CMB-S4 Project Status

CMB-S4 Spring Collaboration Meeting
March 25, 2024

Jim Strait
John Carlstrom

CMB-S4

Slide Title

- Quick Summary of key developments since the last Collaboration Meeting
- Summary of technical progress
- Interactions with the funding agencies
- Summary and conclusions

Key Developments Since the Last Collaboration Meeting

- NSF Office of Polar Programs (OPP) initiated South Pole Master Planning process with a community input “Charette” in August. Final draft Master Plan to be published on the Federal Register for public comment sometime in the next few months.
- Successful and valuable set of internal Conceptual Design Reviews were conducted July - September 2023
- Very successful comprehensive Director’s Review in November (see below)
- Strong support for CMB-S4 by P5 (see below)
- DOE Office of Science-wide evaluation of new or upgraded facilities over the coming 10 years is in process (see below)

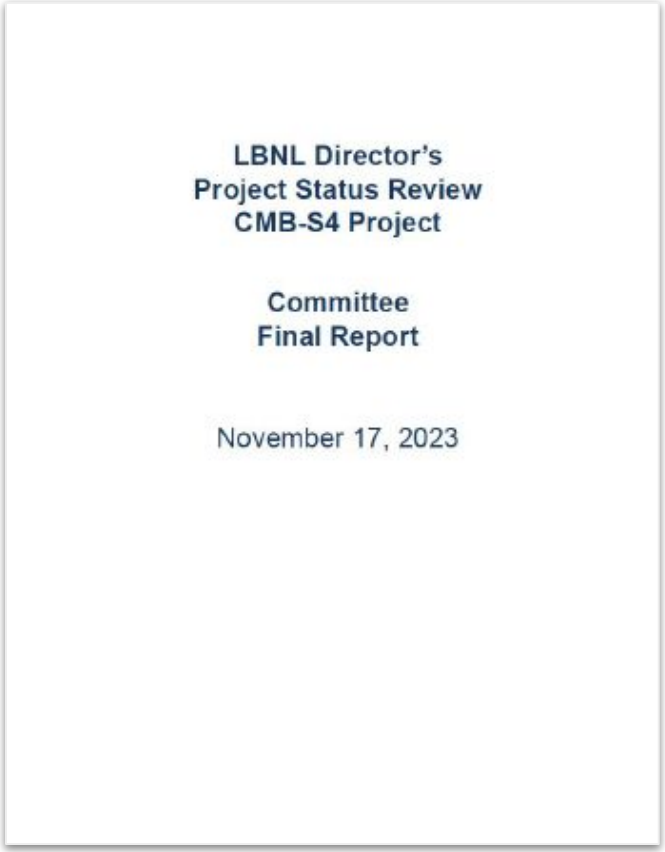
CMB-S4 Director's Review

14–17 Nov 2023
LBNL

A review of the CMB-S4 project to assess readiness for a DOE status review and a NSF CDR.

CMB-S4

High-Level Conclusions of the Director's Review


LBNL Director's
Project Status Review
CMB-S4 Project

Committee
Final Report

November 17, 2023

- *"The committee believes that the project is well positioned to successfully complete the NSF CDR if sufficient directed effort is given in the next few months to the tasks indicated below and others in our subcommittee reports."*
- *"The DOE CD-1 review is expected to take place approximately a year from this review. The committee believes that the project has made substantial progress towards meeting the requirements for that review, but there is still much to be done."*

More information:

- Review page: https://indico.cmb-s4.org/event/52/
- Summary of the review is here.
- Final report is in docdb as CMBS4-doc-1010.

Hitoshi's and Karsten's Slides: https://science.osti.gov/-/media/hep/hepap/pdf/Meetings/2023/P5-HEPAPv2.pdf Full (draft) P5 Report: https://usparticlephysics.org/2023-p5-report/

Report from the Particle Physics Project Prioritization Panel (P5)

Hitoshi Murayama & Karsten Heeger

on behalf of the P5 panel

HEPAP Meeting, December 7, 2023

U.S. DEPARTMENT OF ENERGY | Office of Science

NSF National Science Foundation

Exploring the Quantum Universe

Recommendation 2

Construct a portfolio of major projects that collectively study nearly all fundamental constituents of our universe and their interactions, as well as how those interactions determine both the cosmic past and future.

These projects have the potential to transcend and transform our current paradigms. They inspire collaboration and international cooperation in advancing the frontiers of human knowledge. Plan and start the following major initiatives **in order of priority from highest to lowest**:

Exploring the Quantum Universe

Recommendation 2

Rank-Ordered

a. **CMB-S4**, which looks back at the earliest moments of the universe to probe physics at the highest energy scales. It is critical to install telescopes at and observe from both the South Pole and Chile sites to achieve the science goals (section 4.2).

b. **Re-envisioned second phase of DUNE** with an early implementation of an enhanced 2.1 MW beam—ACE-MIRT—a third far detector, and an upgraded near-detector complex as the definitive long-baseline neutrino oscillation experiment of its kind (section 3.1).

c. **An off-shore Higgs factory**, realized in collaboration with international partners, in order to reveal the secrets of the Higgs boson. The current designs of FCC-ee and ILC meet our scientific requirements. The US should actively engage in feasibility and design studies. Once a specific project is deemed feasible and well-defined (see also Recommendation 6), the US should aim for a contribution at funding levels commensurate to that of the US involvement in the LHC and HL-LHC, while maintaining a healthy US on-shore program in particle physics (section 3.2).

d. **An ultimate Generation 3 (G3) dark matter direct detection experiment** reaching the neutrino fog, in coordination with international partners and preferably sited in the US (section 4.1).

e. **IceCube-Gen2** for study of neutrino properties using non-beam neutrinos complementary to DUNE and for indirect detection of dark matter covering higher mass ranges using neutrinos as a tool (section 4.1).

HEPAP Facilities Subpanel

DOE Office of Science is developing a list of “new or upgraded facilities will best serve our needs in the next ten years (2024-2034).”

