Project Overview & Status

Jim Strait, Project Director
John Carlstrom, Project Scientist

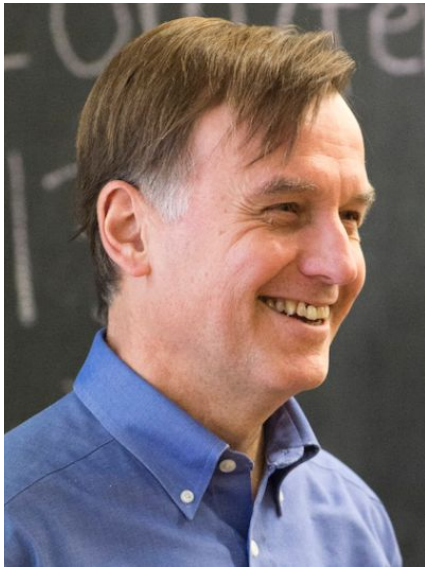
CMB-S4 Collaboration Meeting
August 17-19, 2022

Outline

- New Project Director
- What is new since the May Collaboration Meeting
- Timeline and budget requests
- Analysis of Alternatives and next steps
- Summary

Jim Strait Project Director (Who am I?)

- Joined the LBNL staff and the CMB-S4 Project on July 8, 2022.
- Previously a Fermilab Distinguished Scientist, where he worked since 1985
- Prior experience includes
  - Deputy Project Manager for the Calorimeter Endcap (HGCAL) for the CMS upgrade for the HL-LHC at CERN
  - Project Director of the Long-Baseline Neutrino Experiment
  - Head of Fermilab's Particle Physics Division
  - Program leader for the US Large Hadron Collider Accelerator Research Program (LARP)
  - Project manager for the US LHC Accelerator Project
- Will split time between LBNL (DOE headquarters) and U Chicago (NSF headquarters).



Many positive developments since the May Collaboration Meeting

- Strong support from Snowmass for CMB-S4
- Positive feedback from NSF and DOE regarding the AoA and the alternatives under consideration.
- CHIPS + Science *authorization* bill passed with a good DOE funding profile for CMB-S4:

FY23	FY24	FY25	FY26	FY27
$10M	$25M	$60M	$80M	$80M

- FY23 *appropriation* reports from House and Senate Energy and Water subcommittees:
  - House: “Includes funding for CMB-S4,” but no amount specified
  - Senate: “Not less than $6M”
- Inflation Reduction Act *appropriates* $303M for HEP construction projects, available now.
  - Doesn’t directly affect CMB-S4, but should reduce budget pressure on HEP, which will help us.

Snowmass summary presentation

Cosmic Frontier

The Cosmic Frontier is the bedrock of the field in the 21st century. CF realizes the HEP vision in all its scales and provides a compelling science case on which much of the current HEP program is based. In the next decade, CF will address the most pressing questions facing fundamental physics today, aiming to discover the identity of dark matter, understand the physics of cosmic acceleration, and search for new particles, new forces, and new principles of Nature.

CF seeks increased research support to execute the science goals of all projects in its portfolio, including new funding for cross-survey science leveraging the recently-completed projects DESI and LSST.

Our top project priority is to complete construction CMB-S4, while launching new projects to delve deep and search wide for dark matter, as well as to make the next leap in dark energy and cosmic acceleration research.

July 26, 2022 Highlights and Messages from the Snowmass Summer Study. Prisca Cushman

Strong community support for the importance of the Cosmic Frontier and for CMB-S4 in specific.

This is thanks to the CMB-S4 Collaboration having made a strong case through the whole process!

P5 (Particle Physics Projects Prioritization Panel)

Blueprint for P5 process

Put Caption

Preliminary timeline

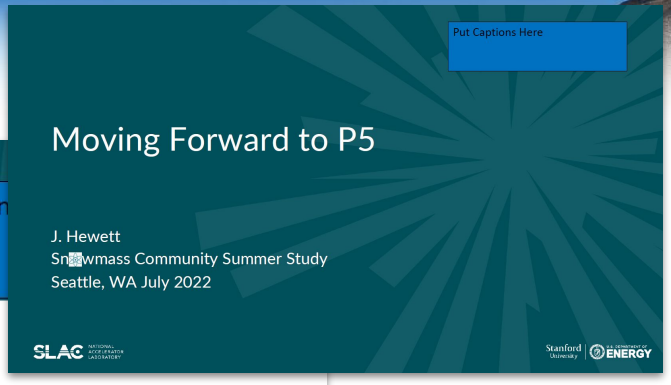
- Form panel by early Fall
  - Call for nominations for P5 members in early Aug 2022
  - Panel members wear a community hat
- Hold hybrid in-person/virtual townhalls in Fall 2022
  - Aim for further community input and further information on potential future projects
  - Opportunity for each panel member to start with equal footing covering all frontiers
- Deliberations Winter/Spring 2023
  - Will provide ample opportunity for further community input
- Aim for report late Spring/Early Summer 2023 for HEPAP to approve and submit to DOE/NSF

Process to select a chair

- Developed a set of criteria/attributes
  - Broad understanding of the field scientifically
  - Well respected
  - Understanding of the agencies and how they work
  - Experience with both universities and labs, and
  - Helps people to work together
  - Will see the program through and able to follow up after the report.
- Agreement between DOE, NSF, HEPAP Chair

4

CMB-S4 must be prepared to make the case to P5 about the importance and excitement about the science and to present a solid, well-considered and realizable project plan.

