LBNL Director's Status Review of the CMB-S4 Project in Preparation for DOE Independent Project Review Final Report

November 16-19, 2021

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1. Introduction

The Lawrence Berkeley National Laboratory (LBNL) Laboratory Director commissioned the LBNL Project Management Office (PMO) to organize and conduct a status review of the Cosmic Microwave Background experiment-Stage 4 (CMB-S4) Project in advance of the Department of Energy (DOE) Office of Project Assessment (OPA) Progress Review. The charge for the review may be found in Appendix A of this report. The three and one half day review consisted of technical, environment, health and safety (EH&S), cost and schedule, managerial and programmatic discussions and took place on November 16-19, 2021. The agenda is included with this report in Appendix B, and it should be noted that the entire review was conducted remotely using Zoom due to COVID-19 restrictions. The review committee consisted of external and internal subject matter experts (SMEs) independent of the project and with relevant experience and knowledge. A full list of committee members may be found in Appendix C along with their respective subcommittee focus assignments.

This report reflects the general findings, comments, and recommendations of the committee. An initial draft version of comments and recommendations from this report comprised the closeout briefing provided at the conclusion of the review.

The following is the CMB-S4 Project background as described in the NSF (Draft) Project Execution Plan (PEP, Document CMBS4-doc-608):

> *The Cosmic Microwave Background Stage-4 experiment (CMB-S4) is designed to tackle questions about fundamental physics from the earliest moments in the Universe through to the epoch of dark energy domination. CMB-S4 will search for signatures of inflation at one end of the energy scale, and for sub-eV particles at the other, including neutrinos and as-yet-undiscovered light relics. CMB-S4 data will trace out the behavior of gravity across cosmological distances and anchor our understanding of how structures form under the gravitational collapse of dark matter moderated by the influence of baryons. These aims require CMB measurements with sensitivity, precision, and accuracy far beyond those obtained to date, roughly two orders of magnitude more sensitive than the summation of all measurements acquired so far, and an order of magnitude more sensitive than Stage-3 experiments.*
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> *CMB-S4 is well aligned with the 2014 Particle Physics Project Prioritization Panel (P5) report "Building for Discovery: Strategic Plan for U.S. Particle Physics in the Global Context", which recommended support for CMB experiments. The P5 report listed CMB-S4 to be developed in the core particle physics program. The 2015 NAS/NRC report "A Strategic Vision for NSF Investments in Antarctic and Southern Ocean Research" recommended a next-generation cosmic microwave background program be pursued as one of three strategic priorities for the current decade. The US Department of Energy, Office of High Energy Physics, and the National Science Foundation (NSF) Divisions of Astronomical Sciences (AST), Physics (PHY), and Polar Programs (PLR) requested that*

the Astronomy and Astrophysics Advisory Committee (AAAC) establish a Cosmic Microwave Background Stage 4 Concept Definition Task force (CMB-S4 CDT) as a subcommittee in order to develop a concept for a CMB-S4 experiment. The CDT concept for CMB-S4 was a single collaboration, experiment and project that requires multiple cameras and telescopes distributed across two sites. CMB-S4 has a rich and diverse set of CMB-S4 scientific goals with four major themes:

1. *Primordial gravitational waves and inflation,*
2. *The dark Universe,*
3. *Mapping matter in the cosmos, and*
4. *The time-variable millimeter-wave sky.*

The first two science themes relate to fundamental physics. The other two themes relate to the broader scientific opportunities made possible by a millimeter-wave survey of unprecedented depth and breadth.

<u>Primordial Gravitational Waves and Inflation.</u> The goal is to measure the imprint of primordial gravitational waves (PGW) on the CMB polarization anisotropy, quantified by the tensor-to-scalar ratio r. Specifically, CMB-S4 will be designed to provide a detection of $r > 0.003$. If inflation is the correct description of our Universe and occurred near the GUT scale, then r is predicted to be at these levels. In the absence of a PGW signal at these predicted levels, CMB-S4 will be designed to constrain $r < 0.001$ at the 95% confidence level, over an order of magnitude more stringent than current constraints.

<u>The Dark Universe.</u> In the standard cosmological model, about 95% of the energy density of the Universe is in dark matter and dark energy. CMB-S4 will address numerous questions about these dark ingredients, such as: How is matter distributed on large scales? Does the dark matter have non-gravitational interactions with baryons? Are there additional unseen components beyond dark matter and dark energy? A key goal of CMB-S4 is to determine the contribution of light relics to the energy density, often parameterized as the "effective number of neutrino species," Neff. Specifically, CMB-S4 will constrain $\Delta N_{eff} < 0.06$ at 95%C.L.

<u>Mapping matter in the cosmos.</u> CMB-S4 will map out normal and dark matter by measuring the fluctuations in the total mass density (using gravitational lensing) and the ionized gas density (using Compton scattering). Observations of gravitational lensing of the CMB are key to many CMB-S4 science goals, including important constraints on dark energy, modified gravity, and the neutrino masses. CMB-S4 maps will provide highly complementary data for investigations of dark energy, modifications to general relativity, and neutrino properties. For example, CMB-S4 will provide two independent determinations of the sum of the neutrino masses, using weak gravitational lensing and the evolution of the number density of galaxy clusters. The maps will also provide a unique and powerful probe of the influence of baryonic feedback on the formation of galaxies and clusters of galaxies.

The time-variable millimeter-wave sky. *CMB-S4 will play an active role in multi-messenger astronomy, providing a long baseline with high-cadence sampling in both intensity and linear polarization over a wide sky area. CMB-S4 will provide key insights into transient or burst events, moving sources such as Solar-System objects, and variable sources such as AGN.*

The current project scope is also summarized:

The infrastructure and facilities that must be designed, built, integrated, tested, and commissioned are described in numerous project documents. The Instrument consists of two major infrastructure components, one located at the Amundsen-Scott South Pole Station and the other located in the northern Atacama Desert in the Republic of Chile. The CMB-S4 Preliminary Baseline Design Report provides a system-level overview of the subsystems that comprise the Instrument.

The scientific facilities constructed at the South Pole are composed of one Large Aperture Telescope (LAT) and 18 Small Aperture Telescopes (SATs). The LAT has one Receiver consisting of 85 optics tubes with each tube containing its own detector focal plane. Groups of 3 SAT optics tubes, each with its own detector focal plane, are cooled by a common cryogenic system and mounted inside a single ground shield.

In addition to the scientific instrumentation, support facilities and infrastructure will be constructed. The LAT will have a dedicated High Bay enclosure to allow for installation and maintenance of the LAT Receiver. Each pair of SATs will have a dedicated laboratory building to allow for installation and maintenance of electronic and mechanical components and subsystems. New generators and electrical distribution systems and computing and data transport systems are also required as part of the facilities and infrastructure to be constructed at the South Pole. Ice pad foundations for the LAT, SATs, laboratory buildings, and major utility subsystems need to be formed prior to the start of all civil work construction.

The scientific facilities constructed in the northern Atacama Desert in Chile consist of two LATs, one High Bay building for and installation and maintenance of the LAT Receivers, and electrical generators and distribution systems, and computing and data transport systems, roads and fencing will also be constructed as part of the required facilities and infrastructure.

This report is organized around the eight review subcommittee sections with relevant charge questions in each corresponding section. In addition to answers to the specific charge questions, findings, comments, and recommendations are provided by each subcommittee.

In addressing each of the charge questions the review committee examined the project status, progress, and planning to identify any concerns for this stage of the project. This

Director’s Review was held in advance of the DOE OPA Progress Review planned for February 15-18, 2022.

2. Overall Assessment

CMB-S4 is planned as a joint DOE & NSF project to address cutting-edge questions in physics and astrophysics using state-of-the-art microwave telescopes located in the Chilean Andes and at the South Pole. The current technically limited cost is $894M including 40% contingency, and the schedule calls for early finish in 2030 with 2 years of schedule-contingency to the late finish date.

The review committee congratulates the project on the impressive progress made in the past year, especially in light of the limited funds available; and for the strong endorsement from the 2020 Decadal Survey. The science-driven technical design has advanced to or beyond the conceptual stage for most of the project and the management structure; documentation and planning is also very advanced for this stage. R&D has progressed well to support the design and understanding and mitigation of technical risks, and the management team is strong and experienced.

The project now faces the challenging goal of being ready for the planned DOE CD-1 (Critical Decision 1) review in about a year, and the NSF PDR (Preliminary Design Review) in a similar time scale. This committee has set as its goal, in addition to responding to the charge, to provide advice to support and help the project plan its activities leading to success at these reviews. Here we call out several of the most significant and challenging tasks the project must handle in the next year. The main body of the report will include more detail about these tasks as well as comments and recommendations meant to help the project move forward successfully.

We also recommend that the project treat the effort needed to prepare for the CD-1 review as a mini-project with activities scheduled and linked, personnel assigned, milestones to gauge progress and tracking.

Tasks that should receive high priority:

1. Increase engagement with the NSF on essential topics including defining joint NSF/DOE governance, a timeline for submitting the MREFC (Major Research Equipment and. Facilities Construction) proposal and for the PDR review, conditions and constraints related to project activities at the South Pole (see # 2, below).
2. Engage with the NSF Office of Polar Programs about a plan for overall South Pole station logistics as a high priority in order to verify the project’s assumptions that drive the schedule of activities at the Pole. Once this is complete, that information should be incorporated into the project budget and schedule.
3. Perform the required alternatives analysis at the level of detail required for the DOE CD1.

4. Continue to develop a defensible production schedule for detectors, readout, module assembly and testing, taking into account factors such as production yield, access to production capabilities, the need for skilled and trained personnel, effective QA/QC, etc. with high priority in the period before CD1. While many of the fundamental components of a scalable production plan for the detectors, readout and modules are coming into being, and the underlying bench top technology appears to be well developed, the real challenge for the project will be the actual production, testing and assembly at the needed scale and schedule.
5. Mature the project's risk management and analysis to assure that adequate cost and schedule contingency is credibly justified and then provided by the funding agencies. This is especially important in the context of NSF's "no overrun" policy.
6. Staff up key positions, especially where people are doing double-duty,and in areas such as data management, EH&S, and systems engineering.
7. Provide an externally reviewed science flow-down with defensible margins or tradeoffs. Such a flow-down is important from the systems engineering perspective and to support the alternatives analysis and KPP (Key Performance Parameters) strategies and assure the flow-down is understood consistently across the project.
8. Develop a procurement plan and resulting obligation plan needed to provide credible funding/obligation/cost profiles for the Project/agencies.
9. Verify the cost range and schedule duration through further analysis of potential cost and schedule drivers (e.g. supply chain and site logistic delays) and include design/estimate maturity in the analysis.

We point out that the NSF requirements (see Sec. 2.3.2) at PDR are more demanding than the DOE CD1 requirements. Whereas DOE requires a cost range at CD1, at NSF PDR the NSF project would, in essence, be baselined with cost, schedule, and scope contingency locked in, and an MREFC proposal must be submitted ahead of the PDR review. If the NSF PDR happens in Q4 of 2022 as the project plans, the effort to understand cost, schedule, etc. in the next year would increase significantly.

Finally, we recognize that the availability of funding in the short term and the funding profiles from both agencies represent significant risks to the project's technically limited cost and schedule. Effective communication and interactions with the agencies will be an important job for the Project Director and collaborating institution's leaders.

3. Committee Recommendations

The following are the 53 recommendations put forward by the committee as a whole and its 8 sub-committees (those recommendations that should be addressed prior to the DOE OPA Status Review are italicized):

SC1: Large Aperture Telescopes & Small Aperture Telescopes

1. *For the OPA status review the project should, in a slide, explain clearly the baseline plan for LATs and how the CCATp and SO opportunities will be utilized and the cost impact of such events.*

2. *For the OPA status review the project should clearly explain how the high level technical risks, such as Risk-224 LATR spillover (excessive loading), will impact the science if not achieved and explain the mitigation plan and impact.*

3. *For the OPA status review, state how much the beam shape, sidelobes and thermal loading in current experiments might contribute to systematic errors or limits. State how much improvement or measurement of these effects are required to meet CMB-S4 science goals and the expected quantitative improvements with the CMB-S4 designs for SPLAT and SAT.*

4. For the DOE CD-1/NSF PDR review, the project should consider supply chain disruptions and the cost impact should be evaluated and planned. This could have a significant impact on NSF funded LATs.

5. By the time of the DOE CD-1/NSF PDR, present a clear Analysis of Alternatives (AoA) with quantitative performance figures of merit and science yield for the chosen designs for LAT telescopes in Chile and the South Pole, in particular the use of SO, CCATp or TMA for the two sites.

SC2: Detectors

6. A subset of detector parameters ranges for acceptable wafers have been presented. In addition to defining these parameters, acceptable ranges of parameters for individual detectors need to be established and a plan for how these criteria will be applied to determine science grade wafer acceptance should be formulated.

7. A specification for the thermal conductivity from the detector wafer to the module assembly should be defined and solutions that have potential to reliably meet this specification should be developed and demonstrated. The reliability of the feed array-to-detector mechanical interface under thermal cycling should also be considered in this setting.

8. In the current plan, each fabrication site will produce quality control documentation in preparation for CD-1. Continued diligence in sharing best practices in process control and test elements is encouraged. Striving for uniformity across fabrication sites in the area of quality control is advocated.

9. We recommend that the fabrication facilities down-select to common materials and processes when possible. This should be strongly considered for facilities experiencing difficulty meeting wafer specifications in the prototyping phase. For example, several designs for the dual transition TES sensor are being pursued. A

fab experiencing difficulty with their process should be encouraged to duplicate one that has been successfully implemented.

SC3: Readout, Module Assembly & Testing

10. Vibrational heating of the detector modules and sub-Kelvin structures in the receivers, could be a significant potential source of heating and low-frequency microphonic noise. In particular, given the significant number of detector modules in each of the SAT and LAT receivers, a requirement on the vibration frequency of the focal plane structure could impose requirements on the detector module weight, which could be challenging to meet. Recommendation: We recommend that the project develop clear vibration frequency requirements, for both the Module structure design (within the MAT L2) and the sub-Kelvin focal plane structure in the SAT and LAT receiver designs (within the SAT and LAT L2s, respectively), and flow those down to requirements on the module weight. Sources of vibration should be identified, their disturbance spectra measured, and used to predict vibrational heating of the cryogenic system.

11. There will be many different clocked signals in the system, and there may be crosstalk among them. Consider synchronizing as many of these as possible, and identify a person/team responsible for tracking all such signals and approving any non-synchronous signals. Develop tests to assure that they don't introduce time varying pickup in the science data. (The plenary speaker indicated that there was no overall plan to manage this.) Recommendation: We recommend that there be a process for management and approval of non-synchronous signals.

12. The reviewers are aware that past reviews have made recommendations about flex cable development. We were shown a design with thin metal traces and thick bond pads. Recommendation: Verify that such a structure is robust under cryo thermal cycling and is not susceptible to cracks forming at the thickness transition.

13. The project plans to test 700 modules and deliver approx 500 to the instruments. It is planned to rework modules which show problems during test. Recommendation: When technically possible document and demonstrate the entire rework process and include in future Module presentations.

14. The L1 project chose to divide Detectors, Readout, and Modules, into separate L2 branches. Clearly a well functioning instrument(s) depends upon strong technical coordination between these subsystems and systems. At L1 there is a group of scientists and engineers with oversight responsibilities for all of CMB-S4.