Each of six Office of Science FACA Committees* charged to categorize (but not rank) facilities against two criteria:

a. The potential to contribute to world-leading science in the next decade:
   (a) absolutely central; (b) important; (c) lower priority; or (d) don’t know enough yet.
b. The readiness for construction:
   (a) ready to initiate construction; (b) significant scientific/engineering challenges to resolve before initiating construction; or (c) mission and technical requirements not yet fully defined.

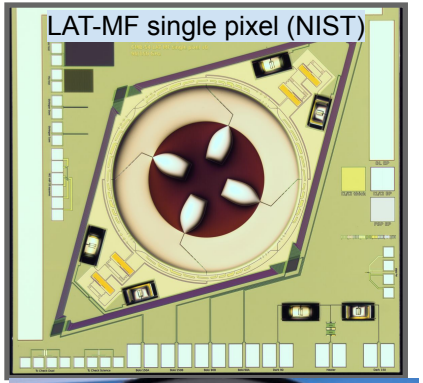
HEPAP Facilities Subpanel, Chaired by Natalie Roe

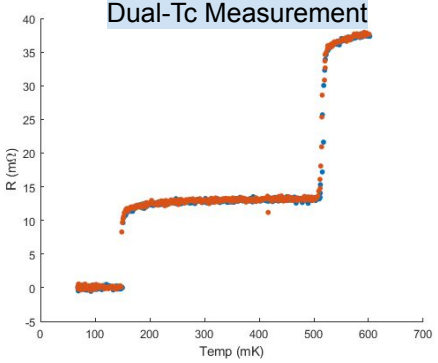
- Collected written input from projects. CMB-S4 submissions are here and here.
- Conducted one public meeting.
- Subpanel will present its report to HEPAP at the May 9-10 meeting.

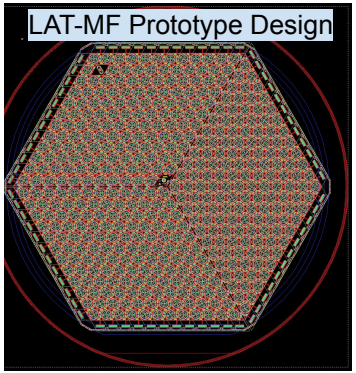
* Advanced Scientific Computing Advisory Committee, Basic Energy Sciences Advisory Committee, Biological and Environmental Research Advisory Committee, Fusion Energy Sciences Advisory Committee, High Energy Physics Advisory Panel, Nuclear Science Advisory Committee

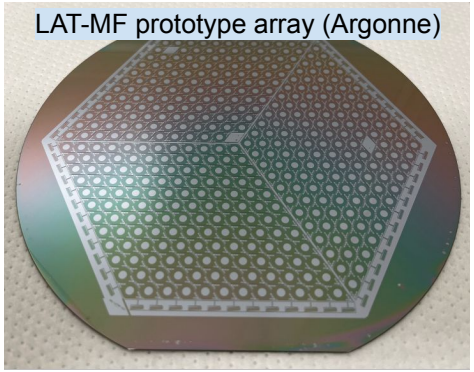
Summary of technical progress

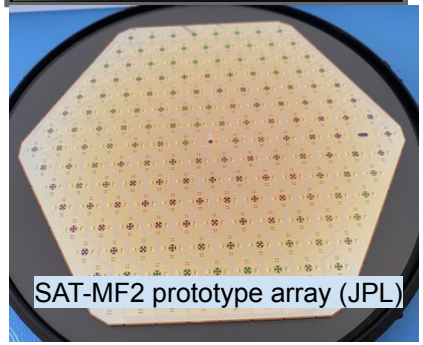
1.03 Detector Subsystem

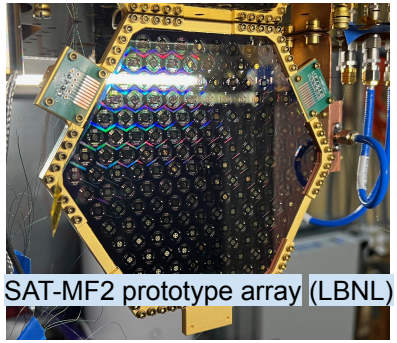

LAT-MF single pixel (NIST)




LAT-MF Prototype Design


LAT-MF prototype array (Argonne)


SAT-MF2 prototype array (JPL)

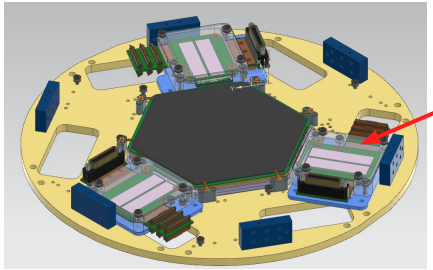

SAT-MF2 prototype array (LBNL)


LAT-LF single pixel fabrication (UCB)


SLAC clean room

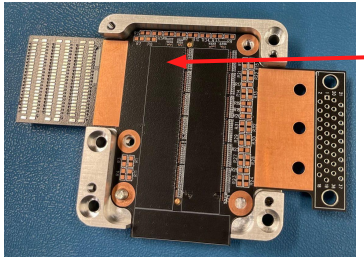
- Multiple fabrication sites proceeding with prototype detector fabrication, single pixel R&D, and clean room installation
- Updating ICD, Requirements, Risk, Schedule and Cost

1.04 Readout Status

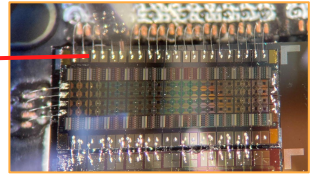


100mK Readout module for <u>testing of detector wafer prototypes</u> on flat detector stage

- first prototype of 2-column, 60-row Readout module with new 2-level row addressing super-conducting mux has been built and is working