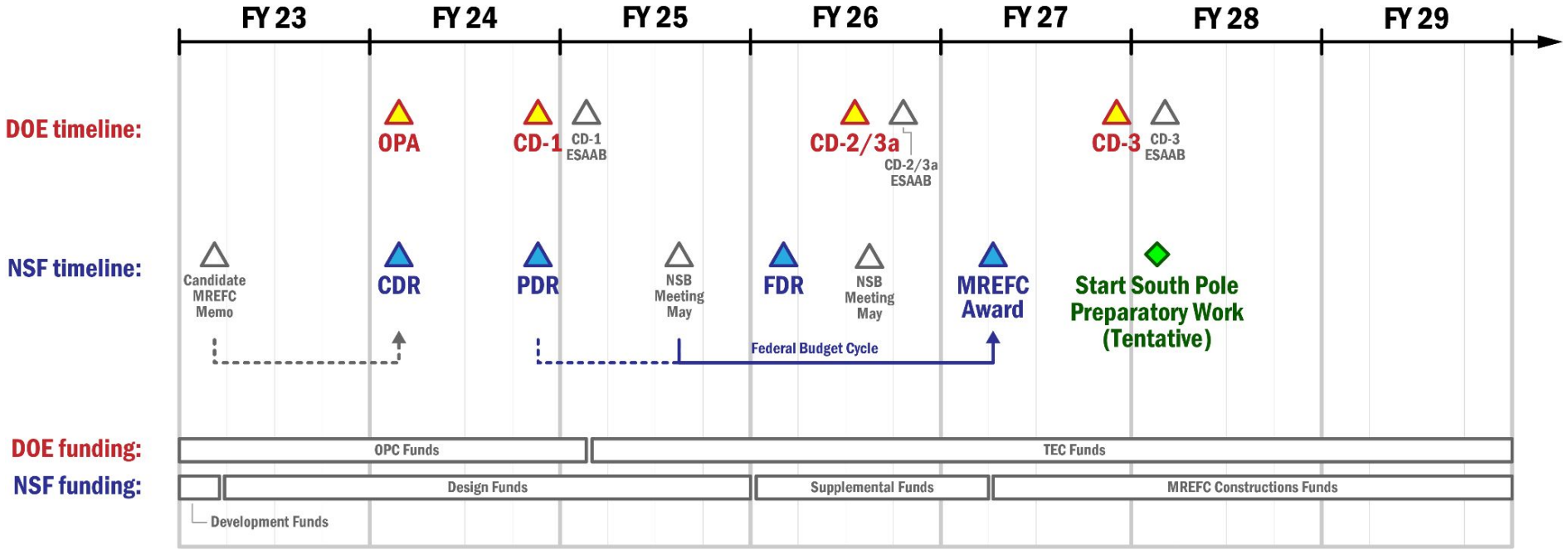


Positive feedback from NSF and DOE regarding the AoA

- In June, we presented to DOE and NSF a snapshot of the state of development of alternative configurations that meet the science goals and fit within our understanding of current South Pole constraints
- Senior representatives from both Agencies were engaged and gave encouraging informal feedback.
- Both DOE and NSF recognized that we have options that will enable the science goals to be achieved within the South Pole constraints.
- NSF told us that they are working toward making CMB-S4 a candidate project for MREFC funding.
- Becoming a candidate MREFC project will trigger an NSF CDR review.
- Our understanding is once CMB-S4 is a candidate MREFC project, OPP will work on South Pole planning for CMB-S4.

CMB-S4 Agency Milestone Chart

Dated: July 26, 2022



- Timeline constructed with input from the Agencies iterated through several meetings with them.
- DOE-NSF Joint Oversight Group (JOG) concurs that this is reasonable for planning purposes at this time.
- Our planning is based on this set of major milestones.

Analysis of Alternatives

Completing the AoA and selecting a new baseline configuration is the top priority of the Project, which is necessary to allow the project to refocus on a well-defined configuration.
We need to complete the process this Fall to support the planned timeline of project approval reviews.

The selected alternative must
- be capable of achieving all of the science goals and
- be compatible with the South Pole constraints

The alternatives are being evaluated with respect to:

1. the science potential of each option in comparison to the goals articulated in the Preliminary Baseline Design Report[1] and the Program-Level Requirements[2];
2. a) the time needed to build and deploy the telescopes and supporting infrastructure and
   b) the required observation time to meet the science goals, i.e. the overall time needed to complete the scientific program;
3. the South Pole infrastructure and logistics required relative to what can be reasonably expected to be available;
4. the estimated capital, operating and life-cycle costs of each of the options;
5. scientific and technical risks.