    Recommendation: We recommend that these L1 engineering and technical oversight roles be clarified with respect to properly integrating Detectors, Readout, and Modules. If appropriate, we further recommend that a team, or person, be identified who will ensure the proper integration of these subsystems.

SC4: Sites Infrastructure, Integration & Commissioning

15. Chile Site: Complete the design bidding with Chilean companies to avoid misunderstandings/problems with future Chilean Contractors. Design from abroad sometimes is different to what local contractors expect (in methods and available materials) and that drives claims further on during construction.

16. Chile Site: As discussed before in the May 2021 review, the available space in the High Site Building may be insufficient for the commissioning stage. This needs review to design the proper size or decide if rented space could be used during construction.

17. South Pole Site: The CBM-S4 management team should work with the NSF to define a process to develop supportable planning assumptions for the project. This information is needed to make the cost and schedule realistic.

18. South Pole Site: The CMB-S4 management team should work with NSF to define how the required electrical power should be supplied for the project. Is the project responsible for the design and construction of the power plant or will NSF supply power through South Pole infrastructure upgrades.

19. South Pole Site: CMB-S4 and IceCube-Gen2 could both benefit from collaboration. A mechanism should be developed to foster this collaboration.

20. CMB-S4 faces difficult logistics for fuel delivery to both sites combined with significant power needs. Photovoltaic electricity production should be seriously considered at both sites to reduce fuel usage.

21. The project should explore including money in the MREFC budget to increase the infrastructure for fuel delivery to Pole. This could include fuel sleds and tractors for the traverse.

SC5: Data Acquisition & Data Management

22. Data Management milestones should be more fully tied to other project milestones and linked to the rest of the project schedule. Presentation of these milestones should link them to internal project goals rather than to the review schedule.

23. Develop a comprehensive data distribution and organizational model showing the data products scientists will receive, how they are organized, and how they will be accessed.

24. Solidify the DAQ interface with regard to observing control and observing priorities. Present a credible observatory control scenario.

25. Clarify the status of MoUs / agreements with key external partners, especially NERSC, REUNA, and U.S. R&E networks (e.g. ESnet).

SC6: Science Requirements, Flow-down & Systems Engineering

26. A science requirements document that can support the Alternative Analysis and KPP strategies should be developed. As part of that process the top-level scientific and technical margins and verification strategies should be stated. For each level in the requirements the project should define the owner of the requirement (agency or project levels). The science requirements document and the supporting science studies (r and Neff) should be reviewed down to the primary measurement requirements by an outside panel of CMB science experts. Any evolution of top-level science requirements with respect to the AAAC/CDT report and DOE Mission Need statement should be clearly presented.

27. Perform and document an alternative analysis. To support the cost, budget and scope range requirements of CD-1 include in presentations and documents the trade space that was analyzed to support alternative designs considered. Include appropriate lifecycle costs in these studies.

28. For CD-1, present threshold KPPs that define the technical & programmatic success of the Project and how these drive the point design. Also present objective KPP's that meet the science expectations from the community.

29. For CD-1, include a verification, validation and commissioning plan for the complete CMB-S4 system, hardware systems at both sites and software included, that delivers the science products, e.g. CMB intensity and polarization maps.

30. For CD-1, provide a basic concept of operations document which includes observing planning and key operations use cases that may impact technical design decisions and cost. Present an observation strategy consistent with the point design that supports meeting the science requirements and objectives. Include whether there is a need for observation scheduling software and optimization between sites.

31. For CD-1, derive a basic upper bound for operations costs with some technical and comparative basis. Provide some initial model for how the operations might be shared between DOE and NSF. This is important to establish the lifecycle costs.

32. For future reviews, the project should identify key background documents and connect them to specific charge questions where possible. They should also formulate formal review recommendation response documents, with response plans, implementation dates, and responsible personnel, keep them updated, and periodically review these with the agencies and describe them in future review plenary presentations.

SC7: Management, Quality Assurance, Environment, Health & Safety

33. *Incorporate the NSF PI in the project governance documentation commensurate with their responsibility to the NSF.*

34. *Immediately resume the search for a permanent project director.*

35. *Prepare and present a detailed staffing plan*

36. *Develop and present a plan and approach for completing the Analysis of Alternatives (AoA) for the Status Review*

37. *Increase the schedule float by 1 year until South Pole installation, logistics, integration, and commissioning are clarified.*

38. *Engage with NSF OPP to develop a plan for South Pole logistics.*

Prior to the CD-1 Review and NSF PDR:

39. Complete an adequate AoA following the GAO and DOE guidance.

40. Develop a charter for and appoint a Project Management Advisory panel.

41. Prepare and clarify the KPP strategy discussion and development and plan on presenting it in the plenary session.

42. Include an assessment of supply chain issues (such as delays, export control, and suspect counterfeit parts) at the CD-1 Review

43. Prepare and present progress on the detailed staffing plan.

SC8: Cost & Schedule

44. *The Project should finalize the cost range, re-assessing the estimate uncertainty, cost/schedule impacts and opportunities for establishing the upper and lower cost range.*

45. *The Risk register needs to be expanded to include the initial risk analysis (pre-mitigation) as well as the transition to post mitigation risk, technical and performance risks. The project should continue updating the Risk Register to incorporate areas of concern that need additional analysis. The risk event cost/schedule impacts should be calculated with a documented basis of estimate.*

46. *The project should reassess the risk schedule impact definitions and to include tiered milestones impacts or other schedule milestone impacts.*

47. *The project should prepare an analysis and justification of their proposed escalation rates.*

Prior to the IPR CD-1/NSF PDR:

48. The project should develop a Project Assumptions document for Programmatic, Scope, Cost, Schedule and Risk assumptions.

49. The project team should bring the detail, backup documentation and traceability from BOE to P6 up to GAO standards in preparation for an ICE review.
50. Prepare and present an assessment of the project's implementation of the GAO standards for cost/schedule.
51. Prepare a funding, obligation and cost plan including contingency usage plan for the project.
52. The Project should finalize the cost contingency and schedule analysis, including correlations between activities.
53. The project should assess uncosted labor in the non-management WBS elements.

4. SC1 – Large Aperture Telescopes & Small Aperture Telescopes

Charge Point #1
Is the progress on the development of the conceptual design and acquisition strategy adequate to meet the project's milestone for completion by CD-1?

Answer: Yes, the team should be ready for CD-1/NSF PDR in approximately 8-10 months.

Charge Point #2
Is the project making adequate progress to show a credible cost range and project duration by CD-1?

Answer: Yes, the systems are in place and are being exercised. However, the worldwide supply chain issues could increase costs and duration and should be considered.

Charge Point #3
Do the project's plans being developed to execute the work make the most efficient use of the financial, human and technical resources available to meet the mission need? Does the project use the human and technical resources available to it at the participating national labs and universities when they are the most efficient choice? Are qualified vendors being sought out where they are the most cost-effective option?

Answer: Yes, but further efforts over the coming months should be directed towards updating significant fabrication contract costs and schedules taking into account potential supply chain issues.

Charge Point #5
Does the project understand its dependencies on outside resources such as participation by researchers with other funding sources and funding from other agencies or international collaborators? (Specific to the LATs and SATs)

Answer: Yes. However, LAT may have difficulty hiring/retaining adequate technical resources at universities.

Charge Point #6
Does the proposed project team have adequate management experience, design skills, and laboratory support to produce a credible technical, cost, and schedule baseline?

Answer: SAT - yes, LAT - probably. Vertex will build CHLATs in Chile. SPLAT may be different, requiring a new design and adequate technical resources to develop suitable plans/estimates.

Charge Point #7
Are the EH&S aspects being properly addressed and is the planning sufficient for this stage of the project?

Answer: Yes. Legacy requirements exist as a solid framework.

Charge Point #8
Are there any other significant issues that require management attention?

Answer: No.

Comments

- The LAT and SAT groups have captured a significant number of risks for the pre-CD-1 stage. However, most of these appear to be related to funding, cost or schedule. The number of purely technical risks which might ultimately impact meeting science requirements seems small. Most of the mitigations were associated with prototyping or running additional simulations and catching problems early enough to redesign and fix. The impression of the committee is that some risks might exist that cannot be mitigated fully prior to construction and will result in not quite meeting a requirement or perhaps in increased survey time to meet the goals of CMB-S4. Some technical issues may only be found in commissioning, too late to fix. The risks should be reviewed with this in mind.
- It was not clear to the committee how CCATp and SO LATs fit into the planning process. It was stated that there are MOUs in development with these collaborations and that they might join CMB-S4, but without discussion of likelihood, how hardware might be integrated into the Project, etc.
- Most of the factor of ~100 sensitivity improvement for CMBS4 comes from the dramatic increase in the number of pixels and integration time. This level of improvement requires a commensurate reduction or mitigation of potential systematic errors.
- The South Pole part of the project is to be congratulated for a very well worked out plan as expected by their extensive experience in deploying CMB experiments at the

pole. The dependence on other L2 components needs to be carefully monitored to stay on schedule.

- SPLAT currently only has +-30 deg bore site rotation. Would +-45 deg bore site rotation allow interchange of the two linear polarization detectors and aid in sorting out systematic effects?
- Quantitative estimates of the change in cryocoolers and detectors performance as a function of orientation relative to gravity, tracking accelerations and the magnetic field may be important in evaluating sources of possible systematic errors.
- The team for each of the three telescopes, CHLAT, SPLAT and SAT should consider running a forward simulation, from sky to detector to science analysis, with pointing errors to verify the pointing knowledge and tracking requirements are sufficient for the science goals. Recovering weaker signals by going deeper in the presence of already detected or foreground signals often requires more accurate knowledge of where the beams are pointed.

Recommendations

1. For the OPA status review the project should, in a slide, explain clearly the baseline plan for LATs and how the CCATp and SO opportunities will be utilized and the cost impact of such events.
2. For the OPA status review the project should clearly explain how the high level technical risks, such as Risk-224 LATR spillover (excessive loading), will impact the science if not achieved and explain the mitigation plan and impact.
3. For the OPA status review, state how much the beam shape, sidelobes and thermal loading in current experiments might contribute to systematic errors or limits. State how much improvement or measurement of these effects are required to meet CMB-S4 science goals and the expected quantitative improvements with the CMB-S4 designs for SPLAT and SAT.
4. For the DOE CD-1/NSF PDR review, the project should consider supply chain disruptions and the cost impact should be evaluated and planned. This could have a significant impact on NSF funded LATs.
5. By the time of the DOE CD-1/NSF PDR, present a clear Analysis of Alternatives (AoA) with quantitative performance figures of merit and science yield for the chosen designs for LAT telescopes in Chile and the South Pole, in particular the use of SO, CCATp or TMA for the two sites.

5. SC2 – Detectors

Charge Point #1

Is the progress on the development of the conceptual design and acquisition strategy adequate to meet the project's milestone for completion by CD-1?

Answer: Yes. The path presented employs the CDFG (CMB-S4 Detector Fab Group) prototype wafers and data to prepare for CD-1. These preliminary detector demonstrations will be used to develop and refine a technically limited schedule consistent with CD-1 level project readiness. Similarly, elements of the "CMB-S4 Detector Optical Coupling Assessment" report and detector workshop documentation can be used to support the alternative analysis process for the detector subsystem.

Charge Point #2

Is the project making adequate progress to show a credible cost range and project duration by CD-1?

Answer: Yes. Inputs for the detector acquisition cost model for fabrication were obtained by openly soliciting inputs from existing and planned academic, industrial, and government superconducting foundries within the United States. The R&D experience gained by these facilities in deploying various stage three CMB experiments inform the estimated average production cost for wafers that meet the needs of the CMB-S4 project. Uncertainty in the fidelity of the individual cost, duration, and yield estimates are partially mitigated through the planned redundancy in sites used to produce the eight detector types. Keys to reducing risk in this area will be definition and demonstration of science grade wafer performance, testing throughput, and wafer yield. Efforts in these areas are underway and will feed into the planned path to CD-1.

Charge Point #3

Do the project's plans being developed to execute the work make the most efficient use of the financial, human, and technical resources available to meet the mission need? Does the project use the human and technical resources available to it at the participating national labs and universities when they are the most efficient choice? Are qualified vendors being sought out where they are the most cost-effective option?

Answer: Yes. The detector acquisition strategy for the CMB-S4 project has engaged existing expertise and facilities for superconducting detector fabrication and testing. The plans leverage a broad range of existing hardware and human assets for electromagnetic design, materials, fabrication, packaging, and testing. These specialized skills and capabilities are derived from multiple national laboratories, academia, and industrial sources. The planned distribution of effort is suitably matched to prior experience in detector fabrication, integration, and testing.

Charge Point #5

Does the project understand its dependencies on outside resources such as participation by researchers with other funding sources and funding from other agencies or international collaborators? (Specific to the Detectors)

Answer: Yes. Linkages between institutional capital investments and potential project risk was conveyed. Several detector fabrication sites identified targeted capital equipment items which could be used to reduce production risk. It was unclear if intra-site co-fabrication has been explored to address these needs. In preparation for CD-1, the distinction between project funded labor and uncosted academic resources could be more clearly and crisply presented.

Charge Point #6

Does the proposed project team have adequate management experience, design skills, and laboratory support to produce a credible technical, cost, and schedule baseline?

Answer: Yes. The extended CMB-S4 detector system team has the technical depth, experience, and support to produce a credible project baseline.

Charge Point #7

Are the EH&S aspects being properly addressed and is the planning sufficient for this stage of the project? (Specific to the Detectors)

Answer: Yes. The EH&S (Environment, Health & Safety) and hazard analysis considerations are appropriate for the current project stage.

Charge Point #8

Are there any other significant issues that require management attention?

Answer: N/A

Findings/Comments

- As discussed in the "Detector Conceptual Design Review Report" (Document Number CMB-S4-doc-757-v2), flow-down of science objectives to specific detector requirements with tolerances represents an important consideration in specifying and managing the risk in the envisioned observational science capability. More broadly, these parameters implicitly set measurement capabilities required for test and validation of the system. Similarly, an understanding of these details will have value in understanding system margin and driving system sensitivities. Progress in these areas was presented and continued diligence in defining these details is advocated as the team moves toward CD-1.

- The detector system test facility development strategy was presented. The reported detector characterization needs (e.g. detector bandpass impact on atmospheric rejection) were largely based upon Stage-3 experience rather than a detailed CMB-S4 science flow down. While this represents a reasonable conceptual starting point the team is encouraged to make the linkage between science and the corresponding calibration accuracy required to support deployment and end use of the system.
- The phasing of staffing and training are seen as likely to present bottlenecks to scaling a subset of the envisioned fabrication and testing activities. The human capital requirements present a significant risk to the project schedule and cost. A detailed plan is warranted.
- The multiple-site strategy described for module testing will likely necessitate continued refinement of test equipment validation, commissioning, and certification plans. The team is encouraged to consider what is (and is not) controlled in each test configuration and the implications for what value an envisioned measurement might provide. A focus on testing which informs the detector yield and performance is advocated. It is important to distinguish between tests which characterize the detectors they will be used versus the implementation in the test apparatus.
- Definition of wafer acceptance ranking criteria can be helpful in refining the testing process and requirements. Development of an incompressible test set for detector and module design validation and a subset of tests for wafer acceptance is required.
- The following recommendation is directly copied from the recent "Detector Conceptual Design Review Report" (Document Number CMB-S4-doc-757-v2)" and remains relevant: "Expand the infrastructure within the WBS that is not tied to a particular fabrication site to focus on quality assurance and requirements development. Consider forming an L2-wide group with the specific charge to supervise development of the requirements and plans for QA across L3 fabricators. Consider naming a group leader with experience in stage 3 detector fabrication,who has ample time to review and support revision of the QA plans following the technical strategy (process development, process monitoring, process control) outlined in the talks by Li and Chang." Standardization of quality control and assurance across fabrication sites will facilitate communication and allow risk identification and mitigation.