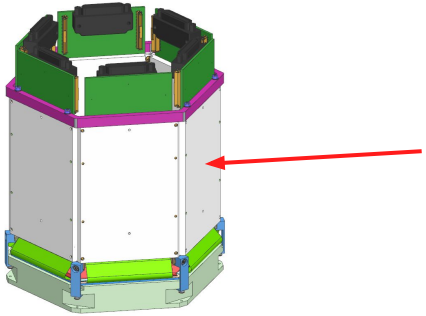


2-column 60-row 100mK RO module with 2-level mux



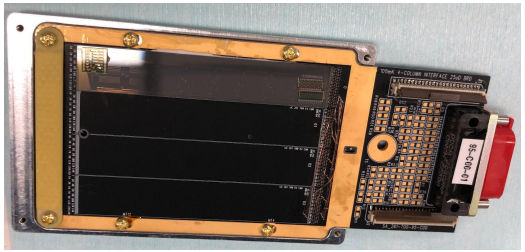
2-level NIST multiplexer chip with 1 chip select and 10 row select channels

Readout integrated into first "flat" detector module prototypes, being tested right now



100mK Readout module for <u>S4 detector tower module</u>

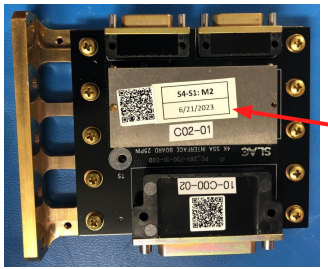
- first prototype of 4-column, 80-row Readout module with new 2-level row addressing super-conducting mux has been built and is working



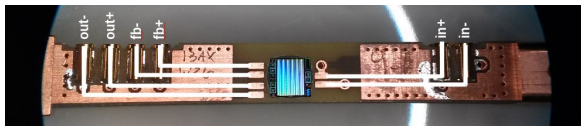
4-column 80-row 100mK RO module with 2-level mux

Readout for the eventual "tower" detector module prototyped

1.04 Readout Status con't

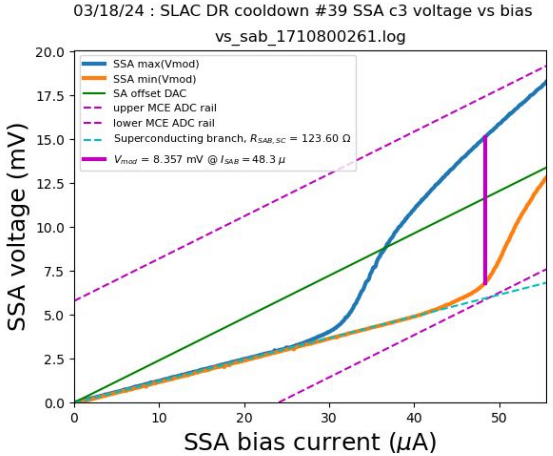


4K: First prototype of new NIST 8-channel SA20 4K SQUID signal amplifier has been received and works. Much larger gain compared to previous version NIST SA13 amplifiers (Vmod of >8mV for a bias current of ~50uA, leads to better system noise performance)

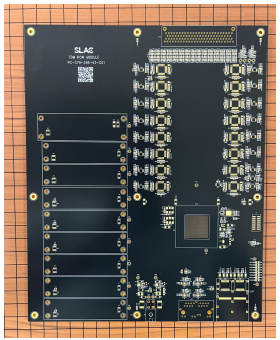


Single channel board with SSA chip (8 per amplifier module)

Higher gain and bandwidth SQUID amplifier designed for CMB-S4 has been tested to meet specs

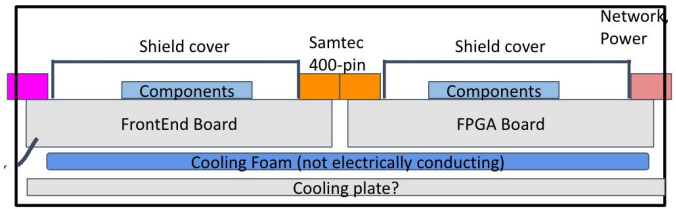


SSA (SQUID Series Array) output voltage as function of applied SSA board current



300K: Rev 0 board: fully operational including firmware. Achieved two-level row addressing operation. Rev 1 targets lower noise

Revision 1 of warm electronics in design. One common FPGA board, two types of front-end modules: column readout and row addressing



