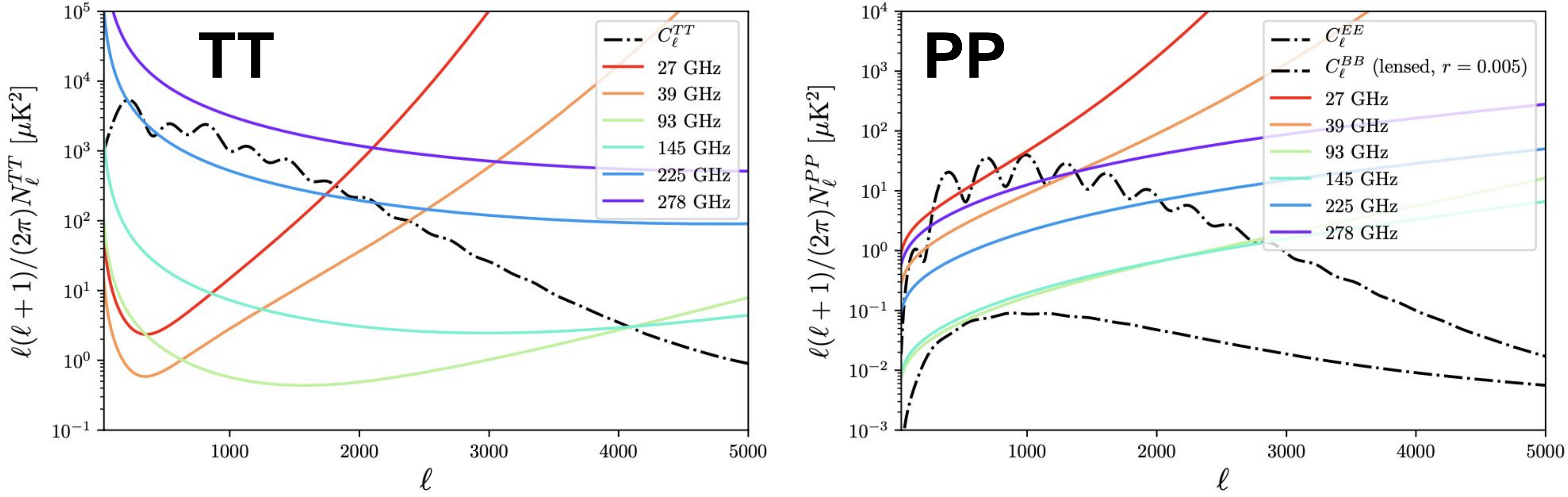


Figure 30: Required noise as a function of multipole for each frequency in intensity (left) and polarization (right) for the high-resolution, wide and deep survey of 68% of the sky.

These Science and Measurement Requirements are "static"

- **We will not move the "goalposts" on r, Neff, etc.**

- Simulations have been done (Appendix A) that show the "measurement requirement" (MR) noise curves allow us to achieve our science goals in the allotted 7 year survey, under reasonable assumptions about observing time.

- **We will not move the MR noise curve "goalposts"** unless shifting them gives some advantage and still achieves the science.

- The "summer 2020" instrument+observation models (barely) achieve the sensitivity shown in the MR noise curves.

Future instrument modeling

More detailed models of the instrument and observations.
Dig deeper into systematics, etc.

- If our "best estimate" instrument model beats our measurement requirements, we have margin.
  Margin is useful.

- If our "best estimate" instrument model does not allow us to meet the measurement requirements, we have a problem.
  Problems need solutions.

Evolution from Reference Design to PBD

(aspects that cross WBS's)

- **LATs**
  - 19tube x (3 + 0.33*3) = 76 wafer cryostats
    -> 85 tube x 1wafer/tube = 85 wafer cryostats
  - Three 6m CD LATs -> Two 6m CD LATs + One 5m TMA LAT

- **SATs**
  - LF, MF: (10 + 0.5*4) wafer layout -> 12 wafer layout
  - LF, MF: Alumina lenses -> HDPE lenses
  - HF: (3-lens, 35 deg FOV) design to (2-lens, 29 deg FOV) design

- **Detectors, Modules**
  - Layouts ("rhombus" vs "hex") chosen. (But under discussion; affects detector count and horn diameters; see detector session on Wednesday).

