Analysis of Alternatives, Rationale and Overview

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Rationale for Analysis of Alternatives (AoA)

Background: A reviewed AoA document for which the alternatives to be analyzed are agreed to in advance with the DOE is a requirement for CD-1. It covers science reach, construction and lifecycle costs, schedule, and risks (both science and technical). See DOE G 413.3-22 AoA guide.

Initially this CMB-S4 AoA document was to cover the following options:

- No new telescopes
- Telescopes only in Chile
- Telescopes only in South Pole
- CMB-S4 Baseline Design Configuration

Rationale for Analysis of Alternatives (AoA)

However, more recently,

- NSF has stated that the South Pole scope of our current baseline design configuration is not supportable, at this time.
- NSF is not currently planning to work with CMB-S4, or others, on South Pole Station logistical needs, at this time.
- This is the reason the February DOE OPA review was postponed.
- NSF has requested that we analyze alternative South Pole options, starting with simply continuing the ongoing SP CMB program, and developing options that fit within the current SP logistical infrastructure, for which a primary, but not sole constraint, is station power generation.

Rationale for Analysis of Alternatives (AoA)

(continued)

- NSF has premised that the continued funding of CMB-S4 Design and Development effort must be directed toward the development and analysis of these options.
- One of the reasons DOE has given for their low level of FY22 Project funding is the lack of alignment between the agencies, i.e., not getting too far ahead of NSF.
- Future NSF funding and engagement and DOE funding rests on showing there is a supportable path forward for NSF at South Pole, or an all-Chile configuration is viable.

We must therefore develop and analyze alternative SP configurations, and not only the initial DOE AoA options.

List of alternatives

Alternatives to be analyzed for required scope to reach CMB-S4 science goals, including cost, schedule, and risk (both science and technical):

- No new telescopes
- Telescopes only in South Pole
- Telescopes only in Chile
- Baseline Chile configuration (2 CHLATS) with alternative South Pole configurations (listed in more detail below)
- Modified dual site configurations
- Possible use of other sites

No new telescopes

We have shown that the current CMB Stage-3 programs will not reach level 1 science goals, e.g., N_{eff} and *r*, unless they ran for order 50 years or more.

This is not feasible for many reasons. We will need to document this finding.

Telescopes only in South Pole

It is estimated that of order 10 SPLATs would be required to achieve our level 1 N_{eff} science goal if located at the South Pole.

This is not practical for many reasons, and certainly not supportable by NSF OPP. We will need to document this finding.

Telescopes only in Chile for non-r science goals

- Most of the sensitivity to reach the CMB-S4 non-*r* level-1 science goals are met with the two CHLATs, although the SPLAT
  - contributes higher ell modes for ΔN_{eff} ($\lesssim$10% effect)
  - deeper survey over ~3% sky for lower mass SZ clusters
  - deeper survey over ~3% sky for GRBs

This is documented in the PBDR.

Telescopes only in Chile for *r* science goal

- We have studied and documented the option of SATs in Chile to achieve the level-1 r goal in the appendix of the Decadal Survey Report (335 citations) and in our refereed 2022 ApJ paper (59 citations).
- These studies have resulted in our baseline design configuration of 18 SAT (6 three shooters) and 1 SPLAT at the South Pole, as detailed in the PBDR.

E.g., South Pole to Chile SAT requirement comparison from our ApJ paper

Table 7
Same as Table 6, but Assuming Additional Foreground Decorrelation Parameters

Number of SATs at each site

Chile\Pole	0	6	9	12	18	30
0		8.4	6.7	6.0	**5.2**	4.4
6	16	7.3	6.2	**5.6**	5.0	4.3
9	12	6.8	**5.9**	5.4	4.9	4.3
12	9.7	**6.4**	5.7	5.3	4.8	4.2
18	**7.8**	5.8	5.3	5.0	4.6	4.1
30	6.0	5.1	4.8	4.6	4.3	4.0

Values are $\sigma(r) \times 10^{-4}$

Keeping only the 28% Cleanest Part of the Sky, Assuming an Observing Efficiency in Chile the Same as at the South Pole, i.e, strictly geographical considerations. (Note ~2.5x more SATs are required in Chile under these assumptions.)