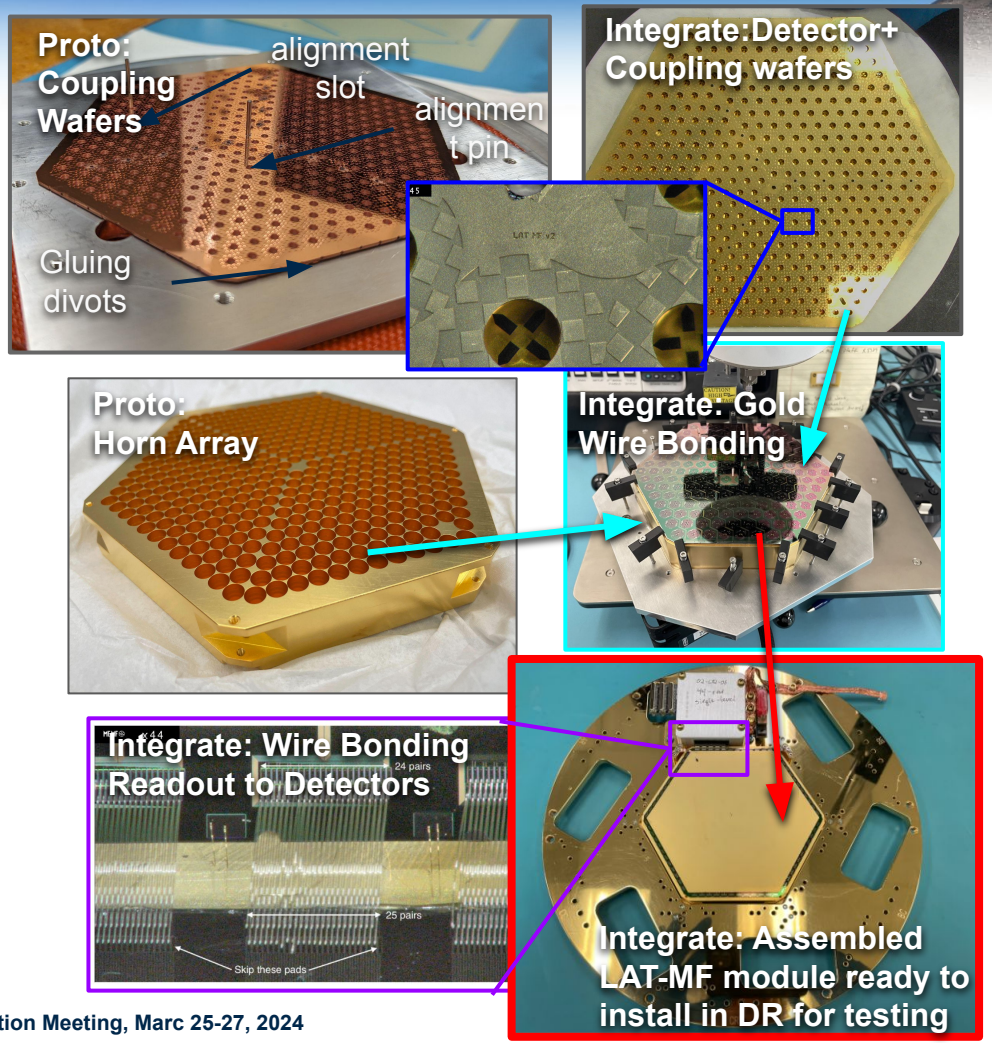
Frontend board (row address or column readout) plugged into common FPGA PCB

New warm readout electronics boards to replace legacy MCE in second iteration

1.05 Modules Update

Three main areas of development:

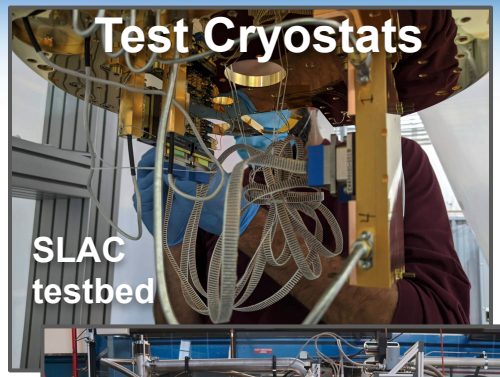
1) **Prototype** module components and **integration** of modules
   a) In the process of design, fabricate, & QA of prototype components (e.g., horn arrays, coupling wafers, module hardware) for LAT-MF, SAT-MF2, and LAT-LF flavors of detector modules.
   b) Both LAT-MF & SAT-MF2 prototype modules have been assembled and tested at 100 mK in a “flat” configuration, with LAT-MF also including prototype “optical coupling” components (i.e., horns, coupling wafers).
   c) Developing QA & testing procedures of proto components as they are built and tested
   d) Aiming for first tests of a prototype “tower” module later in 2024

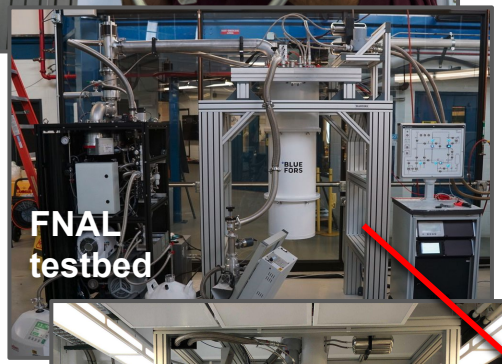


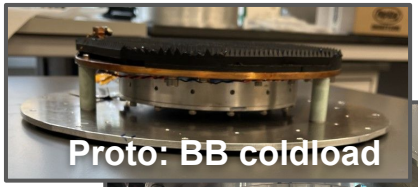
1.05 Modules Update

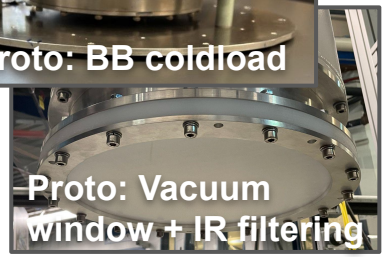
Three main areas of development:

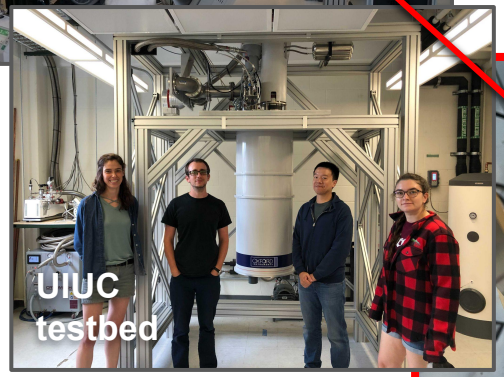
2) Module **test cryostats** and **test equipment**
   a) Have ramped up three DR testbeds to test prototype detector modules at SLAC, FNAL, UIUC using prototype CMB-S4 4K and 100 mK readout electronics
   b) Have designed, fabricated, & QA'ed test equipment, for modules and components (see examples)
   c) Started design of high-throughput cryostat for pre-production (7x) module testing
3) Project Management
   a) Working with L1+L2s on PM updates, for (e.g.) P6 project prototype schedule; risk registry; L2/L3 requirements, ICDs, etc.
   b) ICDs (DET-RO-MOD) has been critical to enable development of first module prototypes
   c) QA procedures (+docs), and JAMA requirements critical for enabling design and verification criteria for components