- **Readout, DAQ, DM, Sites**
  - Handling changes in detector counts, hardware, driven by the evolutions above.

"Instrument" Modeling Areas

1. **Observing Plans**
   - Scan patterns, speeds, etc.

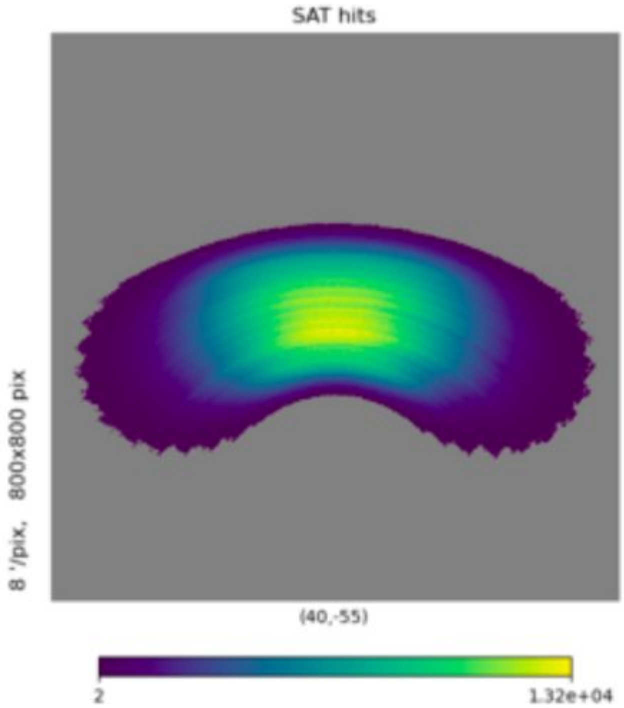
2. **Instantaneous sensitivity**
   - Detector count
   - NET

3. **Calibrations and Systematics**
   - Beams
   - Band characterization
   - Time constants
   - Polarization properties
   - Sidelobes

SAT Scan strategy

29deg FOV

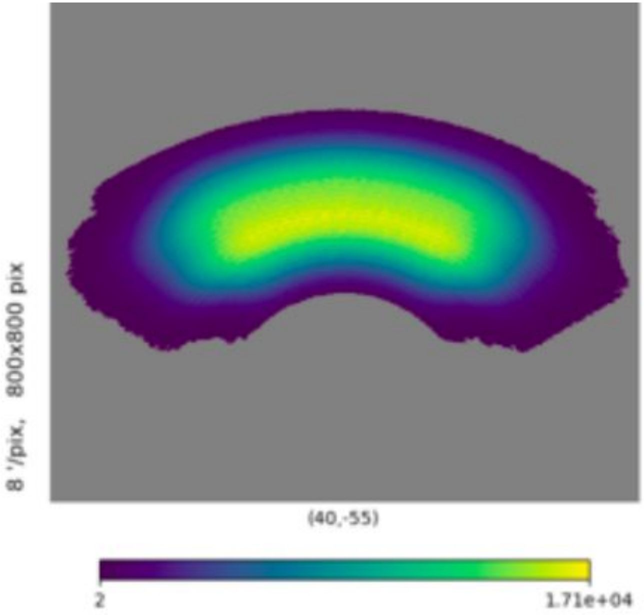
Target Field RA (min, max) - for boresight	(15, 65)	deg
Target field DEC (min, max) - for boresight	(-55, -52.5)	deg
Az scan rate	1.5	deg/s - on sky
Az scan accel	0.97	deg/s^2
Boresight angle step	45	deg
Boresight step time	24	hours
Boresight angle range	[0, 360]	deg