Recommendations

6. A subset of detector parameters ranges for acceptable wafers have been presented. In addition to defining these parameters, acceptable ranges of parameters for individual detectors need to be established and a plan for how these criteria will be applied to determine science grade wafer acceptance should be formulated.
7. A specification for the thermal conductivity from the detector wafer to the module assembly should be defined and solutions that have potential to reliably meet this specification should be developed and demonstrated. The reliability of the feed array-to-detector mechanical interface under thermal cycling should also be considered in this setting.

8. In the current plan, each fabrication site will produce quality control documentation in preparation for CD-1. Continued diligence in sharing best practices in process control and test elements is encouraged. Striving for uniformity across fabrication sites in the area of quality control is advocated.
9. We recommend that the fabrication facilities down-select to common materials and processes when possible. This should be strongly considered for facilities experiencing difficulty meeting wafer specifications in the prototyping phase. For example, several designs for the dual transition TES sensor are being pursued. A fab experiencing difficulty with their process should be encouraged to duplicate one that has been successfully implemented.

6. SC3 – Readout, Module Assembly & Testing

Charge Point #1

Is the progress on the development of the conceptual design and acquisition strategy adequate to meet the project's milestone for completion by CD-1?

Answer: Yes, in many cases the project is well beyond conceptual design and has worked out detailed acquisition strategies and identified key vendors.

Charge Point #2

Is the project making adequate progress to show a credible cost range and project duration by CD-1?

Answer: Yes. Our review focused primarily on technical and organizational aspects. We looked at some examples of BOE's and discussed the schedule, particularly as it relates to the critical path. We would say the progress towards understanding the cost range and project duration is adequate for CD-1.

Charge Point #3

Do the project's plans being developed to execute the work make the most efficient use of the financial, human and technical resources available to meet the mission need? Does the project use the human and technical resources available to it at the participating national labs and universities when they are the most efficient choice? Are qualified vendors being sought out where they are the most cost-effective option?

Answer: Yes, with the following concerns: The project members who made presentations, and the team members they identified, appear to be experts in their areas. This was supported by the quality of the presentations, both of a management and of a technical nature. The balance between use of national labs, universities, non-DOE labs, and vendors appears to be efficient and well motivated. There was concern expressed that with the separation of the project into four L2 activities - detectors, readout, modules/test, and then receivers, that there may be insufficient overall technical coordination to link these complex pieces together, seamlessly. While these connections are well represented by interface charts and interface documents, these are of course “static” constructs. The project may strongly benefit from the dynamic influence of system engineering from detectors through completed receivers.

Charge Point #5

Does the project understand its dependencies on outside resources such as participation by researchers with other funding sources and funding from other agencies or international collaborators? (Specific to the Readout, Module Assembly, and Testing)

Answer: Yes. The project does not depend upon international collaborators nor from institutions funded by sources outside the DOE, per-se (other than NSF of course which is partnered). However, the project critically depends upon the fabrication of superconducting electronics from NIST. In this role, NIST is funded by DOE in a work for other role. So to the extent that NIST has its own projects and those of other customers or collaborators, there is a risk for the project. The project appears to understand this risk, but of course remains vulnerable. The interagency agreements and other tools which solidify obligations are in the realm of L1 management, presumably.

Charge Point #6

Does the proposed project team have adequate management experience, design skills, and laboratory support to produce a credible technical, cost, and schedule baseline?

Answer: Yes. The management team, and their presentations were excellent and impressively extensive. So this gives one confidence that they can produce a credible cost and schedule baseline. The technical baseline consists of two parts. Part one is the basic technical design of the readout/module/testing and this is largely in place. The other part is to design a production process by which these components can be fabricated and tested. Parts of this are in place and the numerology, requirements, flow, and so forth largely known. We are confident that this team can scale the production project up to the required level in a timely fashion. However there will be a learning curve and it is important to establish key pre-production milestones so that when production begins it will transition smoothly.

Charge Point #7

Are the EH&S aspects being properly addressed and is the planning sufficient for this stage of the project? (Specific to the Readout, Module Assembly, and Testing)

Answer: Yes. All speakers addressed EH&S concerns in their presentations and we found nothing there lacking for this stage of the project. Considering the importance of cryogenic methods in the testing phase, EH&S will always need to address those well known issues.

Charge Point #8

Are there any other significant issues that require management attention?

Answer: In executive session we mentioned issues which go beyond these specific WBS items

1. Proper understanding of costed/uncosted labor
2. Any ITAR issues with electronics which need to leave the USA?
3. Are risks well rationalized across WBS?

Findings

- This part of the CMB-S4 project consists of the design, prototyping, pre-production, and production of approx 500 modules. The modules consist of detector wafers (SC-2), feedhorns, interface wafers, readout boards at 100 mK, 4K, and RT, assembly into hexagon modular units, and full testing and characterization at cryogenic temperatures.
- The assembled team has decades of experience in the scientific, engineering, and technical aspects needed to accomplish the project.
- The technical solution proposed is largely based upon proven methods and designs.
- The major organizational, technical, and engineering challenge is to scale the fabrication, assembly, and test to a level considerably larger than accomplished in the past.
- There are numerous risks identified due to the large numbers of components which must be fabricated and procured at scale, with predicted yields and at predicted rates.
- Most of the risks have been defined as moderate or low.
- The high risk items relate to the fabrication of superconducting components at increased rates and the reliability of flex circuits. Development of additional sources is a possible mitigation strategy
- The team appears to understand its high risk items and was able to justify the cost and schedule ranges documented in the risk register.
- For the most part the technical solutions and designs, and plans shown, were well beyond the conceptual stage required for CD-1

Comments

- The committee thanks all the presenters for clear and informative presentations. The team is certainly expert in this technology and science, with decades of combined experience. The management structures appear to be in place to understand cost and schedule, and to have comprehensively identified the elements of the project. The teams are well supported by major national and university laboratories with relevant facilities and infrastructure. We found the team responsive to inquiry and willing to engage in frank and substantive discussion.
- As the prototyping and pre production schedule develops, ahead of CD-1, ensure that sufficient time has been budgeted to respond to the findings of downstream technical and gateway reviews. (ie, don't assume all reviews are passed the first time through).
- The presentations were technically focused, while the major challenge is organizing a large-scale manufacturing project. The committee is impressed with, and confident in, the technical approach, but a well-designed production scheme, and a set of pre-production milestones, to assure that all the risks have been mitigated, is critical. Early output from the fabrication and testing lines to validate the "assembly line" design and the industrial scale of assembly and testing should be key goals for the pre-production phase.
- The project relies on some components with limited sources (flex cables, superconducting ASICs, superconducting cables). Continue efforts to develop additional sources. Be cautious when retiring risks early (in the prototyping or pre production phase) as vendor outputs have been known to change abruptly.
- The allowable AC and DC magnetic fields at SQUIDs should be specified. The attenuation measure is good for tests, but since you may not know the actual ambient field until later in the program, it would be good to specify these in absolute units.
- Module testing relies critically on a set of eight "high throughput" DR systems. Each cycle will require, of order, 14 days. In production, cooldown time could become a major issue. While the focus is on cryostat module capacity, it may be possible to reduce the cooldown time through thermal/mechanical design. Cryostat design begins in 2022. While there is a well-defined set of requirements to accommodate the required cryogenic and optical tests, consider also enabling an accelerated pace of testing. Fast turn around systems will reduce the risk of this test element, so this should be addressed in the design requirements.
- Detectors cannot be fully tested until made into modules and placed in the testing cryostats. In future presentations it would be good to explain the time lag expected in production and how the testing results could be fed back to the detector fabrication process.
- While numerous yield factors were presented, for a variety of components, at times it was unclear at which stage of assembly and test these yields were being defined. For example is detector yield determined at post-fab visual inspection or as a result

of a full module test? In future presentations it would be better to be more explicit about this.

- The team showed a nice explanation of science flowdown, from physics measurement goals all the way to electronics requirements. This was backed up with excellent graphics. We encourage the team to complete and continue these analyses and relate them to fundamental component tolerances which are part of the screening process where possible.

Recommendations

10. Vibrational heating of the detector modules and sub-Kelvin structures in the receivers, could be a significant potential source of heating and low-frequency microphonic noise. In particular, given the significant number of detector modules in each of the SAT and LAT receivers, a requirement on the vibration frequency of the focal plane structure could impose requirements on the detector module weight, which could be challenging to meet. Recommendation: We recommend that the project develop clear vibration frequency requirements, for both the Module structure design (within the MAT L2) and the sub-Kelvin focal plane structure in the SAT and LAT receiver designs (within the SAT and LAT L2s, respectively), and flow those down to requirements on the module weight. Sources of vibration should be identified, their disturbance spectra measured, and used to predict vibrational heating of the cryogenic system.

11. There will be many different clocked signals in the system, and there may be crosstalk among them. Consider synchronizing as many of these as possible, and identify a person/team responsible for tracking all such signals and approving any non-synchronous signals. Develop tests to assure that they don't introduce time varying pickup in the science data. (The plenary speaker indicated that there was no overall plan to manage this.) Recommendation: We recommend that there be a process for management and approval of non-synchronous signals.

12. The reviewers are aware that past reviews have made recommendations about flex cable development. We were shown a design with thin metal traces and thick bond pads. Recommendation: Verify that such a structure is robust under cryo thermal cycling and is not susceptible to cracks forming at the thickness transition.

13. The project plans to test 700 modules and deliver approx 500 to the instruments. It is planned to rework modules which show problems during test. Recommendation: When technically possible document and demonstrate the entire rework process and include in future Module presentations.

14. The L1 project chose to divide Detectors, Readout, and Modules, into separate L2 branches. Clearly a well functioning instrument(s) depends upon strong technical coordination between these subsystems and systems. At L1 there is a group of scientists and engineers with oversight responsibilities for all of CMB-S4.

Recommendation: We recommend that these L1 engineering and technical oversight roles be clarified with respect to properly integrating Detectors, Readout, and Modules. If appropriate, we further recommend that a team, or person, be identified who will ensure the proper integration of these subsystems.

7. SC4 – Sites Infrastructure, Integration & Commissioning

Charge Point #1
Is the progress on the development of the conceptual design and acquisition strategy adequate to meet the project's milestone for completion by CD-1?

Answer: Yes, with the caveat that South Pole construction planning had to be done with enough flexibility to cover possible acquisition options. It would be very helpful for the project to get clarification from NSF on the preferred construction strategy.

Charge Point #2
Is the project making adequate progress to show a credible cost range and project duration by CD-1?

Answer: Yes. The cost and schedule for the Chile site is based on recent experience for very similar work. The cost and schedule for the South Pole site is based on assumptions for logistics, population, and fuel support that have not been adequately verified. The project is seeking verification of these assumptions through an RFI process with NSF, and making appropriate contingency plans. The South Pole construction schedule presented is aggressive but not implausible if the project assumptions can be met.

Charge Point #3
Do the project's plans being developed to execute the work make the most efficient use of the financial, human and technical resources available to meet the mission need? Does the project use the human and technical resources available to it at the participating national labs and universities when they are the most efficient choice? Are qualified vendors being sought out where they are the most cost-effective option?

Answer: Yes. The project has gathered a team with a depth of relevant experience on related projects at each site. The project could benefit from the NSF enabling the Antarctic Support Contractor to provide more support.

Charge Point #5

Does the project understand its dependencies on outside resources such as participation by researchers with other funding sources and funding from other agencies or international collaborators? (Specific to the Sites, Infrastructure, Integration, and Commissioning)

Answer: No. The Chile site dependencies are well understood and the project has a sound basis for planning, but while the project does understand its dependencies on South Pole infrastructure, details about what support will be available to the project are not clear. To advance planning the project needs clarification from NSF on supportable levels of air cargo shipment, traverse shipment, summer and winter population, fuel usage, heavy equipment usage, and other details. If the project's assumptions can not be supported this could significantly impact both cost and schedule. The project has identified this risk.

Charge Point #6

Does the proposed project team have adequate management experience, design skills, and laboratory support to produce a credible technical, cost, and schedule baseline?

Answer: Yes, but there is a specific need for additional system engineering support to help define interfaces.

Charge Point #7

Are the EH&S aspects being properly addressed and is the planning sufficient for this stage of the project?

Answer: Yes. There is an appropriate level of planning for EH&S.

Charge Point #8

Are there any other significant issues that require management attention?

Answer: Planning the work at the South Pole requires clarification of what is supportable within the antarctic program through interactions with NSF. This interaction must happen at the highest management level but include specific details for South Pole site planning.

Findings

- Cost numbers used for logistics of $9.00 per pound and fuel of $37.50 per gallon for fuel used in the project cost estimate were obtained from AIL during the MSRI proposal process. It is surprising that the logistics cost for traverse and air delivery to the Pole are the same.

- The project has received little advice from NSF on the level of logistics, population, fuel, heavy equipment and other support can be expected each season at Pole. The plan is based on assumptions the project is trying to verify
- System engineering has not been supported at the desired level because of funding constraints. Increase in system engineering effort would help with interface planning and control.
- The South Pole schedule is a success oriented technically limited schedule. The schedule has not been adjusted or leveled for supportability of logistics or population since there is very little guidance from NSF.
- Buildings are being designed by the project and the plans are being reviewed by NSF and ASC at review meetings. NSF is the Authority Having Jurisdiction for South Pole but the project will approve the drawings. This is different from what was done for IceCube, but the same as what is being done for the BART project.
- Power plant location has not been proposed. The project assumption is that NSF will provide power from a source they specify and construct.
- There are local cranes incorporated into the structures being built in addition to the mobile cranes.
- Project has bi-weekly meetings with ASC.

Comments

- Some recommendations on South Pole construction.
    - Standardize on a small number of fasteners sizes so it is easier to keep stock of components at Pole. Fasteners that are used outside should be ½" diameter or greater.
    - When you include the cost of shipping, Aluminum is cheaper than steel for use at the South Pole. Consider Aluminum for all structural components.
    - Fiberglass grating is an excellent choice for outside decks.
- Both the South Pole and Chile are high and dry sites. Static control is very important for electrical assembly. Personnel and equipment grounding needs to be addressed in the construction planning. Heat dissipation by electronics is also a concern and testing of electronics at high elevation is important.
- The docked position for the LAT at the South Pole could expose receiver to direct solar radiation through the LAT optics without some sun shield.
- IceCube is installing improved surface array scintillation panels and antenna. Layout information should be shared with CMB-S4.
- IceCube-Gen2 includes a large radio array. Wireless data communication could interfere with CBM-S4. The calibration of the radio array will use "radio pingers" that could interfere with CMB-S4.
- Availability of equipment at the South Pole is always an issue. The project could include purchase of additional equipment to improve control of these resources that are essential to completion of the project. This could include more snow machines (3 seems too small a number), a dedicated 953 or telehandler for use in the dark sector supporting construction, material transport sleds, small generator(s) for construction power.