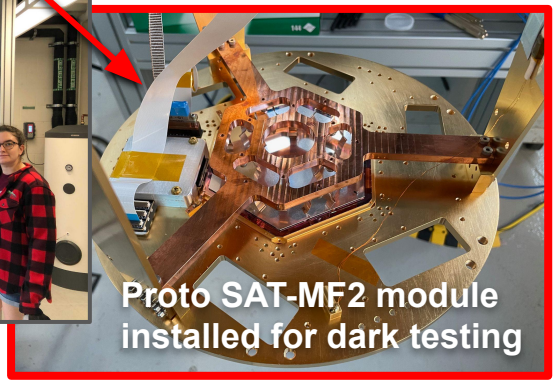








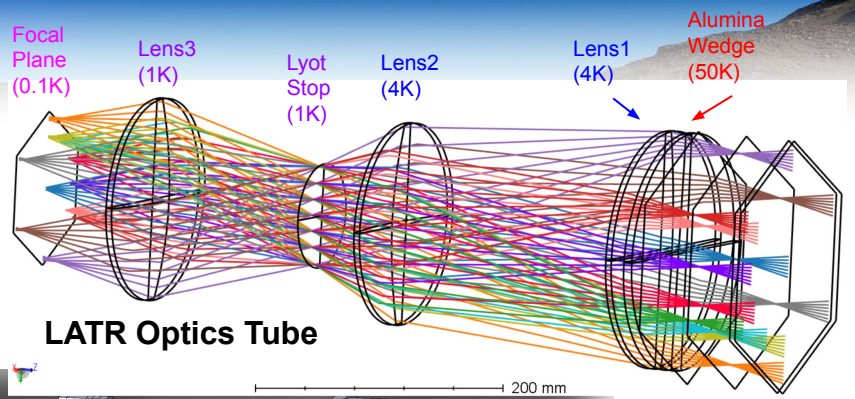




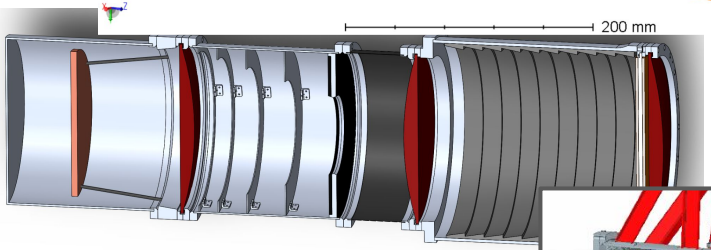
1.06 LAT Status - LATR

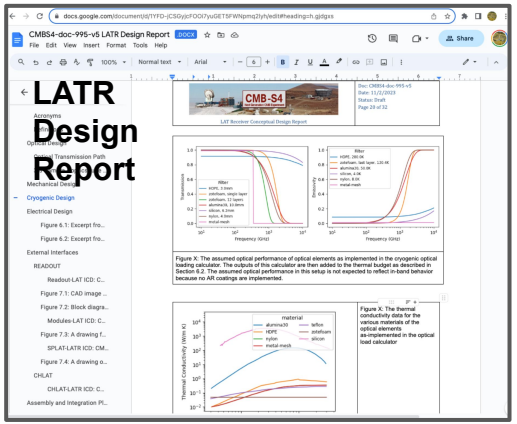
LAT-Receiver (LATR)

- SP-LATR “camera” optical design has been developed, with technical paper published (Gallardo et al. 2022)
- Developing mechanical design and “drawings” of SP-LATR optics tubes, including lenses & mounts, aiming to start fab this year for a set of prototype optics tubes (Harrington)
- Drafted a LATR design report describing high-level design
- LATR cryostat design is continuing, focusing on developing concept designs for key mechanical and thermal components, including:
  - Updating cryostat shell design, to reduce weight (e.g., SS-> Al5083), new readout wiring count, and updated LAT-LATR interface (including total mass table)
  - Updated 300K-50K-4K-1K support structure, performed mechanical and harmonic FEA analysis
  - Updated LATR thermal filtering design, to update mechanical sizing & spacing of components
  - Performed thermal FEA on 100-mK stage to estimate gradients to detector modules
  - Updated overall thermal budget to include updated instrument design (e.g., readout) and temperatures

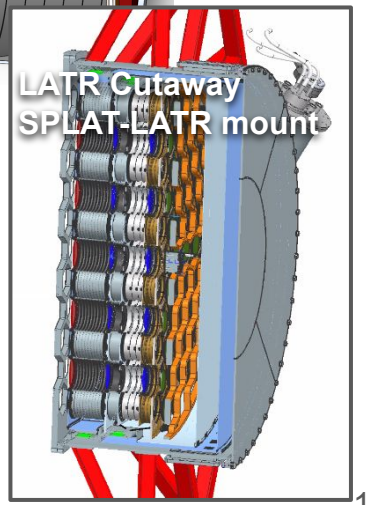


LATR Optics Tube





LATR Design Report

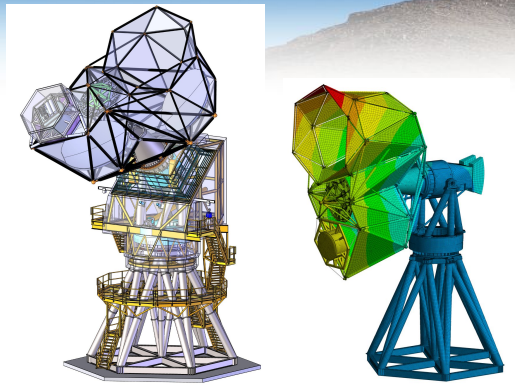


LATR Cutaway SPLAT-LATR mount

1.06 LAT Status - Telescopes

South Pole LAT (SPLAT)

- SPLAT detailed design continues, with significant progress on access structures and the large yoke enclosure
- A test stand is under fabrication to enable inhouse measurement and characterization of the 5m prototype primary mirror
- Telescope Global Finite Element Model under development to help characterize telescope optomechanical performance
- Three SPLAT-related papers published on the prototype mirror fabrication, sidelobe modelling, and optical analysis of the TMA