[1] CMBS4-doc-716
[2] CMBS4-doc-671

Outline for AoA slides

- Why we are doing this, a reminder
- Considerations for alternative South Pole configurations
- Considerations for doing r science from Chile
- Snapshot of the AoA status presented to the agencies in June
- Current status and next steps
- Plan for vetting by Project and Collaboration

Reminder of 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

Reminder of Rationale for Analysis of Alternatives (AoA)

However, after Astro2020 recommendation and before the DOE Office of Project Assessment (OPA) review scheduled for February:

- NSF stated that the South Pole scope of our baseline design configuration was not supportable, at this time.
- This is the reason the February DOE OPA review was postponed.
- Instead, NSF requested that we analyze alternative South Pole options that fit within the current SP logistical infrastructure, for which a primary, but not sole constraint, is station power generation.
- Future NSF funding and engagement (which is also needed for DOE funding) rested on showing that there is a supportable path forward for NSF at South Pole, or that an all-Chile configuration is viable.

Reminder of Rationale for Analysis of Alternatives (AoA)

- Therefore, in addition to the initial DOE AoA options we are developing and analyzing alternative South Pole (SP) configurations, which may require additional scope in Chile.
- The South Pole scope is primarily directed to achieve the r-science goals, so therefore the AoA efforts are focused on the r-science.
- In considering the alternative configurations to achieve the r-science goals:
  - The main issue for the South Pole is the logistical support.
  - The main issues in Chile are not logistical, but instead the challenges to drilling deep on a targeted field from a mid-latitude site, and the mitigation of the higher “sky” noise.

Please note: We are not relaxing our level-1 science goal for *r*. The success of the experiment rests on achieving it!

Alternative South Pole Configurations

Basis for considerations of SP options

- Programmatic foundation:
  - Configurations to fit within our understanding of the existing logistical capacity (power, cargo, etc.)
  - Operational demands at the South Pole should be of a scale similar to existing facilities
  - Science risks need to be understood and include feasible mitigation plans (**true for Chile too!)**
- Scientific foundation:
  - CMB-S4 Inflation science goal, "*r*" must be achievable with high probability and low risk
  - Observing duration should be reasonable
  - Build on Stage 3 experiment successes
- Scientific opportunities:
  - Advances in gapless mirror fabrication for SPLAT and demonstrated improvement of SPT-3G low-ell noise, including the possible mitigation of variable *polarized* atmospheric signal, indicates data from SPLAT may be able to provide significant low-ell sensitivity for "*r*"
  - Use of BICEP Array data

Power assumptions for South Pole (SP) Site

- Current CMB power totals 140 kW
  (plan is to turn off these telescopes when CMB-S4 turns on)
  - SPT 60 kW
  - BICEP3 18 kW
  - BICEP Array 62 kW
  - Not including continued fuel/power for DSL and MAPO laboratory buildings
- Current CMB-S4 SP configuration power estimates:
  - Preliminary Baseline Design: reduced “scrubbed” power estimate (~300 kW) still too high to accommodate with existing SP power plant
  - Alternative 1 (3 SATs + SPLAT): 167 kW
  - Alternative 2 (4 SATs): 145 kW
- We believe the current power generation capability has ~50 kW headroom for steady state SP power generation, but we have not yet received guidance from NSF
- Alternate power generation options could be investigated, including modern solar and/or wind power.

AoA builds on our previous work

- We studied and documented the option of SATs in Chile to achieve the level-1 r goal in the appendix of the Decadal Survey Report and in our refereed 2022 ApJ paper.
- These demonstrated the efficiency of doing the r-science at the South Pole
- These studies resulted in our baseline design configuration of 6 SATs (6 x 3 = 18 telescopes) and 1 SPLAT at the South Pole, as detailed in the Preliminary Baseline Design Report.

AoA activities to assess *r* science from Chile

- We are now developing this comparison further to arrive at a more comprehensive determination of the required Chilean scope (SATs and LATs)
- This is a very fraught problem in that there is no comparable Chilean SAT experiment to scale from its achieved performance.
- Furthermore, ab initio sensitivity calculations have greatly overestimated the performance of degree scale (low-ell) CMB experiments.
- Our forecasting therefore uses simulations coupled to scalings from performance achieved by South Pole SATs.

AoA activities to assess *r* science from Chile

- We are investigating the
  - Impact of more realistic survey scan strategies for Chile, and impact of having to use higher foreground regions of the sky from Chile
  - Required de-lensing effort, and LATs needed to achieve it
  - Impact of observing efficiency differences between sites
  - Sensitivity impact of using half-wave plates in Chile, to mitigate “sky noise”
- Also need to weigh the
  - Systematic and sidelobe risks of different SAT configurations
  - Requirements for solar and ground screening; the impact of 24 hour solar diurnal heating/cooling
  - Technical Risks and required R&D

Ongoing AoA forecasting effort

- Collaboration Science Council's low-ell BB Analysis Working Group
  - Building on work for the Decadal Survey Report and our ApJ paper
- Ad Hoc "Tiger Team" spanning all the necessary areas of expertise
  - Forecasting codes: David Alonso, Colin Bischoff, Victor Buza, Josquin Errard
  - Survey strategies & atmospheric modeling: Reijo Keskitalo
  - Observing efficiencies: Sara Simon
  - Foregrounds: Susan Clark, Brandon Hensley
  - Delensing: Raphael Flauger, Marius Milea
  - Instrument/performance modeling: Jeff McMahon, John Ruhl
  - Data presentation: Cooper Jacobus
  - Coordination: Julian Borrill, John Carlstrom

Snapshot of AoA status presented to NSF and DOE on June 17th, with lots of caveats.