- There was little discussion about installation of the DAQ and analysis electronics required for I & C. The electronics and data transfer infrastructure needs to be in place to do the I & C.
- The historic safety culture at the South Pole has not included written Job Hazard Analysis for work by grantees at the detailed level projected by the current safety plan. The cost and schedule basis for work at the South Pole is based on the pace of work that was accomplished historically. The increased level of work planning may extend schedules and increase cost.
- It would be beneficial to have the Building design firms produce a copy of the building model in the same CAD software the project is using.
- It would be useful for the project to have some historic examples of South Pole building duration from start to finish to compare to the proposed building schedule.
- The IceCube-Gen2 drill power generation capability is about the same as what CMB-S4 needs at the South Pole. Collaborating on power generation could reduce combined project cost.
- Waste heat from the generators could be used to heat buildings in the dark sector for an overall reduction in fuel cost and significant savings. This should be considered during the location of the power plant.
- It would be useful to have a power plant in construction slides with a note that location has not been determined.
- It would be useful to have an introductory slide showing the relation between the organizations for the Chile site.
- It would be useful to add when power needs to be available to the South Pole schedule summary slides.

Recommendations

15. Chile Site: Complete the design bidding with Chilean companies to avoid misunderstandings/problems with future Chilean Contractors. Design from abroad sometimes is different to what local contractors expect (in methods and available materials) and that drives claims further on during construction.
16. Chile Site: As discussed before in the May 2021 review, the available space in the High Site Building may be insufficient for the commissioning stage. This needs review to design the proper size or decide if rented space could be used during construction.
17. South Pole Site: The CBM-S4 management team should work with the NSF to define a process to develop supportable planning assumptions for the project. This information is needed to make the cost and schedule realistic.
18. South Pole Site: The CMB-S4 management team should work with NSF to define how the required electrical power should be supplied for the project. Is the project responsible for the design and construction of the power plant or will NSF supply power through South Pole infrastructure upgrades.
19. South Pole Site: CMB-S4 and IceCube-Gen2 could both benefit from collaboration. A mechanism should be developed to foster this collaboration.

20. CMB-S4 faces difficult logistics for fuel delivery to both sites combined with significant power needs. Photovoltaic electricity production should be seriously considered at both sites to reduce fuel usage.
21. The project should explore including money in the MREFC budget to increase the infrastructure for fuel delivery to Pole. This could include fuel sleds and tractors for the traverse.

8. SC5 – Data Acquisition & Data Management

Charge Point #1

Is the progress on the development of the conceptual design and acquisition strategy adequate to meet the project's milestone for completion by CD-1?

Answer: Yes.

Charge Point #2

Is the project making adequate progress to show a credible cost range and project duration by CD-1?

Answer: Qualified yes. See Recommendation 1 regarding Data Management milestones, which affects justification of project duration and necessary levels of effort.

Charge Point #3

Do the project's plans being developed to execute the work make the most efficient use of the financial, human and technical resources available to meet the mission need? Does the project use the human and technical resources available to it at the participating national labs and universities when they are the most efficient choice? Are qualified vendors being sought out where they are the most cost-effective option?

Answer: Yes, although clearly funding has not been available.

Charge Point #5

Does the project understand its dependencies on outside resources such as participation by researchers with other funding sources and funding from other agencies or international collaborators? (Specific to the Data Acquisition and Data Management)

Answer: Qualified yes. See Recommendation 4 regarding agreements with external partners.

Charge Point #6
Does the proposed project team have adequate management experience, design skills, and laboratory support to produce a credible technical, cost, and schedule baseline?

Answer: Yes.

Charge Point #7
Are the EH&S aspects being properly addressed and is the planning sufficient for this stage of the project? (Specific to the Data Acquisition and Data Management)

Answer: Yes. Safety risks to personnel are being considered.

Charge Point #8
Are there any other significant issues that require management attention?

Answer: Yes, see Recommendation 1. Additionally, previous review recommendations should be implemented.

Findings

- DAQ and DM are in good shape for this stage in the project and considering the lack of funding!
- We have tried not to repeat items already raised in the DAQ and DM CDR reports (CMBS4-doc-751 and CMBS4-doc-742), many of which remain open.

Comments

- The data are the most important product of the experiment. See Recommendation 2 regarding data products, organization (e.g. scope and namespace, disk, tape), and distribution.
- Develop an example showing for DAQ how a typical observation proceeds including the interfaces with Data Management and Readout. The control system clearly works for an instrument in a lab, but at the observatory level, the story was not quite clear (see Recommendation 24).

- Clarify the situation regarding wide area network connectivity to both facilities. Even though the total bandwidth requirement is modest (< 10 Gbps), we suggest developing specifics for both facilities, including potentially implementing at 40 Gbps at the Chilean site, and clarifying the division of responsibilities between the relevant entities (the Project, the Chilean fiber provider, the DWDM equipment owner/operator, ALMA, bandwidth-sharing and QoS with SO).
- Develop a plan for how DAQ timing system needs are communicated to labs for test setups. For both timing and computing needs, consider developing a "reference system" that satisfies the minimum requirements to simplify lab setup from scratch.
- The ICDs are in active development. Continue to add details and solidify open issues (TBDs) in preparation for CD-1. Do not allow ICDs to cause silos within the project — teams need to work together on both sides of the ICDs and modify as needed.
- Docker was mentioned several times, and that is a good start for portability. Consider the next step as you deploy to labs — container orchestration like Kubernetes (at least on the sites) and continuous deployment like ArgoCD or FluxCD will probably be necessary.
- Ensure all high-level risks have mitigation strategies in the risk registry.
- The division between Site IT and DM + DAQ software installation at the sites could be made more crisp. Ensure that staffing on site has sufficient subject-matter expertise.
- Cyber security was said to follow the L1 guidelines, but these guidelines may not be sufficient for DM/DAQ. DAQ Control specifically will need very tight control, e.g. 2FA. You may wish to tighten up this aspect for control.
- DM was not well integrated in the project plan. DM's Gantt chart ties only to review milestones in the project (see Recommendation 1). We were concerned that the project manager's steps to CD-1 (slide 22) did not include DM. To address this, we suggest further developing Design / Development and Data Challenge milestones tied to the rest of the project, both to Point Design Freezes as well as subsequent validation of that design. Another example is the addition of a milestone for the implementation / testing of the Data Management / DAQ interface.

Recommendations

22. Data Management milestones should be more fully tied to other project milestones and linked to the rest of the project schedule. Presentation of these milestones should link them to internal project goals rather than to the review schedule.

23. Develop a comprehensive data distribution and organizational model showing the data products scientists will receive, how they are organized, and how they will be accessed.

24. Solidify the DAQ interface with regard to observing control and observing priorities. Present a credible observatory control scenario.

25. Clarify the status of MoUs / agreements with key external partners, especially NERSC, REUNA, and U.S. R&E networks (e.g. ESnet).

9. SC6 – Science Requirements, Flow-down & Systems Engineering

Charge Point #1

Is the progress on the development of the conceptual design and acquisition strategy adequate to meet the project's milestone for completion by CD-1?

Answer: No, to keep the current review schedule we recommend additional resources to support the work needed to meet review requirements, otherwise the review schedule should be adjusted accordingly.

The technical point design appears to be on track for CD-1, but the science requirements and flowdown needs significant work. In particular, the creation of adequate survey performance margins for r and N_eff is urgent and could have an impact on design decisions.

Concepts for the survey observations that could affect the conceptual design (and cost) were not presented, therefore it was difficult for SC6 to evaluate if the strategy leading to CD-1 was completely on track.

Charge Point #2

Is the project making adequate progress to show a credible cost range and project duration by CD-1?

Answer: No, to keep the current review schedule we recommend additional resources to support the work needed to meet review requirements, otherwise the review schedule should be adjusted accordingly.

There is substantial work to be done prior to the OPA and CD-1 reviews to present the trade space analysis of alternatives to support cost, budget and scope ranges against the scientific objectives and requirements.

Charge Point #3

Do the project's plans being developed to execute the work make the most efficient use of the financial, human and technical resources available to meet the mission need? Does the project use the human and technical resources available to it at the participating national labs and universities when they are the most efficient choice? Are qualified vendors being sought out where they are the most cost-effective option?

Answer: SC6 did not evaluate this.

Charge Point #5

Does the project understand its dependencies on outside resources such as participation by researchers with other funding sources and funding from other agencies or international collaborators? (Specific to the Science Requirements, Flowdown, and Systems Engineering)

Answer: Yes.

Charge Point #6

Does the proposed project team have adequate management experience, design skills, and laboratory support to produce a credible technical, cost, and schedule baseline?

Answer: Yes, emphatically. CMB-S4 has assembled the A-team.

Charge Point #7

Are the EH&S aspects being properly addressed and is the planning sufficient for this stage of the project?

Answer: Yes.

EH&S as presented was focused primarily on issues related to personnel. For a complete picture, EH&S should include an element on the protection of technical systems.

Charge Point #8

Are there any other significant issues that require management attention?

Answer: No.
Please see recommendation SC6-7 regarding documentation organization for the committee.

Findings

- The Project presented the use of a commercial tool for requirements management - JAMA Connect. Explicit flowdown relationships are not yet fully made in the requirements management tool JAMA Connect.
- Commissioning planning was presented for both the Chile and South Pole sites.
- A point design has been presented that meets basic requirements, but it was not clear where the system performance margins lie, where these are managed and what trade space was explored. The Project has a good qualitative sense for where performance margin exists. Some charts and graphs were presented. A nice tool to interactively evaluate the limits for "r" was shown.
- There was not an explicit presentation(s) describing observing or operations strategy.
- The project provided a wealth of background documentation, but it did not inform the committee about the relative importance of the documentation or connect the documentation to the different topic areas of the review. The project did not address how it has responded to previous reviews in open session.

- The installation at the South Pole site as budgeted is about $87M more expensive than those (WBS 1.11) at the Chile site. However, it was not shown if the science optimizations of the instrument to date took these cost differentials into account.
- Some requirements presented were compound - meaning there are multiple specifications within one requirement statement. Example: Measurement requirements for the different frequency bands and their respective noise specifications.
- Simulated coverage and sensitivity maps were presented, however the observing strategy/program required to achieve these maps and their relation to the science requirements were not.
- Systems Engineering at the Project level between now and CD-1 was presented as essentially a single FTE with partial support from L-2 elements.
- There was some confusion about differences between the Science Goals and Science Requirements presented and those contained in the stated mission need stemming from CD-0. This appears to stem in part from the fact that, while CD-0 was achieved in July of 2019, the mission need statement was only released to the project in October of 2021, just prior to this review.
- Each team presented a common understanding of interfaces using a N-squared diagram.

Comments

- It would be helpful for the OPA reviewers to organize the documentation into primary and secondary documentation and to connect documents to charge questions. To maximize the utility of reviews, it's important to identify key/foundational documents and connect them to review charge questions. It is also important to describe for review committees how the project is or has responded to previous review recommendations.

- Performance margins and allocations starting with the top-level science and technical requirements were not presented. The team should be prepared to provide a plan that can achieve the mission with margin against the objective KPPs. It's typical to present a plan where the threshold KPPs are margin free (or negative) while the objective KPPs (the experiment you want to build and have costed) have the allocatable performance margins. It is critical for decision making at this stage of the CMB-S4 project to have clearly articulated margins and an explicit plan for how scientific and technical margins are managed - system level versus allocated subsystem level. These margins will be essential to support design alternatives needed to support CD-1.
- It would be beneficial to the Project to define success criteria both in terms of Key Performance Parameters, threshold KPPs as used by the DOE for minimum success and objective KPP for a higher level success criteria to meet the science expected from the community.
- The AAAC/CDT report had two top-level requirements (r, and Neff) with the other mission science enabled by those top-level requirements without additional hardware. This would appear to be a good strategy. The DOE mission needs statement which derives heritage from that report has a somewhat different list. The project might consider picking r and Neff as the top-level requirements too. Then they could show the other mission requirements at a lower level in the hierarchy where they don't necessarily drive hardware requirements, just the data products. This might open up the possibility of allowing future project de-scopes for such items as the Chilean LAT 225 & 278 GHz bands.
- A typical science requirement document states verifiable parameters in a highly tiered fashion. Between the e.g. science requirement 1.0 and the measurement requirement 1.1 would be a many level hierarchical flow-down. The purpose for putting the time and effort into a longer statement of the science requirements is to allow others to drive the systems engineering process, the development of the alternatives analysis, and make plain the strategy behind the threshold and objective KPPs. A strong science requirements document is part of setting up the future organization and allowing it to function.
- At CD-1 it would be helpful for reviewers and for the project to have requirements traceability established from science requirements to measurement requirements and be able to show examples. As part of the requirements/specification management effort, developing explicit performance budgets derived from science and measurement requirements that include margins that are well defined and specifying to where they are allocated - system level versus subsystem level (e.g. to Level-2 or Level-3) would also be beneficial.
- Best systems engineering practice would be to create a structured set of requirements documents from the JAMA management tool flowing from the science goals/requirements. As another example of best practice, the project could consider breaking up compound requirements into independently verifiable requirements.

- Interface Control Documents have been identified. As part of the Systems Engineering Management Planning the Project should develop a means for proactive monitoring and management of the development, status, implementation and verification of the ICDs across the distributed team and WBS elements.
- It would be beneficial for the project to develop a set of system performance metrics that can be rolled up into an overall science metric to monitor high level performance margin and impacts for lower level performance trades and final as built performance.
- The maximum survey duration observing along with attendant specifications is normally best included as a low-level functional requirement.
- This committee did not have sufficient CMB experts (or time) to be able to provide the needed validation that the stated science reach would hold up in future review or the test of time. Looking back a year at the prior Director's and agency reviews would suggest that a focused, science-only, review charged with examining the science requirements flowdown and supporting science studies should be undertaken (down to the level of the top-level measurement requirements). This is a best practice for this stage and should carefully examine the performance margins assuming a top-level objective, e.g., $r < 0.003$ and Neff < 0.06. Holding such a review prior to CD-1 would strengthen the case going into CD-1.
- Early establishment of flow-down relationships between science goals (objectives) through to lower levels will prove valuable and crucial to decision making as the Project progresses and matures.
- An initial allocation of performance budgets would aid in evaluating subsystem risks and costs.
- A matrix showing requirements traceability and verification method should be developed.
- A final integration and commissioning plan is needed to bring together the hardware and software processing systems. This should include a demonstration validation data set taken with the deployed hardware and processed with the initial software algorithms.
- It is important to include observation and operations concepts into the design decision at the early stages of the Project. How the CMB-S4 is operated should be included in the trade space for alternative analysis between construction costs and operations costs.
- The operations costs stated in the PPEP are a WAG and estimate operations costs at 10% of the construction costs per year. This may be significantly too low, but establish a not-to-exceed expectation at the agencies.
- It is best systems engineering practice to have singular requirements with a "shall" statement for individual specifications. While the derivation of requirements is often coupled, their subsequent verifications are mostly independent.
- It is likely that some technical aspects of the point design will depend on what observing strategy is adopted. The observing strategy may also drive the need for specific scheduling software for observations.
- Developing summary quantitative performance metrics from L-1 down to L-2 or L-3 will be an important tool for the Systems Engineering to monitor the technical

development of the Project. Maintaining these metrics will require significant effort and should be folded into the scope estimation for systems engineering.