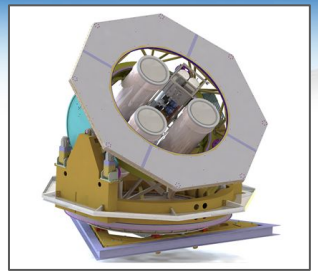
CAD and Finite element models of the SPLAT

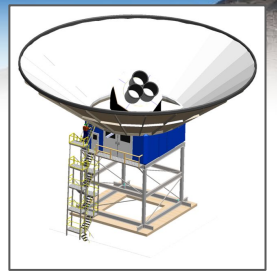
Ongoing fabrication of prototype mirror test stand

Chile LAT (CHLAT)

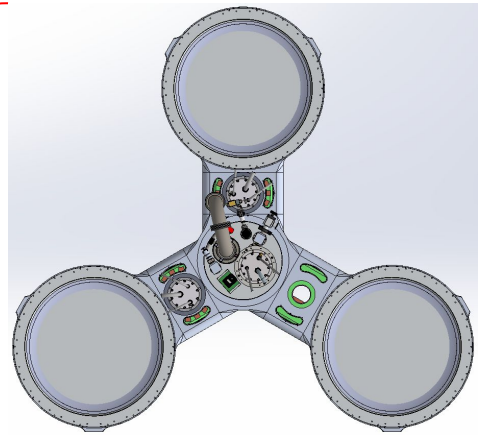
- Simons Observatory and CCAT/FYST telescopes of the same design as the CHLAT are under construction
- Simons Observatory LAT has been assembled in Chile, except the mirrors that are now being completed in Germany, and is now undergoing motion tests with the SO LAT Receiver
- CCAT/FYST test build is well underway in Germany, and mirror integration will be completed there before shipping to Chile

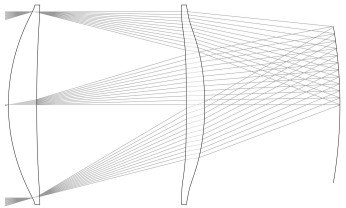
1.07 SAT Status, March 2024



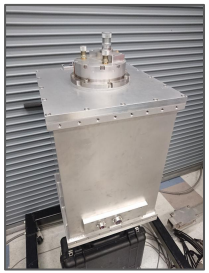


- **Management**
  - Added CAM / Lead Engineer Joe Silber (DESI, STAR-HFT)
  - Fresh bottom-up estimate completed Nov 2023
  - Risks refreshed, requirements internal review process
- **Cryostat**
  - 3-arm design → modularity improved
  - thermal feasibility analyses performed for 2 pulse tube coolers (stays within site power constraints)
- **Optics, I&T**
  - Preliminary test plan in development
  - Coordinating with CfA's off-project PreSAT work, to encourage progress toward CMBS4-applicable development





Design



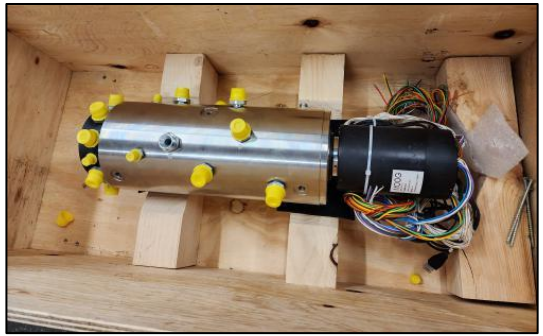
Pulse tube testing

Magnetic pickup

Holography

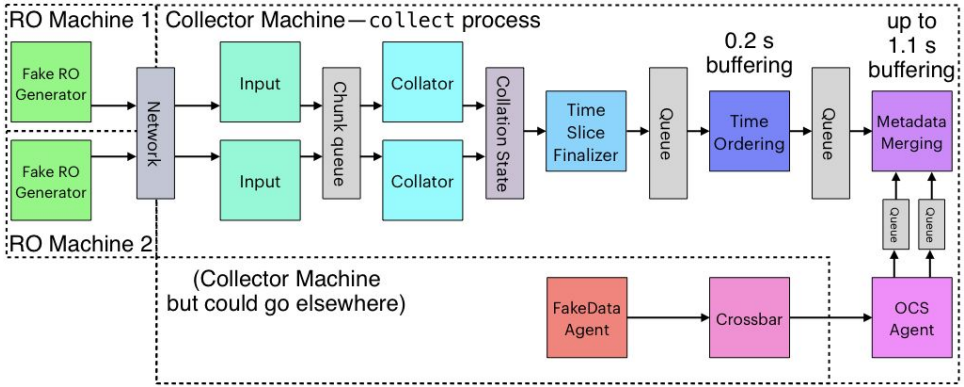
1.07 SAT Status, March 2024

- Calibration Equipment
  - LN2 hold test of aperture-filling load, fabricate forebaffle extension
  - Fourier Transform Spectrometer design work
- Telescope Shields
  - Developing test program (propose new anechoic chamber at BNL), address recommendations on forebaffle and ground shield
  - Interface development with South Pole sites group
- Telescope Mount
  - New prototype helium rotary joint received
    - In-progress testing → key risk retirement
  - BART tower and mount fabrication and integration
    - CMB-S4 compatible
    - And will in fact be used for 1 of 3 SAT assemblies