SPLAT Scan strategy

(9deg FOV; try to ~ match SATs coverage and taper)

Target Field RA (min, max) - for boresight	[-8, 88], [-3, 83], [5, 75]	deg
Target field DEC (min, max) - for boresight	[-60, -47.5], [-62.5, -45], [-66, -42]	deg
Az scan rate	1	deg/s - on sky
Az scan accel	1	deg/s^2
Boresight angle step	22.5	deg
Boresight angle range	[-45,45]	deg



CHLAT Scan Strategy

azimuth min	30	Flips b/t rising and setting
azimuth max	150	
base azimuth scan rate	0.5	deg/s on-sky
Maximum scan rate	1	deg/s on-sky
Maximum azimuth scan acceleration	2.58	deg/s^2 on-mount
elevation	35	deg
Boresight angle step	180	deg
Boresight angle range	[0, 360]	deg

Sensitivity Calculations

Inputs:

Atmosphere: 50th percentile pwv from MERRA-2, site-specific.

Optics: Element temperatures, loss, reflection, scattering, spillover, f/#…

Detector: T_{bath}, T_c, (P_{sat}/$P_{optical}$), n, band, d_{horn}

Readout: Assumed to increase NEP by 5%.

Yield: 80%

Sensitivity used to calculate map depths:
(for PBDR)

LATs: Ab initio, S3-vetted noise calculator and observing efficiencies.

SATs: N_ells per detector-year scaled from those achieved by Bicep Keck, via ratios of noise calculator. *(Still poking at noise calculator.)*

Sensitivity Flowdown

Given target NETs, set limits and/or ranges for:

- **Detectors:** NEP, Psat, responsivity, optical efficiency, band widths and placement, detector count per wafer, yield
- **Readout:** NEI, yield
- **LAT/SAT optics:** optical efficiency, instrument optical load

Status:

- Most of these are available as "targets".
- Few are available as limits/ranges.
- All need iteration to take into account variations (eg of pwv, Tc, etc).

(In progress…)

PBD instrument configuration

SATs

Tube name	**LF**		**MF1**		**MF2**		**UHF**	
Band Centers (GHz)	27	39	85	145	95	155	225	278
Lenses	~60cm HDPE		~60cm HDPE		~60cm HDPE		~45cm Silicon	
Wafers/Tube	12		12		12		6 + 0.5*6	
Pixels/Wafer	12		147		147		469	
Tubes	2		6		6		4	

LATs

Tube name	**UL**	[illegible]		[illegible]		**UHF**	
Band Centers (GHz)	2[illegible]	[illegible]	[illegible]	93	145	225	278
Lenses	20cm Si	20cm Si		20cm Si		20cm Si	
Pixels/Wafer	27	48		432		432	
Tubes in SPLAT	4	9		54		18	
Tubes in two CHLATs	0	16		108		46	

Counts subject to HCP / "Rhombus" layout issue - see Detectors session...

Calibration and Systematics

We have enormous experience from Stage 3 (and earlier) instruments.

Some investigations have been done for CMB-S4, but we need to do a better job enumerating these and ensuring our plans are sufficient to achieve our science. (*See "Technical to Measurement" session on Thursday, and calibration discussions in LATs/SATs)*

Examples:

- Incorrectly deconvolved time constants (for LATs - effectively a beam smearing)
- Readout cross-talk (beam TQU coupling, complicated, depends on wiring arrangement)
- Bandpass calibration requirements
- Beam measurement requirements
- Polarization angle and efficiency calibration requirements
- Far sidelobes/ground pickup

Status: Some map tools developing, timestream sims ramping up.

"Flowdown" Summary

Quantitative Science Goals
(r, Neff, Clusters, transient)

Done.

Quantitative Measurement Requirements
(Frequencies, Map depths, Beams, Sky coverage, Cadence)

~Done.

Quantitative Instrument (Technical) Requirements
(# of detectors, NETs, Aperture sizes, Calibration, etc etc)

Working…