Project Status

Jim Strait (he/him)
LBNL, Project Director

Collaboration Meeting, April 3, 2023

CMB-S4

Outline

- Analysis of Alternatives is Complete
- P5
- Funding and Budget
- Technical progress
- Moving forward

Major Accomplishment of the Past Year: The Analysis of Alternatives

A key event since the last Collaboration Meeting has been the completion of the Analysis of Alternatives.

- The AoA has been completed, establishing a new Preliminary Baseline Configuration
- This was a nearly year-long effort that involved many from the Collaboration and the Project.
- This was an excellent piece of work, which added real understanding of the strengths, weaknesses, risks and opportunities of different ways to configure the experiment.
- Many thanks to all who contributed to this important work.

Analysis of Alternatives

The AoA identified several alternate configurations to the original Preliminary Baseline Design* that

- reduce the impact on and demand for South Pole infrastructure and logistics relative to the previous Preliminary Baseline Design
- can achieve the science goals of the experiment.

A thorough and rigorous process was followed:

- Full involvement of both the Project and the Collaboration
- For each Alternative considered, the analysis evaluated:
  - the science capabilities,
  - the total time and cost needed to construct and operate the experiment,
  - the required South Pole infrastructure and logistics, and
  - scientific and technical risks.

*Preliminary Baseline Design Report, Feb 2022, CMBS4-doc-716-v4, https://docdb.cmb-s4.org/cgi-bin/private/ShowDocument?docid=716

Review by External Committee

Both the AoA process and its conclusions were subjected to review by an External Committee: S.Kahn (UCB, Chair), M.Halpern (UBC), V.Kalogera (NWU), C.Lawrence (JPL), H.Moseley (QCI), A.Sargent (Caltech)

- The Committee included experts in cosmology, astrophysics, CMB measurement methods, and project management.
- The Committee concluded that:

  “The Project Team presented credible options that meet the science requirements of CMB-S4 with a range of impact on the South Pole resources. This study provides a strong foundation for an informed development of a program with the agencies.”

Choosing among the Alternatives

Following an initial scoping exercise in which a broad range of options was considered, three main alternatives to the Current Project Baseline were chosen for detailed analysis.

The studies revealed a clear priority ordering in terms of
- science capabilities,
- observing time,
- comparative cost, and
- scientific and technical risk.

Alternative	South Pole Scope	Chile (Atacama) Scope	Comparative Project Cost (*Pre CD-1/CDR*)
Previous Project Baseline	6 Small-Aperture Telescopes 1 Large-Aperture Telescope	2 Large-Aperture Telescopes	$930M
Alternative 1: SATs & LAT at South Pole	3 Small-Aperture Telescopes 1 Large-Aperture Telescope	2 Large-Aperture Telescopes	$770M
Alternative 2: Only SATs at South Pole	4 Small-Aperture Telescopes	3 to 5 Large-Aperture Telescopes	$780M to $940M
Alternative 3: Nothing at South Pole		≥9 Small-Aperture Telescopes ≥3 Large-Aperture Telescopes	≥$840M

Selection of the Preferred Alternative

Alternative 1 is the clearly preferred alternative

3 SATs (9 optics tubes) + 1 LAT at the South Pole; 2 LATs in Chile

- It is scientifically superior and lower risk relative to the other alternatives.
- The time needed to reach the inflation science goal is the shortest
- Its construction and lifecycle costs are lowest.

Alternative 2 is a viable backup if Alternative 1 cannot be accommodated

4 SATs (12 optics tubes) at the South Pole; 5 LATs in Chile

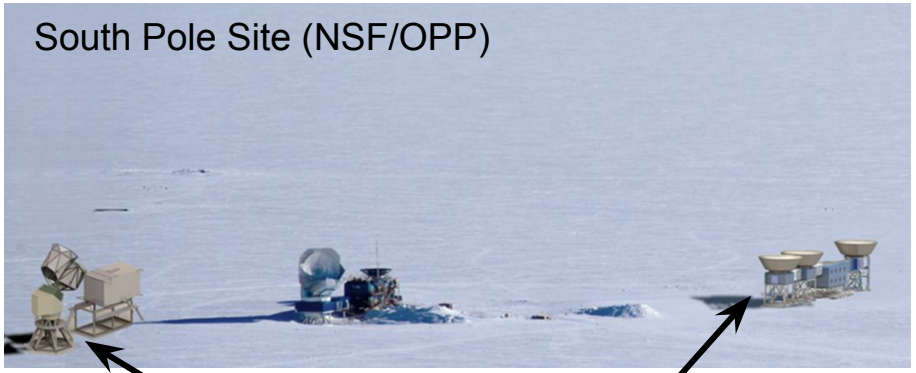
- It retains some of the scientific and risk benefits of observing from the Pole.
- Higher cost and longer observing time are required than for Alternative 1.
- It offers fewer systematic error cross-checks than Alternative 1, increasing scientific risk.