- Many of the components in the CMB-S4 experiment are replicants of a unit design. Increasing the count of replicated elements may prove to be a more cost effective means for developing scientific and system margin than improving the specific technical performance of said components. The team should explore the cost-benefit of replicating more system units - e.g. SATs as a means for developing science and system margin.
- Preparations for CD-1 in Systems engineering should not be underestimated. Systems engineering should be viewed as an investment in reducing technical risk later on in the Project life cycle. Given the high recommendation from the 2020 decadal review we believe investment in Systems Engineering is low risk with high return.
- It would benefit the project to enhance the Project FTE level systems engineering effort to bring together the necessary requirements and trade tools needed to meet CD-1.

Recommendations

26. A science requirements document that can support the Alternative Analysis and KPP strategies should be developed. As part of that process the top-level scientific and technical margins and verification strategies should be stated. For each level in the requirements the project should define the owner of the requirement (agency or project levels). The science requirements document and the supporting science studies (r and Neff) should be reviewed down to the primary measurement requirements by an outside panel of CMB science experts. Any evolution of top-level science requirements with respect to the AAAC/CDT report and DOE Mission Need statement should be clearly presented.
27. Perform and document an alternative analysis. To support the cost, budget and scope range requirements of CD-1 include in presentations and documents the trade space that was analyzed to support alternative designs considered. Include appropriate lifecycle costs in these studies.
28. For CD-1, present threshold KPPs that define the technical & programmatic success of the Project and how these drive the point design. Also present objective KPP’s that meet the science expectations from the community.
29. For CD-1, include a verification, validation and commissioning plan for the complete CMB-S4 system, hardware systems at both sites and software included, that delivers the science products - e.g. CMB intensity and polarization maps.
30. For CD-1, provide a basic concept of operations document which includes observing planning and key operations use cases that may impact technical design decisions and cost. Present an observation strategy consistent with the point design that supports meeting the science requirements and objectives. Include whether there is a need for observation scheduling software and optimization between sites.

31. For CD-1, derive a basic upper bound for operations costs with some technical and comparative basis. Provide some initial model for how the operations might be shared between DOE and NSF. This is important to establish the lifecycle costs.
32. For future reviews, the project should identify key background documents and connect them to specific charge questions where possible. They should also formulate formal review recommendation response documents, with response plans, implementation dates, and responsible personnel, keep them updated, and periodically review these with the agencies and describe them in future review plenary presentations.

10. SC7 – Management, Quality Assurance, Environment, Health & Safety

Charge Point #1
Is the progress on the development of the conceptual design and acquisition strategy adequate to meet the project's milestone for completion by CD-1?

Answer: Yes.

Charge Point #2
Is the project making adequate progress to show a credible cost range and project duration by CD-1?

Answer: Yes, but lack of clarity as to NSF's full commitment, and the marginal schedule float pose complications.

Charge Point #3
Do the project's plans being developed to execute the work make the most efficient use of the financial, human and technical resources available to meet the mission need? Does the project use the human and technical resources available to it at the participating national labs and universities when they are the most efficient choice? Are qualified vendors being sought out where they are the most cost-effective option?

Answer: Partially. The large number of interim positions is a long-term concern, but the project has assigned excellent interim staff and institutional responsibilities and leadership are very good. Additional documentation for the qualified sourcing is essential.

Charge Point #4
Is the Transition to Operations strategy being developed appropriately, considering the experimental equipment will be installed and operated at remote sites?

Answer: The Transition to Operations development is adequate for a project at this stage of a project (pre CD-1). However, a good strategy will be needed by CD-1.

Charge Point #5
Does the project understand its dependencies on outside resources such as participation by researchers with other funding sources and funding from other agencies or international collaborators?

Answer: Yes. The Project has taken a conservative approach by assuming no in-kind contributions are in the base estimate.

Charge Point #6
Does the proposed project team have adequate management experience, design skills, and laboratory support to produce a credible technical, cost, and schedule baseline?

Answer: Yes, but key interim positions prior to CD-1 must be filled and the balance of unfilled positions must be filled prior to CD-2.

Charge Point #7
Are the EH&S aspects being properly addressed and is the planning sufficient for this stage of the project?

Answer: Yes, and the Project should be able to be ready for CD-1, but draft documentation ought to be ready for the DOE Status Review. Additional resources are needed immediately to complete the PHAR – a key design and functional document.

Charge Point #8
Are there any other significant issues that require management attention?

Answer: The integrated project governance will benefit from clarification (see comments & recommendations).

Findings

- A Preliminary Quality Assurance Plan (QAP) , Preliminary Hazards Analysis Report (PHAR) and Project Integrated Safety Management (ISM) Plan have been drafted.
- The Chile and South Pole sites have drafted Site Specific EH&S Plans.
- EH&S and Quality topics are integrated into the Project presentations.
- Currently no opportunities are assumed as being realized within the present project plan. This includes possible in-kind contributions.
    - The realization of opportunities must generally occur prior to the PDR for NSF and CD-2 for DOE.
- One of the major opportunities would be the better use of industrial fabrication and greater yield in the detector production.
- The risk registry does not include a pre-mitigation assessment.
- The PHAR, the NEPA Strategy, General Safeguards and Security requirements and preliminary security vulnerability assessment are planned to be completed prior to the DOE Status Review.

Comments

- In the majority of aspects, the Project is very mature in its development for a project that is pre CD-1.
- The team that has been assembled, even in the interim positions, is very strong and looks to be working well.
- The unification of several groups (including previous competitors) into a cohesive unit is very impressive.
- The project has developed an impressive set of management documents, tools, processes, and plans which will prove useful to bring the project to a successful CD-1.
- The Cloud-based QA platform will be a strong benefit to the distributed project.
- The incorporation of the QA and Manufacturing Engineering in the project is a strength. The charts that presented the relative relationships and handoffs in particular are particularly notable.
- DOE Laboratories and Universities that are supplying hardware should be given and required to follow the same level of QA/QC rigor and oversight as commercial vendors.
- Comments about the QA Plan:
    - Section 9.4 regarding suspect counterfeit items, should acknowledge the emerging risk of counterfeit items due to the supply chain shortage;
    - "Design for Safety," which is described in the ISM Plan, should be referenced in the Design section 10.3;
    - Safety requirements should be referenced in Section 11.1 on supplier selection, evaluation, and management;
    - Work Planning section should reference the Project ISM Plan (see pg 27 of the QAP).

- The committee is very concerned that the Project EH&S lead will become overloaded without additional help very soon.
- The LBNL Off-Site Safety Plan should be included in the list of references of the PHAR as well as the Chile Safety, Health & Environment Plan and the South Pole Safety Plan.
- The topics covered in the Chile Safety, Health & Environment Plan and the South Pole Safety Plan should be consistent with each other.
- The Risk Review Board meetings should include EH&S representation as needed.
- Because of the nature of the equipment hazards, Systems Engineering should work closely with EH&S.

For Status Review

- Consider improving the WBS description with assumptions and deliverables (including fixtures, software, data and hardware) as it will help understand any change to scope and cost growth. Presently, not all WBS elements have the same level of detail. This also applies to the risk registry.
- The top down cost contingency of 40% appears commensurate with the estimate uncertainty, risk exposure and schedule exposure driven by standing army costs. However, the resulting cost range and schedule float appear marginal. The additional motivation for the top-down 40% contingency (uncertainty, standing army, and risk registry) should be discussed earlier in the plenary talks.
- As a result of the natural constraints and limitations of access to the South Pole site, the slightest perturbation can almost immediately result in the addition of a year to the completion of activities. Until there is additional clarity and understanding surrounding the limitations and constraints of activities at the South Pole, it is prudent to add an additional year of float to the project schedule.
- The Project may wish to consider leveraging the DOE portions of the project to assist in promoting additional clarity surrounding activities with the NSF Office of Polar Programs (OPP) as it has no pending proposals with the NSF.
- The project does not have a Project Management Plan (PMP). Only a draft PEP for the DOE and NSF portions of the Project. A detailed PMP would be useful to expand the project management plan beyond the usual PEP and provide the integration into a unified project office (R2A2s for all positions, laying out the management plan structures, and additional detail, etc.). Similarly, as the PEPs require agency approval and signoff – not only initially, but for any modifications – any items that are likely to have changes throughout the project should be considered for inclusion in the PMP rather than the PEPs.
- Clarify the long-term relationship of the engagement of the collaboration possibly through the spokesperson in the management plan.
- There is a structural deficiency in the governance and integrated project team. The NSF PI does not appear to have a clear role in the integrated project team. Since the PI has ultimate authority for cost for the NSF side, the structure should incorporate the PI role in the org chart with roles and authority and a description of how the project manages changes that impacts both sources of funding.

- LBNL had suspended the search for a permanent project director, but has recently restarted. Such a search takes considerable time and it is a necessary position to facilitate the filling of other key positions.
- Complete the value engineering plan to set the stage and show how the value engineering process and analysis of alternatives will be conducted between the status review and the CD-1 review.
- The strategy and plan for the Analysis of Alternatives (AoA) needs to be clearly defined and presented at the status review.
- Similarly, the strategy and development plan for the Key Performance Parameters (KPPs) needs to be clearly presented at the status review.
- Optimize the schedule and date for the CD-1 IPR with necessary NSF pre-MREFC milestones.
- To allow the review committee to better assess the project's progress, provide greater detail with intermediate milestones needed for the successful preparation of the NSF PDR and DOE CD-1.
- Develop a more focussed strategy for the status review. Overall, DOE/SC-OPA will clearly want an assessment of readiness and progress towards the CD-1 review. All plenary talks should hone in on this point to make the reviewers' jobs easier.
- Along the same lines, be more direct and proportionate in addressing the charge points. This was done only in the project director's plenary presentation. Many talks essentially only addressed charge points 1 and 2, and then not directly. Consequently, it could be argued that the Project was unresponsive to the last sentence of charge point 3, and insufficiently responsive to charge point 5.
- Taking into account effects of Zoom fatigue and a likely more geographically distributed IPR committee, consider reducing the number slides in the plenary talks and perhaps even the number of talks overall. A talk in plenary should focus on charge questions.
- Sufficient discussion time during a review is an absolute necessity. Ensure this through reducing the size and amount of details in the plenary talks. Some talks might be combined.
- Recent experience suggests that DOE IPRs will demand great clarity on definition of scope, alignment of proposed DOE scope with DOE mission needs, and external dependencies on delivering scope (NSF in this case). The Project may be assuming that the need and motivation for the Chilean LATs are obvious to DOE and its review committees; this will not be the case. Provide a succinct strong DOE-centric scientific motivation.
- Prior to DOE CD-3 and NSF MREFC awardIt is unlikely that it is unlikely that project reviews will successfully be conducted as joint reviews. That being the case, careful tailoring of the emphasis and messaging for each review audience will be a necessary consideration.
- The Project should describe its position on international partnerships with greater transparency and clarity.
- Improve situational awareness:
    - The present Administration highly prioritizes Diversity Equity and Inclusion (DEI). An unfilled DEI manager of an advisory organization outside the line

    management structure does not help the cause. The Project should also establish and explain an inclusive process through which Collaboration members can be appointed to high visibility Project leadership positions.
    - The present Administration also highly prioritizes climate science. The power generation schemes for Chile and the South Pole suggest alarmingly high carbon footprints. Take alternatives analyses seriously.
    - Supply chain issues are very much on the mind of the Office of Science. A workshop convened by SC-2 just ended. The initial Project responses to questions on supply chain dependencies were unsatisfactory.
    - Export control issues are continually evolving and complicated and can consume significant time and resources for resolution.
    - COVID-19 has not gone away, nor is it likely to go away anytime soon.
    - DOE HEP is hiring an additional Cosmic Frontier program manager (per HEPAP meeting). Establish this person's role with respect to CMB-S4.
    - The Office of Science and OPA have become receptive to sub-projects for billion-dollar class projects. Sub-projects could appeal to DOE-HEP, so be ready with counter-arguments as needed. For example, SPLAT, CHLAT, SP SAT, SP infrastructure, and Chile infrastructure divides fairly independent pieces of scope in a way that could allow more flexibility in managing NSF dependencies and bringing detector production sites online.
    - The last sentence of charge point 3 clearly signals DOE HEP discomfort with using national labs as manufacturing sites. The Project should take this concern seriously and improve its justification.
- The current/pre-mitigated assessment should be added to the risk management process as well as a performance impact.

<u>In preparation for CD-1</u>

- The Project needs to ensure adequate PMCS resources to support to ensure proper preparation is made available for CD-1 Review
- Review the need to add detector vendors to the MoA/NDA with the detector working group. It is likely that the vendor information will be protected and cannot be distributed to other labs without their permission. The procurement leads at institutions awarding to vendors should be involved to ensure agreements are within the terms and conditions of the contracts for intellectual property.
- Focus on analysis of alternatives. In particular high-level value engineering (trade studies) should be properly documented.
- Finalize the Analysis of Alternatives (AoA) for the CD-1 review.
- Similarly, present the preliminary Key Performance Parameters (KPPs) with the motivation clearly enunciated at the CD-1 review.
- Identify a project director prior to CD-1.
- Clearly communicate that control accounts (CA) do not have mixed DOE and NSF funding and review whether CAMs should be added to manage DOE-only Control Accounts below level 2 as necessary. This may require shifting some of the CAM LOE to be represented for these new CAMs.

- Consider separating out the risks of the LAT from the SAT for DOE delays to the NSF. There may be similar split needed on the reverse (NSF delays impacting DOE standing army cost)

The team has been very successful to date in advancing the project despite the limited resources and funding.

Recommendations

Prior to the Status Review:

33. Incorporate the NSF PI in the project governance documentation commensurate with their responsibility to the NSF.
34. Immediately resume the search for a permanent project director.
35. Prepare and present a detailed staffing plan
36. Develop and present a plan and approach for completing the Analysis of Alternatives (AoA) for the Status Review
37. Increase the schedule float by 1 year until South Pole installation, logistics, integration, and commissioning are clarified.
38. Engage with NSF OPP to develop a plan for South Pole logistics.

Prior to the CD-1 Review and NSF PDR:

39. Complete an adequate AoA following the GAO and DOE guidance.
40. Develop a charter for and appoint a Project Management Advisory panel.
41. Prepare and clarify the KPP strategy discussion and development and plan on presenting it in the plenary session.
42. Include an assessment of supply chain issues (such as delays, export control, and suspect counterfeit parts) at the CD-1 Review
43. Prepare and present progress on the detailed staffing plan.

11. SC8 – Cost & Schedule

Charge Point #2

Is the project making adequate progress to show a credible cost range and project duration by CD-1?

Answer:

Yes, with some additional analysis, see comments.

Charge Point #3

Do the project's plans being developed to execute the work make the most efficient use of the financial, human and technical resources available to meet the mission need? Does the project use the human and technical resources available to it at the participating national labs and universities when they are the most efficient choice? Are qualified vendors being sought out where they are the most cost-effective option?

Answer:
Yes, with concerns. See detailed answers from review Subcommittees 1 through 6.