Telescopes only in Chile for *r* science goal

- Our studies show that based solely on geographical considerations, i.e., ignoring atmospheric based observing efficiencies, foreground levels, and other site based conditions, 2.5x more SATs are required in Chile than at South Pole to achieve our level-1 r science goal.

- Note that 2.5x is only a lower bound.

- This is used to justify our baseline design configuration.

Telescopes only in Chile for *r* science goal

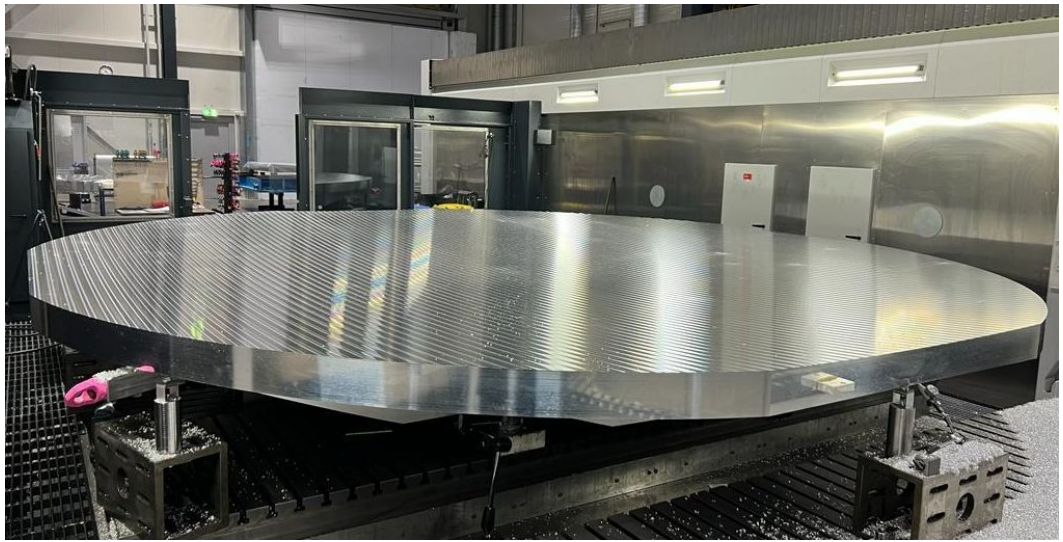
- We are now asked to develop this comparison further to arrive at a more comprehensive determination of the required Chilean scope (SATs and LATs), not just a lower bound. We need to assess:
  - Impact of observing efficiency differences between sites
  - Impact and mitigation of sky noise (e.g., ½ wave plates in Chile?)
  - Impact of more realistic survey scan strategies for Chile, and impact of using higher foreground regions of sky
  - Solar and ground screening
  - Required de-lensing effort, and LATs needed to achieve it
  - Risks and required R&D
  - Site infrastructure implications of SATs in Chile
- These issues are the focus of Wednesday's "Chile Alternatives" AoA Session

Alternative South Pole Configurations

Basis for considerations of SP options

- Programmatic foundation:
  - Configurations to fit within scope of existing/planned logistical capacity (power, transport, lodging)
  - Project implementation risks must be lowered relative to CMB-S4 baseline design
  - Science risks need to be understood and include feasible mitigation plans
  - Operational demands should be of a scale similar to existing facilities
- Scientific foundation:
  - Recent advances in gapless mirror fabrication for SPLAT (NSF funded) & demonstrated improvement of SPT-3G low-ell noise, including understanding and the possible mitigation of variable *polarized* atmospheric signal, indicates data from SPLAT may be able to provide significant low-ell sensitivity for "*r*"
  - CMB-S4 Inflation science goal, "*r*" must be achievable with high probability and low risk
  - Observing duration should be reasonable and short enough to ensure other initiatives do not "beat us to the punch."
  - Build on Stage 3 experiment successes

SPLAT TMA Primary Mirror Development (NSF funded)