Summary of Initial Projection Estimates

Alternative	Pole Scope	Chile Scope	time to r goal / comments
Current Project Baseline	**6 SAT** **1 SPLAT**	**0 SAT** **2 LAT**	7 yrs with science r margin and systematic cross checks provided by low-ell (degree angular scale) SPLAT data
Alternative 0: Continue SP and Chile CMB programs	**0 SAT** **0 SPLAT**	**0 SAT** **0 LAT**	Exceeds 50 yrs for all goals
Alternative 1: LAT and reduced SATs in SP, LATs in Chile	**3 SAT** **1 SPLAT**	**0 SAT** **2 LAT**	14 yrs with same risks as baseline, additional r margin and systematic cross checks from low-ell SPLAT data; 9 yrs using pre-CMB-S4 SPO data, same risks, additional margin and cross checks from SPLAT; 7 yrs using pre-CMB-S4 SPO data and low-ell SPLAT data, cross-checks but no margin from SPLAT
Alternative 2: Reduced SATs in SP, LATs in Chile	**[illegible] SAT** **0 SPLAT**	**0 SAT** **5 LAT**	10.5 yrs, no r margin or cross checks; 9 yrs using pre-CMB-S4 BA data, no r margin or cross checks
Alternative 3: All telescopes in Chile	**0 SAT** **0 SPLAT**	**18 SAT** **5 LAT**	10.5 yrs, no r margin or cross checks; 9 yrs potentially using pre-CMB-S4 BA data, no r margin or cross checks; (impact of "sky noise" mitigation not included)

Snapshot of the evolving AoA

CMB-S4

Slide 62

June AoA Agency Briefing Feedback and Recent Developments

- Agency representatives were engaged and gave encouraging informal feedback.
- NSF is now working toward making CMB-S4 a candidate project for MREFC funding.
- Becoming a candidate MREFC project will trigger an NSF CDR review.
- Our understanding is once CMB-S4 is a candidate MREFC project, OPP will work on South Pole planning for CMB-S4.

The above are excellent developments. We now need to fully develop, vet and review the alternatives.

Configurations currently being evaluated

Alternative	Pole Scope	Chile Scope
Current Project Baseline	**6 SAT** **1 SPLAT**	**0 SAT** **2 LAT**
Alternative 1: SATs & LAT at South Pole	**3 SAT** **1 SPLAT**	**0 SAT** **2 LAT**
Alternative 2: Only SATs at South Pole	**4 SAT** **0 SPLAT**	**0 SAT** **3-5 LAT**
Alternative 3: Nothing at South Pole	**0 SAT** **0 SPLAT**	**9 SAT*** **3 LAT***

* analysed and then scaled to determine the numbers of telescopes required to meet science goals

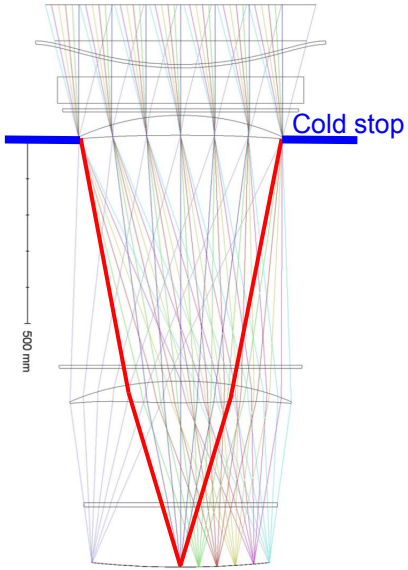
Simulations: Inputs

- 7 instrument models (Ruhl)
  - 2 SPSAT models (baseline, aggressive)
  - 3 CHSAT models (baseline, baseline scaled optics with HWP, aggressive HWP)
  - 1 CHLAT models (CD)
  - 1 SPLAT models (TMA)
- 9 survey strategies (Keskitalo)
  - 1 SPSAT survey (deep)
  - 2 CHSAT surveys (SO-like, S4-like)
  - 5 CHLAT surveys (wide; SO-like, S4-like, SP-like; hybrid)
  - 1 SPLAT survey (deep)
- 14 instrument model x survey strategy (Simon, Keskitalo)
- 3 foreground models (Clark, Hensley)
  - Optimistic, Best Guess, Pessimistic (description here, pg 23)

SAT instrument models

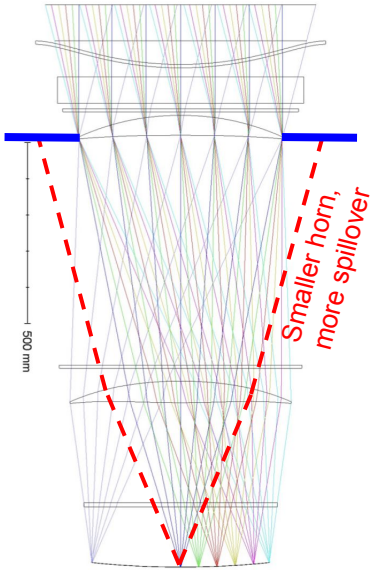
South Pole (no HWP)