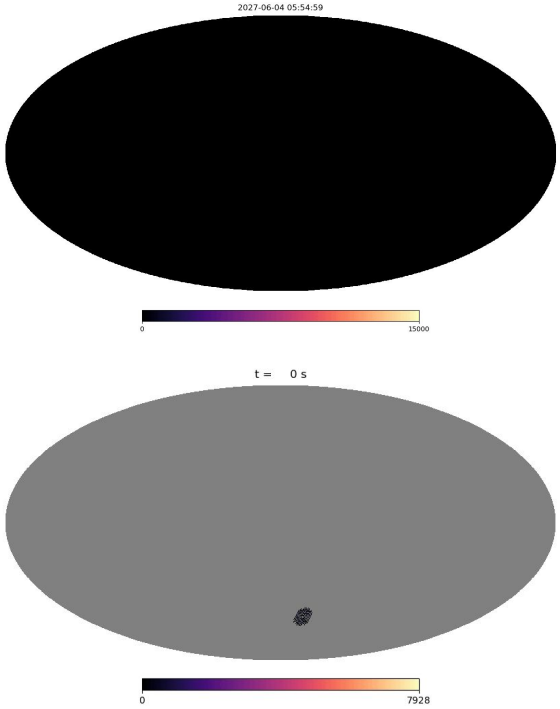
WBS 1.08 DAQ and Control

- Refining of high-speed data collector prototype
- Work continues on OCS interface for control of Readout
- Prototype OCS Agent for Dilution Refrigerator
- Meetings with Lab users to determine and prioritize needs for OCS for control and monitoring of test stands
- We benefit from synergies with work going on for SO, whose DAQ is quite similar to ours.



1.09: Data Management

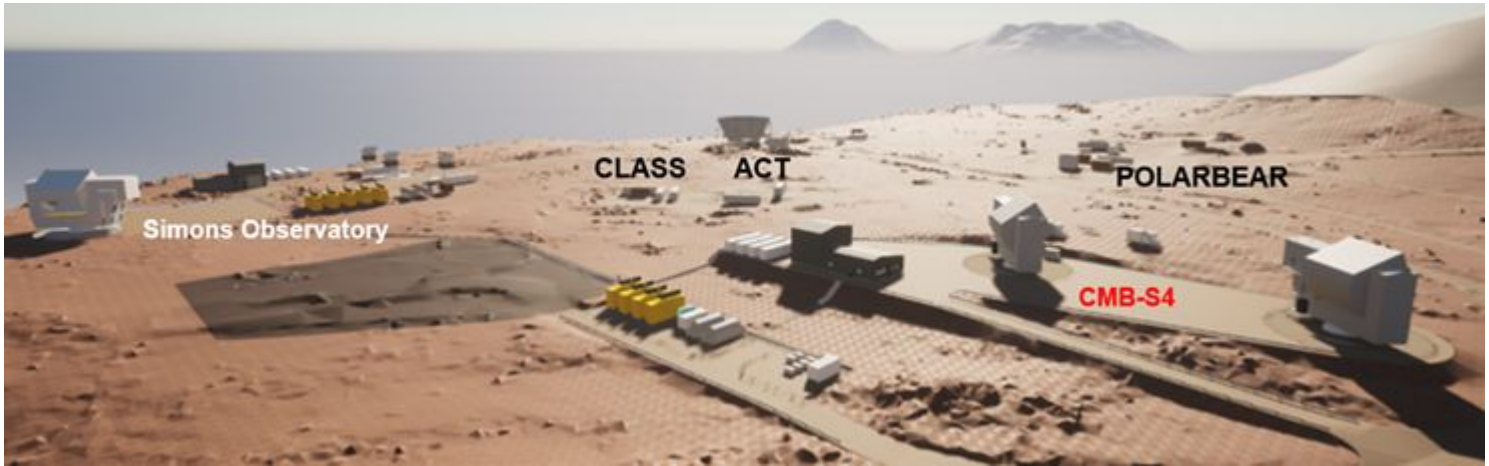
- Completed Data Challenge 0
  - 1 year of time-ordered data from all telescopes
  - Reduced to maps of each observation (~hourly)
  - Combined & rescaled to full mission maps with multiple data splits (1-, 2-, 4-, 8-, 16- & 32-way)
  - Validated that current point design meets measurement requirements
- Exercised SPT transient detection software on DC0
- Rescoped South Pole compute systems to fit new power constraints
- Building prototype Data Registration system (Rucio) for Data Challenge 1
- Identifying extensions required for Data Challenge 2
  - Systematics
  - Calibration campaigns
- Working on all necessary documentation for possible upcoming reviews



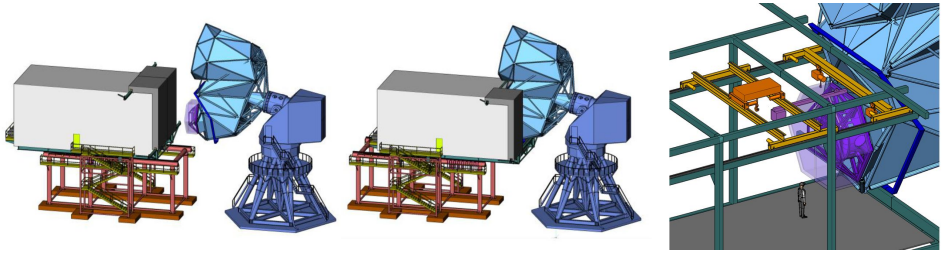
DC0 CHLAT & SPSAT Surveys

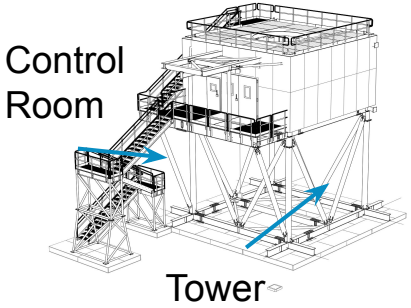
1.10 Chile Infrastructure, Integration & Commissioning