South Pole Alternatives to be Evaluated

Configuration		$r \geq 10^{-3}$ at 95% CL; $r > 3\times10^{-3}$ at 5σ [$\sigma(r) = 5\times10^{-4}$]	Power req'ts	Comments
0	Nothing	No progress beyond SPO	None past SPO	None
1a	Maintain SPT-3G & BICEP Array (BA) (including BICEP3)	~50yrs to reach goal (suffers from lack of de-lensing LAT power)	No change	Current level logistical support
1b	Install BICEP Array (BA) Tower (BART) and BA mount (i.e., CMB-S4 SAT mount); Install CMB-S4 detectors in 1 BA tube, i.e., pathfinder SAT (pSAT)	Same as 1a (still suffers from lack of de-lensing LAT power)	No increase, roughly neutral	Allows MAPO Lab bldg raise w/o interrupting BA observations; Allows field testing of CMB-S4 detectors and tests to optimize SATs
2a	Install SPLAT/LATR; Turn-off SPT and BICEP3 when SPLAT turns on.	Evaluate: 1) 7 yr survey of SPLAT + BA with pre-SPLAT BA data; 2) time to reach CMB-S4 goal	Approximately neutral since SPLAT power ~ SPT + BICEP3 power; High Bay power only during receiver maintenance	Construction: SPLAT, High Bay, and Ice pads Logistics: Minimize airlift cargo with traverse; req'd for SPLAT mirrors
2b	Add CMB-S4 SAT on site of current BA tower (MAPO configured with 2 towers as in the past)	Evaluate: 1) 7 yr survey with pre-SPLAT BA data; 2) time to reach CMB-S4 goal	Increase of ~37kW from current; fits within *current* SP power generation	Reuse existing BA SAT mount; New BART(or possibly reuse old)
2c	SPLAT/LATR with 3 CMB-S4 SATs (BA replaced with 2 CMB-S4 SATs)	Evaluate: 1) 7 yr survey with pre-SPLAT BA data; 2) time to reach CMB-S4 goal	Increase of ~53kW from current; may fit within *current* SP power generation	New CMB-S4 SATs and new SAT mount and tower
3	Instead, two or more smaller aperture SPLATs (smaller than baseline 5 meter design) with or without SATs	Could be designed to achieve r goal, but risks need to be assessed. Smaller SPLAT would not likely meet non-r SPLAT science reqts.	Two or more SPLATs will exceed current power generation capacity	Smaller SPLAT has reduced de-lensing and low-ell sensitivity; will require 2 or more SPLATs; Lack of checks for systematics if not paired with SATs, including SPLATxSAT correlations
4	CMB-S4 Current Baseline Design: 6x3 SATs, Lab Bldg, SPLAT, High-Bay	7 yr survey meets goal, as shown in the PBDR; with margin provided by SPLAT low-ell data	~368kW SS (~210 kW beyond current CMB usage, assuming SPT and BA turned off)	As described in CMB-S4 Preliminary Baseline Design Report (PBDR)

Value Engineering Approach for SP Configurations 1 & 2

- Follows past trend of reusing equipment, while continuing to make progress toward “r”
- Provide continuous stream of science results; engage scientists; addresses OPP’s “capacity building” for Antarctic scientists
- Use of traverse for all but Do Not Freeze (DNF) materials significantly reduces demand on LC-130 fleet and provide opportunities for increased efficiency in site construction with pre-assembly at MCM
- Does not require a new laboratory building
- Carefully consider methods to increase detector/power of SATs and SPLAT
- Need to investigate further power savings opportunities, as well as alternate power generation, e.g., solar, wind.

Wednesday AoA South Pole Session

- Rationale for, and overview of, alternative South Pole configurations
- Potential of low-ell measurements with the TMA design of the SPLAT
  - Review TMA justification
  - New developments in mirror fabrication
  - Estimates for low-ell sensitivity with SPLAT
- Status of r projections for SP configurations* for different assumptions of low-ell sensitivity, SAT and SPLAT auto and cross correlations
- Risks, R&D
- Site impact & comparison to baseline design; value engineering options

* Not evaluating smaller SPLATs at this time
* Not evaluating distribution of SATs and LATs between sites until Chile r option better understood

Thursday AoA Q&A session

- Given the limited time for discussion during the Wednesday Chile and South Pole AoA sessions and to give people time to think through the issues, an AoA Q&A session is scheduled for Thursday.
- To allow full and frank discussions the Wednesday and Thursday AoA sessions are open to Project and Collaboration members only.

Summary

- We are investigating options, not making decisions
- We need to show that there are viable path(s) forward to engage NSF in the planning
- For DOE to ramp up funding, it is also important for NSF to acknowledge that there is a viable path forward