Baseline



Baseline Optics

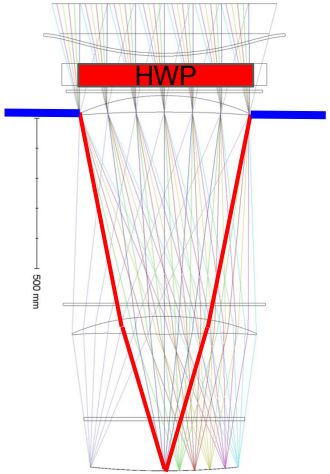
Aggressive



Baseline Optics
with **more (smaller) horns**,
to match SO spillover

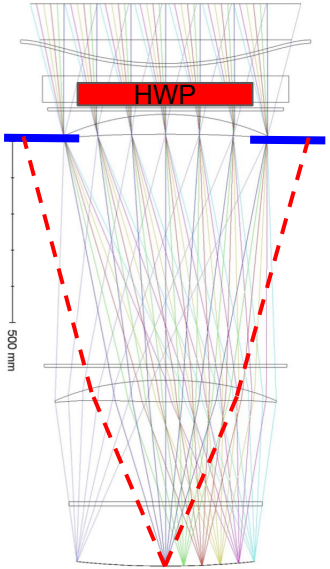
Chile (with HWP)

Baseline Scaled Optics



Scaled Optics,
(same f/#)
so (**fewer) horns**

Aggressive



Smaller aperture,
(higher f/#)
with **more (smaller) horns**,
to match SO spillover

Delensing Projections

- 3 SAT surveys with 5 delensing configurations
  - CHSAT SO-like survey
    - CHLAT wide + SO-like surveys
  - CHSAT S4-like survey
    - CHLAT wide + S4-like surveys
  - SPSAT deep survey
    - SPLAT deep survey
    - CHLAT wide + SP-like surveys
    - CHLAT hybrid survey

Analyses

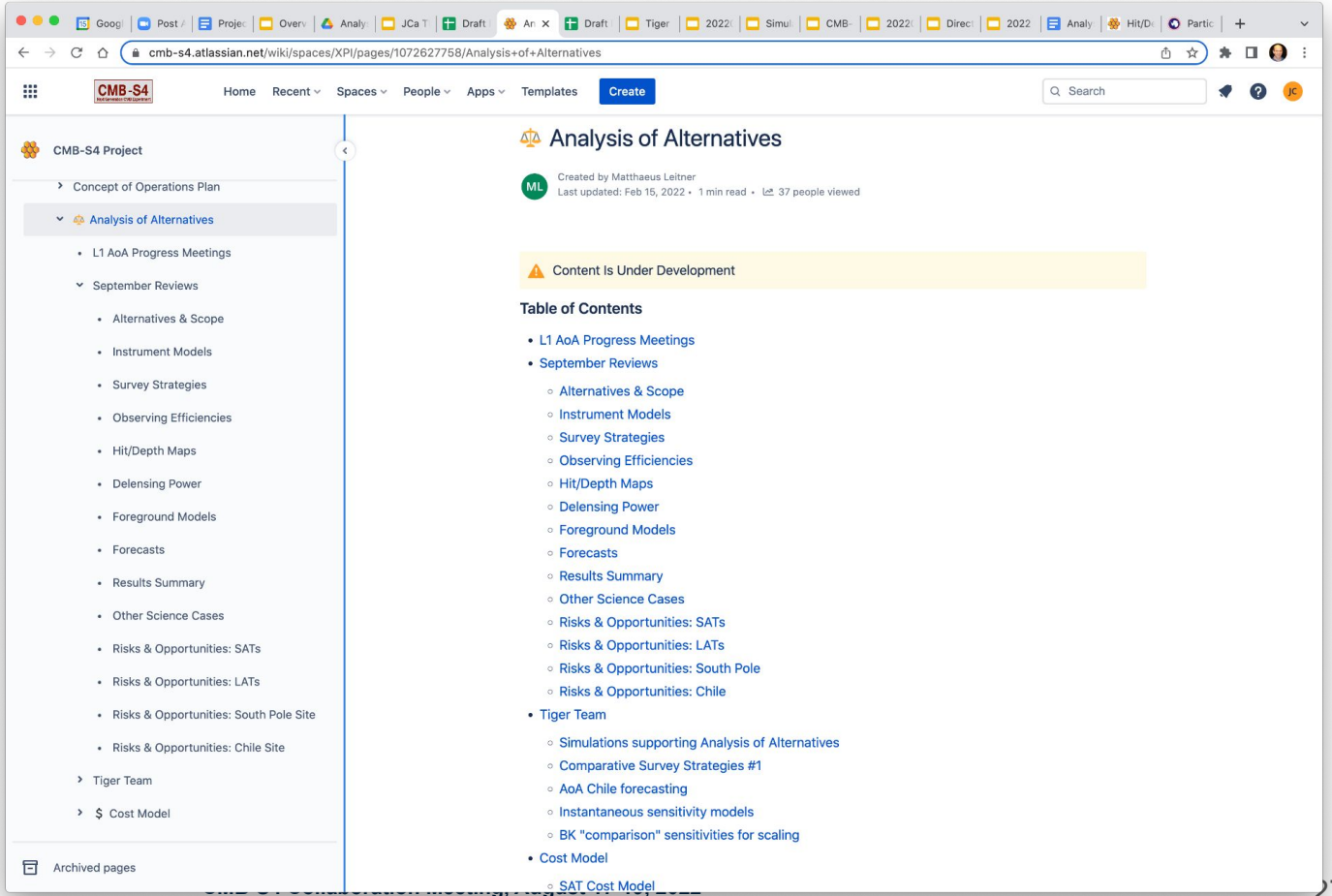
- 3 x SPSAT + 1 x SPLAT; 0 x CHSAT + 2 x CHLAT
  - 2 model x 1 survey x 3 foregrounds x 1 delensing = 6
- 4 x SPSAT + 0 x SPLAT; 0 x CHSAT + 3,4 & 5 x CHLATs
  - 2 model x 1 survey x 3 foregrounds x 2 delensing = 12
- 0 x SPSAT + 0 x SPLAT; 9* x CHSAT + 3* x CHLAT
  - 3 model x 2 survey x 3 foregrounds x 1 delensing = 18