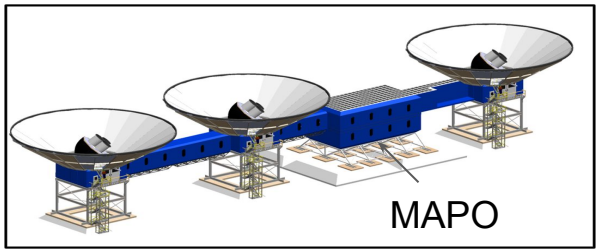
- Scope: Local management of all Chile-based activities:
  - legal structure, regulatory compliance, human resources, vendor contracts, local procurements, broader impact, etc.
  - design and construction of infrastructure at the Chile site, including safety, health & environment
  - integration and verification of the two Large-Aperture Telescopes
- All aspects are proceeding well, based on the extensive experience with previous and current observatories: ACT, POLARBEAR, CLASS, CCAT', SO, …
- Highbay, earthworks, roads, and site master plan all created and costed by a Chilean architect
- Power generation baseline will be a hybrid diesel and photovoltaic



1.11 South Pole Infrastructure, Integration & Commissioning







- Preliminary design of high bay complete
- BART tower design adopted for SAT towers
- MAPO interior plan in development
- Conceptual design of renewable energy hybrid system started

Working groups are Thursdays, 3pm central, ~every other week.
Everyone is welcome. southpolesite@cmb-s4.org #southpolewg

Interactions with the Funding Agencies

Interactions with NSF

We are working regularly with our NSF contacts but challenges remain, e.g.,

- OPP not yet engaged with CMB-S4 on South Pole logistical planning.
- Polar Journal article, which paints an extremely negative picture of the Antarctic infrastructure situation, is being used as an excuse to delay science
- Challenging NSF FY 2024 budget means the 2nd year of our Continuing Design Cooperative Agreement will likely be less than the full proposed amount.
    - The NSF Research and Related Activities funding for all Science Directorates is down 6% in the FY 2024 appropriation.

Interactions with NSF

But there are some positive movements:

- New Acting Director of OPP: Jean Cottam. She was the Deputy Head of Physics and has strong background in astroparticle science.
- OPP has asked BICEP to plan for initiation of the construction of BART at the South Pole and a related plan to raise the MAPO laboratory building.
- Internal NSF Memo to enter CMB-S4 into the MF Design Stage is being actively iterated among MPS, GEO and the Director's Office (CORF). Once approved, a CDR can be scheduled. We are expecting CDR by end of CY24.
- There is pressure to recapitalize the LC-130 fleet:
  - Authorization legislation passed – but not appropriations yet.
  - Letter from Senators Schumer and Gillibrand to the Secretary of the Air Force: "we urge you to prioritize the recapitalization of the LC-130 fleet."

Interactions with DOE

DOE leadership (Gina Rameika, head of HEP, and Harriet Kung, Acting head of the Office of Science) continue to support CMB-S4.

- They are setting up a meeting with NSF management (heads of MPS, MPS/AST, GEO, GEO/OPP and the Chief Officer for Research Facilities) to work on moving CMB-S4 forward.
- They are looking for confirmation that NSF is on board, particularly regarding access to the South Pole.
- However, they are being cautious about investing in CMB-S4 until they are convinced that NSF will move forward with them.
    - The FY 2024 appropriation cuts HEP research by 5%, which doesn't help.

Interactions with DOE

- FY 2024 funding is tough:
  - Funding of $3M was received in October 2023.
  - This is substantially less than the budget guidance of $9M that we had been given up until November 2023.
  - Additional funding may be provided from the FY 2024 appropriations just passed, but the amount is not clear. Until it is known, we cannot plan on it.
- Supplemented by carryover of $5.5M from FY 2023 (mainly FY22 IRA funds) => Total funding available for FY 2024 = $8.5M.
- We have adjusted the project plan to fit within this reduced funding and still make progress. Focus is on CDR readiness; CD-1 readiness delayed.
- We will adapt further once we know the final FY 2024 funding level.

Interactions with DOE

- FY 2025 funding is potentially difficult.
  - The President's Budget Request for CMB-S4 is $4.5M.
  - Of course, the PBR is just the start of the budget process; the final word comes from the Congressional appropriations bills, which we can work to influence. See below.
  - We are developing plans for how to best adapt to the FY 2025 funding level, which will be presented by all the labs at budget briefings next month.
  - We have already made DOE/HEP aware of the potential impacts to the progress of CMB-S4 if this becomes the FY 2025 funding level.
  - We have also advocated to DOE/HEP that substantial additional funding this year, some of which could be carried over to FY 2025, would help maintain progress.

How are we addressing these challenges?

- Continuously remind the funding agencies of the high priority of this science – so they know why to support it and the scientific consequences if they do not.
- Continuously remind them of the advanced state of project planning.
- Make clear to the funding agencies what funding we need to keep moving forward.
- Continue to emphasize our readiness to work with OPP and the flexibility of our plans to fit within their constraints.
- We are working with our congressional delegations and institution government affairs liaisons to ensure that the challenges with South Pole Infrastructure and Logistical Support and their impact on science are understood at the highest levels.

How are we addressing these challenges?

- Periodic briefings for Congressional staff regarding CMB-S4, jointly organized by LBNL and UChicago Government Relations offices. The next set of briefings are planned for this Spring.
- CMB-S4 to participate in April APS and AAS congressional visits in April. The official APS/DPF Ask is to support:
  - The P5 priorities, including specifically CMB-S4;
  - $1.385B for DOE/HEP (vs. $1.200B FY24 enacted and $1.231B in the FY25 PBR);
  - $11.9B for the NSF (vs. $9.06B FY24 enacted and $10.183B in the FY25 PBR).

Summary

- CMB-S4 has made excellent technical progress, as recognized the the Director's Review.
- P5 recommends CMB-S4 as the highest priority new project for HEP.
- The Project planning puts us in an excellent position for a successful NSF CDR and later a DOE CD-1 Review.
- There is progress toward NSF placing CMB-S4 in the Design Stage, which will lead to scheduling a CDR.
- Change in leadership of OPP may lead to more effective implementation of the needed infrastructure recapitalization and to more engagement with us and other South Pole experiments.
- Federal funding is very challenging; but we are doing all we can both to manage within the constraints and at the same time to remove (or at least improve) the constraints.