Charge Point #6
Does the proposed project team have adequate management experience, design skills, and laboratory support to produce a credible technical, cost, and schedule baseline?

Answer: Yes.

Charge Point #8
Are there any other significant issues that require management attention?

Answer: See Recommendations.

Findings

- The project presented a cost range based on DOE guidance and an initial assessment of "Class of the Estimate".
- The Project does not have a Project Assumptions Document that provides guidelines and assumptions for cost and schedule estimating and other planning.
- The posted BOEs for documentation at WBS Level 2 and other varying levels of the WBS. Drilldown exercises for WBS 1.04 Readout and 1.11 South Pole revealed detailed BOE documentation down to Level 3 and lower in these WBS elements.
- The Project uses a standard escalation rate of 2.1% for non-labor costs and 3.5% for labor escalation. There is no rationale for the choice presented in either the Cost Estimating Plan or in an Assumptions Document.
- The project presented a funding profile based on spending rather than obligations. The project has not prepared an obligation profile.
- The PM stated that the CAMs are at WBS Level 2, with Cost/Control Accounts identified in the RAM at lower WBS levels.
- The Project stated they are planning on a CD-3A for Long lead procurements and presented the cost and contingency for Long lead procurements.
- The project Staffing Plan, including hiring plans were not yet prepared.
- The project resource loaded schedule has 7K + activities, is technically limited and includes a critical path. Acumen Fuse analysis of schedule integrity was at a score of 84.
- Cost and schedule contingency assessment is currently developed as a top down assessment based on standard assessments from previous projects - cost contingency was assessed at 40% and schedule contingency at 24 months.

- The project has developed a risk management plan and a risk registry that analyzes and ranks cost and schedule threats and opportunities. The risk register does not include technical and performance risk. The register includes mitigation handling strategies. The risk analysis includes only post mitigated risks not pre-mitigated risk.

Comments

- The schedule is very detailed for this stage of the project with resources identified by partner/Universities using their rates when provided. The project schedule has handoff milestones and some activity durations and aspects of the technically limited schedule appear to be optimistic. Concerns include funding delays in 2022, standard procurement durations that appear to be optimistic given institutional capabilities, current supply chain delays and site logistics. Standard shipping durations also seem optimistic in light of recent experience. Procurement strings have not been added to all areas of the schedule. All project reviews should be included in the schedule.
- Robust project control tools (P6, Cobra, Dash360) are in place and being utilized effectively to plan the project. The detector workflow production chart was an excellent communication tool for the team.
- The cost range presented was based on DOE guidance, the range the project developed is -10% and +35% of the point estimate based on the assumed class of the estimate between Class 3 and 4. There is concern the upper end of the range could be low. A more in depth analysis of the potential drivers and maturity of the estimates is needed to support a more realistic cost range, possibly closer to +40 to +45%.
- The Project does not have a draft assumptions document that outlines the costing and scheduling methodologies and assumptions. A few assumptions are documented in the PPEP and in the Cost Estimating Plan. Without a complete assumptions document, reviewers cannot ascertain whether assumptions are being followed, nor can they be used by project staff for planning guidance.
- The Project BOEs were posted, in some cases, at varying levels of the WBS including Level 2. The BOEs presented at the drilldown sessions (WBS 1.04-Readout, WBS-1.11 South Pole) were detailed for labor and material/non-labor. The estimate backup resides in Dash360 but was difficult for the reviewer to review and trace. The BOEs included backup detail calculations/rationale on how unit costs, labor hours, travel estimates, etc. were determined. Traceability and a summary of the backup detail would be helpful.
- Some of the cost estimates and activity durations appear optimistic for some labor estimates. As an example, there was concern regarding the shipping durations which were typically 5 days in duration and did not include cost estimates.
- The project escalation rate of 2.1% used for non-labor costs appears low given the current price increases in commodities, electronics, and supply chain issues in terms of schedule. There is no rationale for the choice presented in either the Cost Estimating Plan or in an Assumptions Document.

- The project needs to assess the BA/BO profile to include the spend plan (cost plan), and the obligation profile, and a nominal funding profile. This profile includes contingency usage.
- The CAMs for the Project should be at least one level below Level 2 of the WBS. Consider assigning the title of Deputy Level 2 Managers who have CAM oversight and assign the title of CAM at the control account (Level 3 or below).
- The project RAM should include the organizational breakdown in addition to the CAM names.e.g. NSF/DOE by identifying Lab/Univ./Dept/Div/Group/Name, etc.
- The project should develop/justify a contingency usage plan to show a preliminary timephased planned usage of cost contingency. This supports the BA/BO profiles that are expected for CD-1.
- The project's plans for CD-3A need to be assessed to ensure design maturity will be at a final stage. Ensure the project Long lead procurements meet the DOE criteria for LLP justification. Obtain a copy of the OPA LLP CD-3A Justification template and prepare a draft for review by DOE.
- Project Controls staff appear sufficient once the planned staff is brought onto the project.
- Staffing plans will need to be generated based on project P6 requirements and staff availability (labor pool) to support development of the project hiring plan.
- The risk register needs to be matured and updated to include pre and post mitigation risk assessment. The cost and schedule impacts should be documented with a basis of estimate to assess cost/benefit of the risk. Risk analysis needs to be applied consistently across the project, training and guidelines should be considered to facilitate this. Include technical and performance risks in the Risk Register. Consider adding or modifying risks identified as concerns by reviewers such as a risk for equipment storage at sites due to transport and shipping delays. Develop mitigation strategies to be considered in the estimate and the risk registry.
- Cost and schedule contingency assessment is currently developed as a top down assessment at 40% and schedule contingency at 24 months. Contingency needs to be fully assessed to include an in depth analysis of cost estimate/schedule uncertainty and risk event impacts/drivers. It is the opinion of the Review team that the schedule contingency should be closer to 3 years in duration.
- The project should continue assessing risk using the Monte Carlo simulations.
- The project provided a plan for handling uncosted management labor on the project. Some project team members did not have an understanding of the concept of uncosted vs. costed labor.

Recommendations

Prior to the OPA Status Review:

44. The Project should finalize the cost range, re-assessing the estimate uncertainty, cost/schedule impacts and opportunities for establishing the upper and lower cost range.
45. The Risk register needs to be expanded to include the initial risk analysis (pre-mitigation) as well as the transition to post mitigation risk, technical and

performance risks. The project should continue updating the Risk Register to incorporate areas of concern that need additional analysis. The risk event cost/schedule impacts should be calculated with a documented basis of estimate.

46. The project should reassess the risk schedule impact definitions and to include tiered milestones impacts or other schedule milestone impacts.
47. The project should prepare an analysis and justification of their proposed escalation rates.

Prior to the IPR CD-1/NSF PDR:

48. The project should develop a Project Assumptions document for Programmatic, Scope, Cost, Schedule and Risk assumptions.
49. The project team should bring the detail, backup documentation and traceability from BOE to P6 up to GAO standards in preparation for an ICE review.
50. Prepare and present an assessment of the project's implementation of the GAO standards for cost/schedule.
51. Prepare a funding, obligation and cost plan including contingency usage plan for the project.
52. The Project should finalize the cost contingency and schedule analysis, including correlations between activities.
53. The project should assess uncosted labor in the non-management WBS elements.

Appendix A - Review Charge

INTEROFFICE MEMORANDUM

To: **Emil Nassar**
LBNL PMO Deputy, Science Projects

From: **Natalie Roe**
LBNL Associate Laboratory Director for Physical Sciences Area

CC: **J. Corlett, M. Leitner, M. Witherell, M. Brandt, C. Burns**

Date: **October 22, 2021**

Re: **Request to conduct Director's Project Status Review of the CMB-S4 Project**

I request that your office organize and conduct a LBNL Director's Project Review of the Cosmic Microwave Background Stage 4 (CMB-S4) project status on November 16-19, 2021. The purpose of this review is to assess the conceptual design, technical progress, and quality of the cost and schedule estimates developed by the project team, in advance of a DOE Independent Project Review (IPR) that will be held on February 15-18, 2022. The scientific Mission Need (CD-0) for the development of the CMB-S4 was approved on July 25, 2019 and the project is currently preparing for a CD-1 review in Q4 FY2022.

In carrying out its charge, the review committee should assess the following specific questions:

1. Is the progress on the development of the conceptual design and acquisition strategy adequate to meet the project's milestone for completion by CD-1?
2. Is the project making adequate progress to show a credible cost range and project duration by CD-1?
3. Do the project's plans being developed to execute the work make the most efficient use of the financial, human and technical resources available to meet the mission need? Does the project use the human and technical resources available to it at the participating national labs and universities when they are the most efficient choice? Are qualified vendors being sought out where they are the most cost-effective option?
4. Is the Transition to Operations strategy being developed appropriately, considering the experimental equipment will be installed and operated at remote sites.
5. Does the project understand its dependencies on outside resources such as participation by researchers with other funding sources and funding from other agencies or international collaborators?
6. Does the proposed project team have adequate management experience, design skills, and laboratory support to produce a credible technical, cost, and schedule baseline?

7. Are the ES&H aspects being properly addressed and is the planning sufficient for this stage of the project?
8. Are there any other significant issues that require management attention?

I request that you provide the final closeout report to the CMB-S4 project team and me within 21 days of the review.

Signed by ______________________ Date October 22, 2021

Appendix B - Review Agenda

CMB-S4 Next Generation CMB Experiment

Plenary Sessions and Daily Summaries

session organizer: Matthaeus Leitner

Start [PT]	End [PT]	Start [CT]	End [CT]	Start [ET]	End [ET]	Duration [min]	Title	Time Allocation	Presenter
Tuesday, Nov 16, 2021									
07:00 AM	08:00 AM	09:00 AM	10:00 AM	10:00 AM	11:00 AM	60	Full Committee Executive Session (Meet with Lab Director and Associate Lab Director at 07:30 AM)		
08:00 AM	08:15 AM	10:00 AM	10:15 AM	11:00 AM	11:15 AM	15	Welcome Address	15	Michael Witherell
08:15 AM	08:55 AM	10:15 AM	10:55 AM	11:15 AM	11:55 AM	40	Project Overview	30+10	John Corlett
08:55 AM	09:35 AM	10:55 AM	11:35 AM	11:55 AM	12:35 PM	40	CMB-S4 Science Overview and Preliminary Baseline Design Report	30+10	John Carlstrom
09:35 AM	*10:05 AM*	*11:35 AM*	*12:05 PM*	*12:35 PM*	*01:05 PM*	*30*	*Break*		
10:05 AM	10:45 AM	12:05 PM	12:45 PM	01:05 PM	01:45 PM	40	Project Management	30+10	Matthaeus Leitner
10:45 AM	11:15 AM	12:45 PM	01:15 PM	01:45 PM	02:15 PM	30	Systems Engineering and Design Maturity	20+10	Robert Besuner
11:15 AM	*11:45 AM*	*01:15 PM*	*01:45 PM*	*02:15 PM*	*02:45 PM*	*30*	*Break*		
11:45 AM	12:15 PM	01:45 PM	02:15 PM	02:45 PM	03:15 PM	30	CMB-S4 Technical Baseline Overview and Requirements Flowdown	20+10	John Ruhl
12:15 PM	12:40 PM	02:15 PM	02:40 PM	03:15 PM	03:40 PM	25	WBS 1.03 Detectors Overview	20+5	Brenna Flaugher
12:40 PM	01:05 PM	02:40 PM	03:05 PM	03:40 PM	04:05 PM	25	WBS 1.04 Readout Overview	20+5	Zeesh Ahmed
01:05 PM	01:30 PM	03:05 PM	03:30 PM	04:05 PM	04:30 PM	25	WBS 1.05 Module Assembly and Testing Overview	20+5	Brad Benson
01:30 PM	*02:00 PM*	*03:30 PM*	*04:00 PM*	*04:30 PM*	*05:00 PM*	*30*	*Break*		
02:00 PM	03:00 PM	04:00 PM	05:00 PM	05:00 PM	06:00 PM	60	Full Committee Executive Session		
03:00 PM	*03:00 PM*	*05:00 PM*	*05:00 PM*	*06:00 PM*	*06:00 PM*	*0*	*Adjourn*		
Wednesday, Nov 17, 2021									
08:00 AM	08:25 AM	10:00 AM	10:25 AM	11:00 AM	11:25 AM	25	WBS 1.06 Large Aperture Telescopes Overview	20+5	Mike Niemack
08:25 AM	08:50 AM	10:25 AM	10:50 AM	11:25 AM	11:50 AM	25	WBS 1.07 Small Aperture Telescopes Overview	20+5	John Kovac
08:50 AM	09:15 AM	10:50 AM	11:15 AM	11:50 AM	12:15 PM	25	WBS 1.08 Data Acquisition Overview	20+5	Laura Newburgh
09:15 AM	09:40 AM	11:15 AM	11:40 AM	12:15 PM	12:40 PM	25	WBS 1.09 Data Management Overview	20+5	Julian Borrill
09:40 AM	*10:10 AM*	*11:40 AM*	*12:10 PM*	*12:40 PM*	*01:10 PM*	*30*	*Break*		
10:10 AM	10:35 AM	12:10 PM	12:35 PM	01:10 PM	01:35 PM	25	WBS 1.10 Chile Site and Integration & Commissioning Overview	20+5	Kam Arnold
10:35 AM	11:00 AM	12:35 PM	01:00 PM	01:35 PM	02:00 PM	*25*	WBS 1.11 South Pole Site and Integration & Commissioning Overview	*20+5*	Amy Bender
11:00 AM	11:25 AM	01:00 PM	01:25 PM	02:00 PM	02:25 PM	25	EH&S and PHAR Status	20+5	Ingrid Peterson
11:25 AM	*12:05 PM*	*01:25 PM*	*02:05 PM*	*02:25 PM*	*03:05 PM*	*40*	*Break*		
12:05 PM	02:00 PM	02:05 PM	04:00 PM	03:05 PM	05:00 PM	115	Breakout Sessions (SC-1, SC-2, SC-3, SC-4, SC-5, SC-6, SC-7, SC-8)		
02:00 PM	03:00 PM	04:00 PM	05:00 PM	05:00 PM	06:00 PM	60	Full Committee Executive Session		
03:00 PM	*03:00 PM*	*05:00 PM*	*05:00 PM*	*06:00 PM*	*06:00 PM*	*0*	*Adjourn*		
Thursday, Nov 18, 2021									
08:00 AM	02:00 PM	10:00 AM	04:00 PM	11:00 AM	05:00 PM	360	Breakout Sessions (SC-1, SC-2, SC-3, SC-4, SC-5, SC-6, SC-7, SC-8)		
02:00 PM	03:00 PM	04:00 PM	05:00 PM	05:00 PM	06:00 PM	60	Full Committee Executive Session		
03:00 PM	*03:00 PM*	*05:00 PM*	*05:00 PM*	*06:00 PM*	*06:00 PM*	*0*	*Adjourn*		
Friday, Nov 19, 2021									
08:00 AM	09:00 AM	10:00 AM	11:00 AM	11:00 AM	12:00 PM	60	Q&A, Subcommittee Lead Briefings		
09:00 AM	12:00 PM	11:00 AM	02:00 PM	12:00 PM	03:00 PM	180	Full Committee Executive Session		
12:00 PM	01:30 PM	02:00 PM	03:30 PM	03:00 PM	04:30 PM	90	Closeout Presentation		
01:30 PM	*01:30 PM*	*03:30 PM*	*03:30 PM*	*04:30 PM*	*04:30 PM*	*0*	*Adjourn*		