In each case analyze (i) standalone, (ii) with additional data (SPO/SO, SPLAT low-ell)

* rescalable post hoc to other numbers of telescopes

Documentation

Documentation on [confluence](), e.g.,



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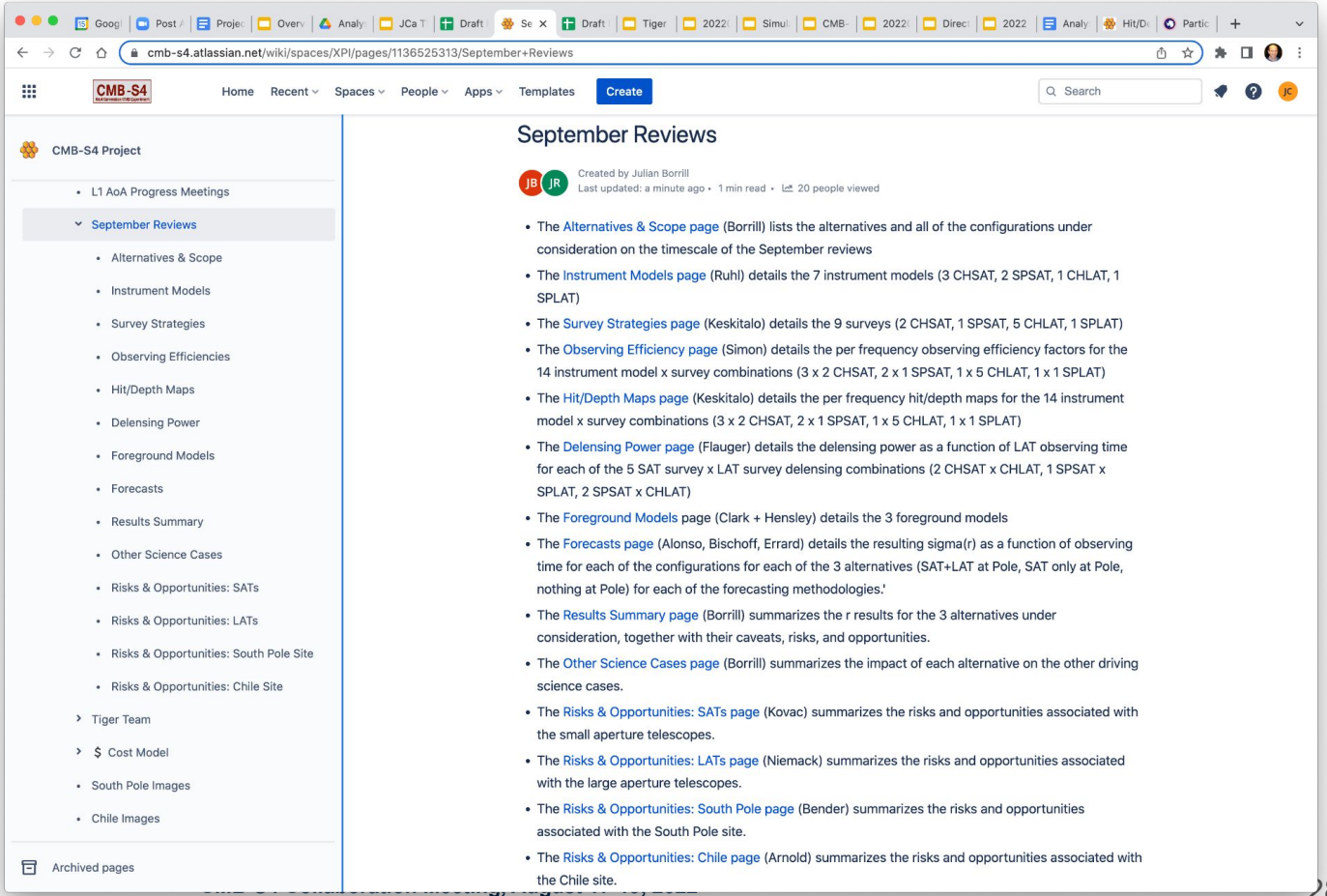

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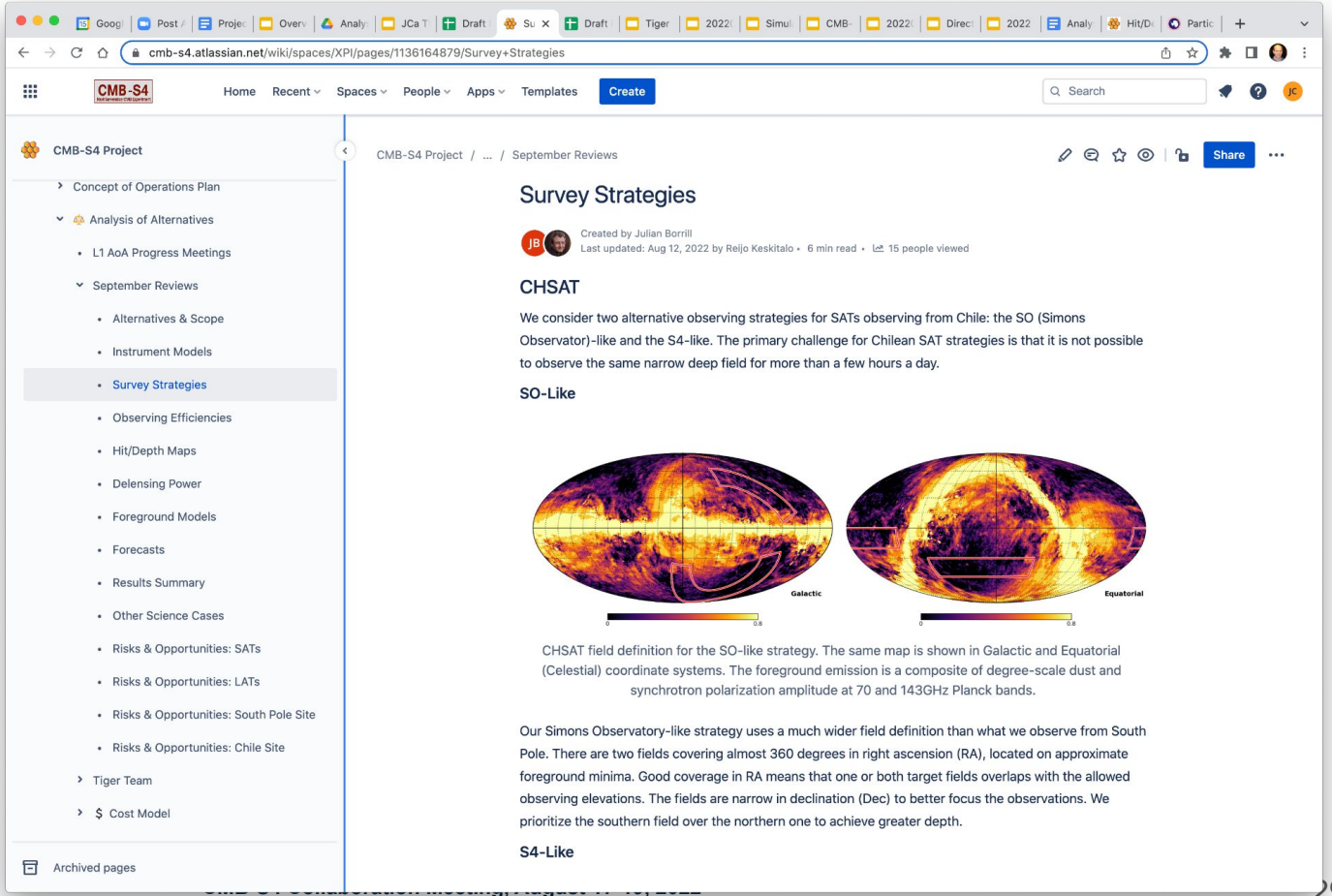

Draft Agenda for Sep 8-9th vetting

Thursday, September 8, 2022

			10	Welcome / Introductions / Review agenda	10	
8:00 AM	8:30 AM		30	Project Introduction and Status	20 + 10	Jim Strait
8:30 AM	9:30 AM		60	Analysis of Alternatives - Overview - Summary of Results and Risks	45 + 15	John Carlstrom
9:30 AM	10:00 AM		30	Analysis of Cost Ranges	20 + 10	Matthaeus Leitner
10:00 AM	*10:30 AM*		*30*	*Break*		
10:30 AM	11:00 AM		30	Analysis of Alternatives - Detail - Instruments (John R) [SAT configurations, de-lensing LAT configurati	20 + 10	John Ruhl
11:00 AM	11:20 AM		20	- Surveys (Reijo) [CHLAT, SPLAT, CHSAT, SPSAT]	15 + 5	Reijo Keskitalo
11:20 AM	11:40 AM		20	- Observing Efficiencies (Sara) [instrument x survey]	15 + 5	Sara Simon
11:40 AM	*12:00 PM*		*20*	*Break*		
12:00 PM	12:20 PM		20	- Depth/Hit Maps (Reijo) [instrument x survey, simulation & rescaling]	15 + 5	Reijo Keskitalo
12:20 PM	12:40 PM		20	- Delensing Power	15 + 5	Raphael Flauger
12:40 PM	1:00 PM		20	- Foreground Models	15 + 5	Brandon Hensley/Susan Clark
1:00 PM	1:30 PM		30	- Forecasting (Colin) [methodology, code comparison]	20 + 10	Colin Bischoff
1:30 PM	2:00 PM		30	- Results and Caveats/Opportunities	20 + 10	Julian Borrill
2:00 PM	2:30 PM		30	Discussion	30	