REV14 Nov11

CMB-S4 Next Generation CMB Experiment

SC-1 Telescopes

session organizer: Mike Niemack

Start [PT]	End [PT]	Start [CT]	End [CT]	Start [ET]	End [ET]	Duration [min]	Title	Time Allocation	Presenter
Wednesday, Nov 17, 2021									
12:05 PM	12:45 PM	02:05 PM	02:45 PM	03:05 PM	03:45 PM	40	1.06.01 LAT Management (CAM Talk)	30+10	Nick Emerson
12:45 PM	01:15 PM	02:45 PM	03:15 PM	03:45 PM	04:15 PM	30	1.06.02 SPLAT Design and Optics	20+10	Nick Emerson
01:15 PM	01:45 PM	03:15 PM	03:45 PM	04:15 PM	04:45 PM	30	1.06.03 CHLAT Design and Optics	20+10	Mike Niemack
01:45 PM	*02:00 PM*	*03:45 PM*	*04:00 PM*	*04:45 PM*	*05:00 PM*	*15*	*Break*		
02:00 PM	03:00 PM	04:00 PM	05:00 PM	05:00 PM	06:00 PM	60	Full Committee Executive Session		
03:00 PM	*03:00 PM*	*05:00 PM*	*05:00 PM*	*06:00 PM*	*06:00 PM*	*0*	*Adjourn*		
Thursday, Nov 18, 2021									
08:00 AM	08:20 AM	10:00 AM	10:20 AM	11:00 AM	11:20 AM	20	1.06.06 LAT Calibration Hardware	15+5	Johanna Nagy
08:20 AM	09:00 AM	10:20 AM	11:00 AM	11:20 AM	12:00 PM	40	1.06.04, 1.06.05 LAT Receivers & Commissioning Receiver	30+10	Brad Benson
09:00 AM	09:40 AM	11:00 AM	11:40 AM	12:00 PM	12:40 PM	40	1.07.01 SAT Management (CAM Talk)	30+10	Tim Norton
09:40 AM	10:10 AM	11:40 AM	12:10 PM	12:40 PM	01:10 PM	30	Break		
10:10 AM	10:40 AM	12:10 PM	12:40 PM	01:10 PM	01:40 PM	30	1.07.02, 1.07.03 SAT Cryostat Design	20+10	Joe Saba
10:40 AM	11:10 AM	12:40 PM	01:10 PM	01:40 PM	02:10 PM	30	1.07.04, 1.07.05 SAT Optics	20+10	Abigail Vieregg
11:10 AM	11:40 AM	01:10 PM	01:40 PM	02:10 PM	02:40 PM	30	1.07.07, 1.07.08 SAT Mount and Ground Shield	20+10	Clem Pryke/Ben Schmitt
11:40 AM	12:20 PM	01:40 PM	02:20 PM	02:40 PM	03:20 PM	40	Break		
12:20 PM	12:40 PM	02:20 PM	02:40 PM	03:20 PM	03:40 PM	20	1.07.06 SAT Calibration Hardware	15+5	Kirit Karkare
12:40 PM	01:00 PM	02:40 PM	03:00 PM	03:40 PM	04:00 PM	20	1.07.09 SAT US Integration	15+5	Akito Kusaka
01:00 PM	*02:00 PM*	*03:00 PM*	*04:00 PM*	*04:00 PM*	*05:00 PM*	*60*	*Discussion/Break*		
02:00 PM	03:00 PM	04:00 PM	05:00 PM	05:00 PM	06:00 PM	60	Full Committee Executive Session		
03:00 PM	*03:00 PM*	*05:00 PM*	*05:00 PM*	*06:00 PM*	*06:00 PM*	*0*	*Adjourn*		

CMB-S4 Next Generation CMB Experiment

SC-2 Detectors

session organizer: Brenna Flaugher

Start [PT]	End [PT]	Start [CT]	End [CT]	Start [ET]	End [ET]	Duration [min]	Title	Time Allocation	Presenter
Wednesday, Nov 17, 2021									
12:05 PM	12:35 PM	02:05 PM	02:35 PM	03:05 PM	03:35 PM	30	1.03 Detectors Overview	20+10	Brenna Flaugher
12:35 PM	01:05 PM	02:35 PM	03:05 PM	03:35 PM	04:05 PM	30	1.03 Flowdown to Detector Requirements	20+10	John Ruhl
01:05 PM	01:35 PM	03:05 PM	03:35 PM	04:05 PM	04:35 PM	30	1.03.01 Detector Management (CAM Talk)	20+10	John Joseph
01:35 PM	*02:00 PM*	*03:35 PM*	*04:00 PM*	*04:35 PM*	*05:00 PM*	*25*	*Break*		
02:00 PM	03:00 PM	04:00 PM	05:00 PM	05:00 PM	06:00 PM	60	Full Committee Executive Session		
03:00 PM	*03:00 PM*	*05:00 PM*	*05:00 PM*	*06:00 PM*	*06:00 PM*	*0*	*Adjourn*		
Thursday, Nov 18, 2021									
08:00 AM	08:30 AM	10:00 AM	10:30 AM	11:00 AM	11:30 AM	30	1.03.02 ANL Wafer Fabrication and Testing	20+10	Clarence Chang
08:30 AM	09:00 AM	10:30 AM	11:00 AM	11:30 AM	12:00 PM	30	1.03.03 SLAC Wafer Fabrication and Testing	20+10	Dale Li
09:00 AM	09:30 AM	11:00 AM	11:30 AM	12:00 PM	12:30 PM	30	1.03.04 JPL Wafer Fabrication and Testing	20+10	Jamie Bock
09:30 AM	10:00 AM	11:30 AM	12:00 PM	12:30 PM	01:00 PM	30	Break		
10:00 AM	10:30 AM	12:00 PM	12:30 PM	01:00 PM	01:30 PM	30	1.03.05 NIST Wafer Fabrication and Testing	20+10	Shannon Duff
10:30 AM	11:00 AM	12:30 PM	01:00 PM	01:30 PM	02:00 PM	30	1.03.06 LBNL/SeeQC Wafer Fabrication and Testing	20+10	Aritoki Suzuki
11:00 AM	11:30 AM	01:00 PM	01:30 PM	02:00 PM	02:30 PM	30	1.03.07 UCB/Marvell Wafer Fabrication and Testing	20+10	Adrian Lee
11:30 AM	12:20 PM	01:30 PM	02:20 PM	02:30 PM	03:20 PM	50	Discussion/Break		
12:20 PM	12:55 PM	02:20 PM	02:55 PM	03:20 PM	03:55 PM	35	1.05.07 Module Test Plan (w. SC-3)	25+10	Adam Anderson
12:55 PM	01:20 PM	02:55 PM	03:20 PM	03:55 PM	04:20 PM	25	1.05.06 Module Test Equipment (w. SC-3)	15+10	Johanna Nagy
01:20 PM	*02:00 PM*	*03:20 PM*	*04:00 PM*	*04:20 PM*	*05:00 PM*	*40*	*Discussion/Break*		
02:00 PM	03:00 PM	04:00 PM	05:00 PM	05:00 PM	06:00 PM	60	Full Committee Executive Session		
03:00 PM	*03:00 PM*	*05:00 PM*	*05:00 PM*	*06:00 PM*	*06:00 PM*	*0*	*Adjourn*		

CMB-S4
Next Generation CMB Experiment

SC-3 Readout Modules and Testing

session organizer: Zeesh Ahmed

Start [PT]	End [PT]	Start [CT]	End [CT]	Start [ET]	End [ET]	Duration [min]	Title	Time Allocation	Presenter
Wednesday, Nov 17, 2021									
12:05 PM	12:45 PM	02:05 PM	02:45 PM	03:05 PM	03:45 PM	40	1.04.01 Readout Management (CAM Talk)	30+10	Gunther Haller
12:45 PM	01:15 PM	02:45 PM	03:15 PM	03:45 PM	04:15 PM	30	1.04.02 100mK Electronics	20+10	Jeff Filippini
01:15 PM	01:45 PM	03:15 PM	03:45 PM	04:15 PM	04:45 PM	30	1.04.04 Warm Electronics	20+10	Shawn Henderson
01:45 PM	*02:00 PM*	*03:45 PM*	*04:00 PM*	*04:45 PM*	*05:00 PM*	*15*	*Break*		
02:00 PM	03:00 PM	04:00 PM	05:00 PM	05:00 PM	06:00 PM	60	Full Committee Executive Session		
03:00 PM	*03:00 PM*	*05:00 PM*	*05:00 PM*	*06:00 PM*	*06:00 PM*	*0*	*Adjourn*		
Thursday, Nov 18, 2021									
08:00 AM	08:30 AM	10:00 AM	10:30 AM	11:00 AM	11:30 AM	30	1.04.03 4 K Electronics	20+10	Darcy Barron
08:30 AM	09:00 AM	10:30 AM	11:00 AM	11:30 AM	12:00 PM	30	1.04 Prototyping Status and Plans	20+10	Gunther Haller
09:00 AM	09:40 AM	11:00 AM	11:40 AM	12:00 PM	12:40 PM	40	1.05.01 Module Asm. and Test Mgmt. (CAM Talk)	30+10	John Joseph
09:40 AM	10:10 AM	11:40 AM	12:10 PM	12:40 PM	01:10 PM	30	Break		
10:10 AM	10:40 AM	12:10 PM	12:40 PM	01:10 PM	01:40 PM	30	1.05.02, 1.05.04 Module Mech Structure and Assembly	20+10	Greg Derylo
10:40 AM	11:10 AM	12:40 PM	01:10 PM	01:40 PM	02:10 PM	30	1.05.03 Optical Coupling	20+10	Sara Simon
11:10 AM	12:20 PM	01:10 PM	02:20 PM	02:10 PM	03:20 PM	70	Discussion/Break		
12:20 PM	12:55 PM	02:20 PM	02:55 PM	03:20 PM	03:55 PM	35	1.05.07 Module Test Plan (w. SC-2)	25+10	Adam Anderson
12:55 PM	01:20 PM	02:55 PM	03:20 PM	03:55 PM	04:20 PM	25	1.05.06 Module Test Equipment (w. SC-2)	15+10	Johanna Nagy
01:20 PM	*02:00 PM*	*03:20 PM*	*04:00 PM*	*04:20 PM*	*05:00 PM*	*40*	*Discussion/Break*		
02:00 PM	03:00 PM	04:00 PM	05:00 PM	05:00 PM	06:00 PM	60	Full Committee Executive Session		
03:00 PM	*03:00 PM*	*05:00 PM*	*05:00 PM*	*06:00 PM*	*06:00 PM*	*0*	*Adjourn*		

CMB-S4
Next Generation CMB Experiment

SC-4 Sites

session organizer: Amy Bender

Start [PT]	End [PT]	Start [CT]	End [CT]	Start [ET]	End [ET]	Duration [min]	Title	Time Allocation	Presenter
Wednesday, Nov 17, 2021									
12:05 PM	12:45 PM	02:05 PM	02:45 PM	03:05 PM	03:45 PM	40	1.11.01 South Pole Management (CAM Talk)	30+10	Erik Nichols
12:45 PM	01:10 PM	02:45 PM	03:10 PM	03:45 PM	04:10 PM	25	1.11.03 South Pole Site Design	15+10	Amy Bender
01:10 PM	01:35 PM	03:10 PM	03:35 PM	04:10 PM	04:35 PM	25	1.11.03 South Pole Logistics, Construction, EH&S, QA	20+5	Erik Nichols
01:35 PM	*02:00 PM*	*03:35 PM*	*04:00 PM*	*04:35 PM*	*05:00 PM*	*25*	*Break*		
02:00 PM	03:00 PM	04:00 PM	05:00 PM	05:00 PM	06:00 PM	60	Full Committee Executive Session		
03:00 PM	*03:00 PM*	*05:00 PM*	*05:00 PM*	*06:00 PM*	*06:00 PM*	*0*	*Adjourn*		
Thursday, Nov 18, 2021									
08:00 AM	08:30 AM	10:00 AM	10:30 AM	11:00 AM	11:30 AM	30	1.11.04 South Pole LAT Integration and Commissioning	20+10	Tyler Natoli
08:30 AM	09:00 AM	10:30 AM	11:00 AM	11:30 AM	12:00 PM	30	1.11.04 South Pole SAT Integration and Commissioning	20+10	Marion Dierickx
09:00 AM	09:40 AM	11:00 AM	11:40 AM	12:00 PM	12:40 PM	40	1.10.01 Chile Management (CAM Talk)	30+10	Mauricio Pilleux
09:40 AM	10:10 AM	11:40 AM	12:10 PM	12:40 PM	01:10 PM	30	Break		
10:10 AM	10:40 AM	12:10 PM	12:40 PM	01:10 PM	01:40 PM	30	1.10.03 Chile Site Design	20+10	Kam Arnold
10:40 AM	11:00 AM	12:40 PM	01:00 PM	01:40 PM	02:00 PM	20	1.10.02 Chile Business Office	15+5	Mauricio Pilleux
11:00 AM	11:20 AM	01:00 PM	01:20 PM	02:00 PM	02:20 PM	20	1.10 Chile EH&S, QA	15+5	Mauricio Pilleux
11:20 AM	11:50 AM	01:20 PM	01:50 PM	02:20 PM	02:50 PM	30	1.10.04 CHLAT Integration and Commissioning	20+10	Tyler Natoli
11:50 AM	*02:00 PM*	*01:50 PM*	*04:00 PM*	*02:50 PM*	*05:00 PM*	*130*	*Discussion/Break*		
02:00 PM	03:00 PM	04:00 PM	05:00 PM	05:00 PM	06:00 PM	60	Full Committee Executive Session		
03:00 PM	*03:00 PM*	*05:00 PM*	*05:00 PM*	*06:00 PM*	*06:00 PM*	*0*	*Adjourn*		