Friday, September 9, 2022

			5	Review agenda	5	
8:00 AM	8:30 AM		30	CD and TMA LAT Features, Tradeoffs, and Risks (incl low-ell from LA	20 + 10	Mike Niemack
8:30 AM	9:00 AM		30	Risks Associated With SAT Design Choices	20 + 10	John Kovac
9:00 AM	*9:30 AM*		*30*	*Break*		
9:30 AM	10:00 AM		30	Site Layout and Infrastructure Implications at South Pole [inc power]	20 + 10	Amy Bender
10:00 AM	10:30 AM		30	Site Layout and Infrastructure Implications in Chile [inc power]	20 + 10	Kam Arnold
10:30 AM	11:30 AM		60	Discussion	60	

Estimating the costs of the different alternatives

The cost of each alternative is based on Project plans originally developed for the DOE Status Review that was planned for February 2022.

- Based on thorough scope definition and a well defined project organizational structure
- Detailed engineering, production, testing, shipping, and installation schedule
- South Pole energy and accommodation costs depend on telescope counts and are included
- Reviewed by experienced committees (NSF Status Review and Director's Review)
- Parametric models developed to evaluate the construction cost the alternative scenarios based on each specific configuration.
- Annual operating costs are estimated in a similar way. They will be multiplied by the estimated number of observation years required for each alternative to achieve the science goals.

Next steps for AoA

- September 8-9
  - Vetting of analysis of alternatives, by the Project Technical Working Groups and the collaboration Analysis Working Groups
- September 28-29
  - Internal review of the AoA by external experts, chaired by Steve Kahn
- October
  - Brief agencies & request agency guidance
- Fall
  - Project proposes preferred alternative and plan with input from Project (TWG), Collaboration (SC AWGs), review panel report, and agencies.
  - All-Hands meeting for discussion / input and possible iteration to find consensus
- FY23
  - Concept development and preparations for NSF CDR and DOE OPA Status reviews
- FY24
  - Q1 NSF CDR and DOE OPA reviews
-

AoA Review by external experts

Charge

The review committee is asked to assess whether the analyses presented are sufficiently comprehensive in the selection of options, appropriate in depth of assessment for each option, and unbiased, and whether the estimates of cost, schedule and risk are credible and adequately documented for this stage of the project. In conducting the review, the committee is requested to respond specifically to the following charge questions:

1. Has the CMB-S4 team considered an appropriate range of alternatives to be presented to the Agencies?
2. Have the appropriate assumptions, hardware configurations, and uncertainties been identified and clearly presented?
3. Has the science potential of each option been adequately assessed and presented at the level needed for the comparative analysis? Are the alternatives capable of achieving each of the science goals of the experiment?
4. Are a) the relative construction and operating costs, b) the relative construction times, and c) required survey durations of the different alternatives well enough understood to help inform decisions among them?
5. Have scientific and technical risks been identified and evaluated adequately for this stage of the project for each option to support the comparative analysis?

The committee is requested to provide an informal closeout report to the CMB-S4 team at the end of the review meeting, and a final written report within 2 weeks after the review.

Process to come to conclusions

- Formally the decision is the responsibility of the Project Director, who is responsible to the Funding Agencies for the execution of the Project.
  - Decision will be developed working in close consultation with the Project Scientists, the L1 team, the AWGs and the AoA Tiger Team.
  - The exact decision process is under development.
- Full engagement by and input from the Collaboration is essential in developing the decision.
  - The Project will work with the Collaboration Executive Team to ensure that input is obtained from the Science Council and through it from the Analysis Working Groups.
  - Possible all-hands meeting for discussion / input and possible iteration to find consensus.
- The aim is to have a consensus conclusion as to which alternative we will choose going forward.
- Remaining uncertainties may require that we maintain a “backup” alternative in case subsequent information, e.g., from OPP or engineering realities, bring our preferred option into question.
- Once a conclusion is reached, we will brief NSF and DOE and seek their feedback and approval.
- Hope to complete this process no later than first part of November.
- Then continue development of the project on the basis of the new configuration.

Summary

- Many positive developments in the past several months.
  - Strong support from the HEP community via the Snowmass process
  - Favorable budget news from Congress
  - Renewed engagement by NSF and positive feedback from both Funding Agencies
  - Planning timeline agreed with NSF and DOE
- Completing the AoA is the top Project priority.
  - Active work underway by the Collaboration AWGs and the tiger-team
  - Supporting effort on construction and operations costs
  - 2-day vetting meeting planned for September 8-9
  - Internal review by committee of external experts planned for September 28-29
  - Aim for consensus conclusion as to the preferred alternative that will form the basis for the project going forward.
  - Hope to complete this process by the first part of November and proceed with the project.
- The job for the coming year will be to prepare for the upcoming project approval reviews.