CMB-S4
Next Generation CMB Experiment

SC-5 DAQ and DM

session organizer: Laura Newburgh

Start [PT]	End [PT]	Start [CT]	End [CT]	Start [ET]	End [ET]	Duration [min]	Title	Time Allocation	Presenter
Wednesday, Nov 17, 2021									
12:05 PM	12:45 PM	02:05 PM	02:45 PM	03:05 PM	03:45 PM	40	1.08.01 DAQ Management (CAM Talk)	30+10	Laura Newburgh
12:45 PM	01:15 PM	02:45 PM	03:15 PM	03:45 PM	04:15 PM	30	1.08.02 and 1.08.04 Observatory Control System, Slow Controls, Monitoring	20+10	Koopman, Deaconu
01:15 PM	01:45 PM	03:15 PM	03:45 PM	04:15 PM	04:45 PM	30	1.08.03 Observatory DAQ	20+10	Nathan Whitehorn
01:45 PM	*02:00 PM*	*03:45 PM*	*04:00 PM*	*04:45 PM*	*05:00 PM*	*15*	*Break*		
02:00 PM	03:00 PM	04:00 PM	05:00 PM	05:00 PM	06:00 PM	60	Full Committee Executive Session		
03:00 PM	*03:00 PM*	*05:00 PM*	*05:00 PM*	*06:00 PM*	*06:00 PM*	*0*	*Adjourn*		
Thursday, Nov 18, 2021									
08:00 AM	08:30 AM	10:00 AM	10:30 AM	11:00 AM	11:30 AM	30	1.08.05 Lab Subsystem DAQ	20+10	Abigail Crites
08:30 AM	09:00 AM	10:30 AM	11:00 AM	11:30 AM	12:00 PM	30	1.08.06 Deployment and Integration of DAQ	20+10	Abigail Crites
09:00 AM	09:30 AM	11:00 AM	11:30 AM	12:00 PM	12:30 PM	30	Discussion/Break		
09:30 AM	10:10 AM	11:30 AM	12:10 PM	12:30 PM	01:10 PM	40	1.09.01 Data Management (CAM Talk) (w. SC-6)	30+10	Kevin Long
10:10 AM	10:30 AM	12:10 PM	12:30 PM	01:10 PM	01:30 PM	20	1.09.07 Site Hardware (w. SC-6)	15+5	Crawford/Rahlin
10:30 AM	10:50 AM	12:30 PM	12:50 PM	01:30 PM	01:50 PM	20	1.09.02 Data Movement (w. SC-6)	15+5	Eli Dart
10:50 AM	11:10 AM	12:50 PM	01:10 PM	01:50 PM	02:10 PM	20	1.09.03 Software Infrastructure (w. SC-6)	15+5	Bard/Kisner
11:10 AM	11:50 AM	01:10 PM	01:50 PM	02:10 PM	02:50 PM	40	Break		
11:50 AM	12:10 PM	01:50 PM	02:10 PM	02:50 PM	03:10 PM	20	1.09.04 Data Simulation (w. SC-6)	15+5	Simon/Zonca
12:10 PM	12:30 PM	02:10 PM	02:30 PM	03:10 PM	03:30 PM	20	1.09.05 Data Reduction (w. SC-6)	15+5	Bischoff/Keskitalo
12:30 PM	12:50 PM	02:30 PM	02:50 PM	03:30 PM	03:50 PM	20	1.09.06 Transients (w. SC-6)	15+5	Petravick/Whitehorn
12:50 PM	*02:00 PM*	*02:50 PM*	*04:00 PM*	*03:50 PM*	*05:00 PM*	*70*	*Discussion/Break*		
02:00 PM	03:00 PM	04:00 PM	05:00 PM	05:00 PM	06:00 PM	60	Full Committee Executive Session		
03:00 PM	*03:00 PM*	*05:00 PM*	*05:00 PM*	*06:00 PM*	*06:00 PM*	*0*	*Adjourn*		

CMB-S4 Next Generation CMB Experiment

SC-6 Science, Flowdown, and Systems Engineering

session organizer: Robert Besuner

Start [PT]	End [PT]	Start [CT]	End [CT]	Start [ET]	End [ET]	Duration [min]	Title	Time Allocation	Presenter
Wednesday, Nov 17, 2021									
12:05 PM	12:10 PM	02:05 PM	02:10 PM	03:05 PM	03:10 PM	5	Introduction to SC-6 Breakout Session	5	John Carlstrom
12:05 PM	12:35 PM	02:05 PM	02:35 PM	03:05 PM	03:35 PM	30	Overall CMB Science Case	20+10	Joel Meyers
12:10 PM	12:40 PM	02:10 PM	02:40 PM	03:10 PM	03:40 PM	30	Science Goals to Measurement Requirements	20+10	Kevin Huffenberger
12:40 PM	01:10 PM	02:40 PM	03:10 PM	03:40 PM	04:10 PM	30	Measurement Requirements to Survey Design	20+10	John Carlstrom
01:10 PM	*01:30 PM*	*03:10 PM*	*03:30 PM*	*04:10 PM*	*04:30 PM*	*20*	*Break*		
01:30 PM	02:30 PM	03:30 PM	04:30 PM	04:30 PM	05:30 PM	60	Full Committee Executive Session		
02:30 PM	*02:30 PM*	*04:30 PM*	*04:30 PM*	*05:30 PM*	*05:30 PM*	*0*	*Adjourn*		
Thursday, Nov 18, 2021									
08:00 AM	08:30 AM	10:00 AM	10:30 AM	11:00 AM	11:30 AM	30	Survey Design to Technical Implementation Requirements	20+10	John Ruhl
08:30 AM	09:00 AM	10:30 AM	11:00 AM	11:30 AM	12:00 PM	30	Systems Engineering Processes and Tools	20+10	Robert Besuner
09:00 AM	09:30 AM	11:00 AM	11:30 AM	12:00 PM	12:30 PM	30	Break		
09:30 AM	10:10 AM	11:30 AM	12:10 PM	12:30 PM	01:10 PM	40	1.09.01 Data Management (CAM Talk) (w. SC-5)	30+10	Kevin Long
10:10 AM	10:30 AM	12:10 PM	12:30 PM	01:10 PM	01:30 PM	20	1.09.07 Site Hardware (w. SC-5)	15+5	Crawford/Rahlin
10:30 AM	10:50 AM	12:30 PM	12:50 PM	01:30 PM	01:50 PM	20	1.09.02 Data Movement (w. SC-5)	15+5	Eli Dart
10:50 AM	11:10 AM	12:50 PM	01:10 PM	01:50 PM	02:10 PM	20	1.09.03 Software Infrastructure (w. SC-5)	15+5	Bard/Kisner
11:10 AM	11:50 AM	01:10 PM	01:50 PM	02:10 PM	02:50 PM	40	Break		
11:50 AM	12:10 PM	01:50 PM	02:10 PM	02:50 PM	03:10 PM	20	1.09.04 Data Simulation (w. SC-5)	15+5	Simon/Zonca
12:10 PM	12:30 PM	02:10 PM	02:30 PM	03:10 PM	03:30 PM	20	1.09.05 Data Reduction (w. SC-5)	15+5	Bischoff/Keskitalo
12:30 PM	12:50 PM	02:30 PM	02:50 PM	03:30 PM	03:50 PM	20	1.09.06 Transients (w. SC-5)	15+5	Petravick/Whitehorn
12:50 PM	*02:00 PM*	*02:50 PM*	*04:00 PM*	*03:50 PM*	*05:00 PM*	*70*	*Discussion/Break*		
02:00 PM	03:00 PM	04:00 PM	05:00 PM	05:00 PM	06:00 PM	60	Full Committee Executive Session		
03:00 PM	*03:00 PM*	*05:00 PM*	*05:00 PM*	*06:00 PM*	*06:00 PM*	*0*	*Adjourn*		

CMB-S4 Next Generation CMB Experiment

SC-7 Management

session organizer: Matthaeus Leitner

Start [PT]	End [PT]	Start [CT]	End [CT]	Start [ET]	End [ET]	Duration [min]	Title	Time Allocation	Presenter
Wednesday, Nov 17, 2021									
12:05 PM	12:35 PM	02:05 PM	02:35 PM	03:05 PM	03:35 PM	30	Project Governance (w. SC-8)	20+10	John Corlett
12:35 PM	01:15 PM	02:35 PM	03:15 PM	03:35 PM	04:15 PM	40	Management of CMB-S4 Cost and Schedule (w. SC-8)	30+10	Matthaeus Leitner
01:15 PM	01:35 PM	03:15 PM	03:35 PM	04:15 PM	04:35 PM	20	Project Communication Tools (w. SC-8)	15+05	Julian Borrill
01:35 PM	*02:00 PM*	*03:35 PM*	*04:00 PM*	*04:35 PM*	*05:00 PM*	*25*	*Discussion/Break*		
02:00 PM	03:00 PM	04:00 PM	05:00 PM	05:00 PM	06:00 PM	60	Full Committee Executive Session		
03:00 PM	*03:00 PM*	*05:00 PM*	*05:00 PM*	*06:00 PM*	*06:00 PM*	*0*	*Adjourn*		
Thursday, Nov 18, 2021									
08:00 AM	08:20 AM	10:00 AM	10:20 AM	11:00 AM	11:20 AM	20	Astro2020 (w. SC-8)	20	Julian Borrill
08:20 AM	08:50 AM	10:20 AM	10:50 AM	11:20 AM	11:50 AM	30	NSF Project Management Overview (w. SC-8)	20+10	Jeff Zivick
08:50 AM	09:20 AM	10:50 AM	11:20 AM	11:50 AM	12:20 PM	30	MOUs and Opportunities (w. SC-8)	20+10	Gil Gilchriese
09:20 AM	09:50 AM	11:20 AM	11:50 AM	12:20 PM	12:50 PM	30	Break		
09:50 AM	10:30 AM	11:50 AM	12:30 PM	12:50 PM	01:30 PM	40	Risk Management and Contingency (w. SC-8)	30+10	Jeff Zivick
10:30 AM	11:00 AM	12:30 PM	01:00 PM	01:30 PM	02:00 PM	30	Integrated Project Mgmt. Systems and Project Controls Overview (w. SC-8)	20+10	David Sala
11:00 AM	11:30 AM	01:00 PM	01:30 PM	02:00 PM	02:30 PM	30	Cost Book, Cost and Schedule Methodology, and Plans for EVMS (w. SC-8)	20+10	Long/Humphrey
11:30 AM	12:00 PM	01:30 PM	02:00 PM	02:30 PM	03:00 PM	30	Break		
12:00 PM	12:40 PM	02:00 PM	02:40 PM	03:00 PM	03:40 PM	40	Quality Assurance	30+10	Jessica Aguilar
12:40 PM	01:20 PM	02:40 PM	03:20 PM	03:40 PM	04:20 PM	40	One-on-One Meeting EHS (Ingrid Peterson and Jim Tarpinian)	40	Ingrid Peterson
01:20 PM	01:40 PM	03:20 PM	03:40 PM	04:20 PM	04:40 PM	20	Responses To Charge Questions	20	John Corlett
01:40 PM	*02:00 PM*	*03:40 PM*	*04:00 PM*	*04:40 PM*	*05:00 PM*	*20*	*Discussion/Break*		
02:00 PM	03:00 PM	04:00 PM	05:00 PM	05:00 PM	06:00 PM	60	Full Committee Executive Session		
03:00 PM	*03:00 PM*	*05:00 PM*	*05:00 PM*	*06:00 PM*	*06:00 PM*	*0*	*Adjourn*		

SC-8 Cost and Schedule

session organizer: David Sala

Start [PT]	End [PT]	Start [CT]	End [CT]	Start [ET]	End [ET]	Duration [min]	Title	Time Allocation	Presenter
Wednesday, Nov 17, 2021									
12:05 PM	12:35 PM	02:05 PM	02:35 PM	03:05 PM	03:35 PM	30	Project Governance (w. SC-7)	20+10	John Corlett
12:35 PM	01:15 PM	02:35 PM	03:15 PM	03:35 PM	04:15 PM	40	Management of CMB-S4 Cost and Schedule (w. SC-7)	30+10	Matthaeus Leitner
01:15 PM	01:35 PM	03:15 PM	03:35 PM	04:15 PM	04:35 PM	20	Project Communication Tools (w. SC-7)	15+05	Julian Borrill
01:35 PM	*02:00 PM*	*03:35 PM*	*04:00 PM*	*04:35 PM*	*05:00 PM*	*25*	*Discussion/Break*		
02:00 PM	03:00 PM	04:00 PM	05:00 PM	05:00 PM	06:00 PM	60	Full Committee Executive Session		
03:00 PM	*03:00 PM*	*05:00 PM*	*05:00 PM*	*06:00 PM*	*06:00 PM*	*0*	*Adjourn*		
Thursday, Nov 18, 2021									
08:00 AM	08:20 AM	10:00 AM	10:20 AM	11:00 AM	11:20 AM	20	Astro2020 (w. SC-7)	20	Julian Borrill
08:20 AM	08:50 AM	10:20 AM	10:50 AM	11:20 AM	11:50 AM	30	NSF Project Management Overview (w. SC-7)	20+10	Jeff Zivick
08:50 AM	09:20 AM	10:50 AM	11:20 AM	11:50 AM	12:20 PM	30	MOUs and Opportunities (w. SC-7)	20+10	Gil Gilchriese
09:20 AM	09:50 AM	11:20 AM	11:50 AM	12:20 PM	12:50 PM	30	Break		
09:50 AM	10:30 AM	11:50 AM	12:30 PM	12:50 PM	01:30 PM	40	Risk Management and Contingency (w. SC-7)	30+10	Jeff Zivick
10:30 AM	11:00 AM	12:30 PM	01:00 PM	01:30 PM	02:00 PM	30	Integrated Project Mgmt. Systems and Project Controls Overview (w. SC-7)	20+10	David Sala
11:00 AM	11:30 AM	01:00 PM	01:30 PM	02:00 PM	02:30 PM	30	Cost Book, Cost and Schedule Methodology, and Plans for EVMS (w. SC-7)	20+10	Long/Humphrey
11:30 AM	12:00 PM	01:30 PM	02:00 PM	02:30 PM	03:00 PM	30	Break		
12:00 PM	12:20 PM	02:00 PM	02:20 PM	03:00 PM	03:20 PM	20	DRM Production Schedule Overview (Assumptions + Schedule Walkthrough)		Joseph/Nelson
12:20 PM	01:00 PM	02:20 PM	03:00 PM	03:20 PM	04:00 PM	40	Drill Down 1 - Readout		
01:00 PM	01:40 PM	03:00 PM	03:40 PM	04:00 PM	04:40 PM	40	Drill Down 2 - South Pole		
01:40 PM	*02:00 PM*	*03:40 PM*	*04:00 PM*	*04:40 PM*	*05:00 PM*	*20*	*Break*		
02:00 PM	03:00 PM	04:00 PM	05:00 PM	05:00 PM	06:00 PM	60	Full Committee Executive Session		
03:00 PM	*03:00 PM*	*05:00 PM*	*05:00 PM*	*06:00 PM*	*06:00 PM*	*0*	*Adjourn*		

Appendix C - Review Committee

Subcommittee	Name	Affiliation
Chair	Jay Marx	PMO Consultant
SC-1	**Large Aperture Telescopes & Small Aperture Telescopes**	
	Bill Edwards*	PMO Consultant
	Dave Woody	Caltech
	Jeff Kingsley	U. Arizona
SC-2	**Detectors**	
	Ed Wollack*	NASA Goddard
	Bill Holzapfel	UC Berkeley
SC-3	**Readout, Module Assembly & Testing**	
	Carl Haber*	LBNL
	Harvey Moseley	NASA/GSFC
SC-4	**Sites Infrastructure, Integration & Commissioning**	
	Jeff Cherwinka*	PSL/Wisconsin
	Eduardo Donoso	NAOC-Chile
SC-5	**Data Acquisition & Data Management**	
	John Kelley*	Icecube/Wisconsin
	Robert Gardner	U. Chicago
	Wil O'Mullane	LSST
SC-6	**Science Requirements, Flowdown & Systems Engineering**	
	Michael Levi*	LBNL
	Chuck Claver	LSST
	Josh Frieman	U. Chicago
SC-7	**Management, QA and EH&S**	
	Kem Robinson*	PMO Consultant
	Vincent Riot	LLNL
	Jim Tarpinian	PMO Consultant
	Tim Bolton	Kansas State University
SC-8	**Cost & Schedule**	
	Cathy Lavelle*	BNL
	Carol Wilkinson	PMO Consultant

*Subcommittee Chair