Alternative 3 could offer a way to make the measurements, if we are unable to access the Pole.

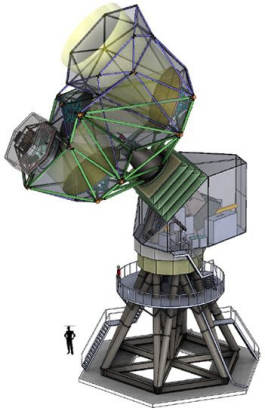
9 SATs (27 optics tubes with half-wave plates) and 3 LATs in Chile

- It has the highest scientific risk that the inflation science goal would not be met.
- Longer observing time are required than for either of the other two alternatives.
- Its lifecycle cost is higher than Alternative 1 and comparable to Alternative 2.
- It has additional technical risk and possibly longer development time.

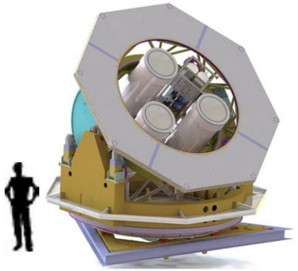
New Preliminary Baseline Design (Alternative 1)

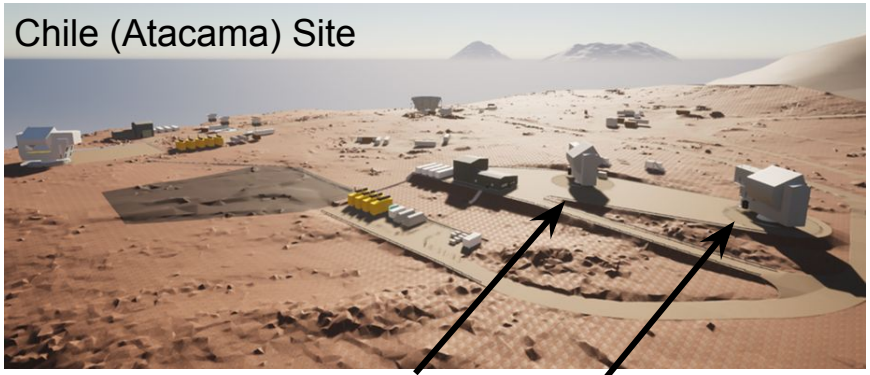


1 Large Aperture
(5 m) Telescope

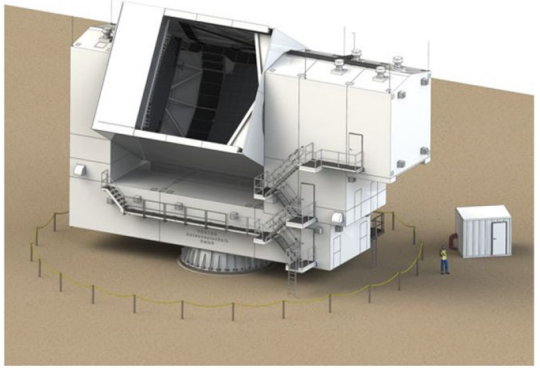


3 Small Aperture Telescopes
(9 0.5-m aperture optics tubes)

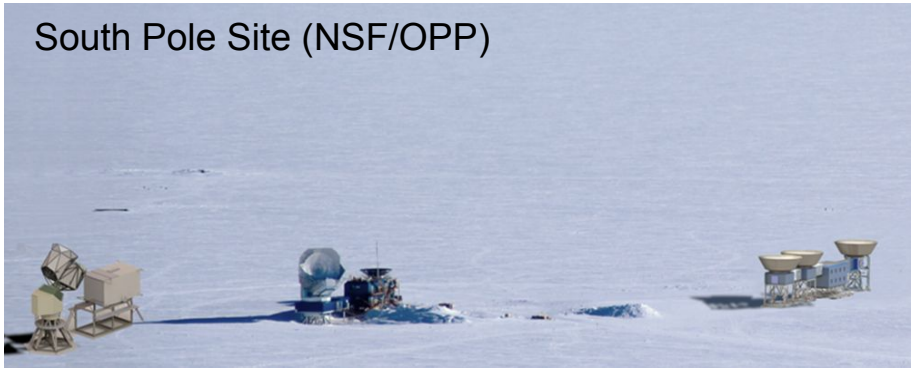


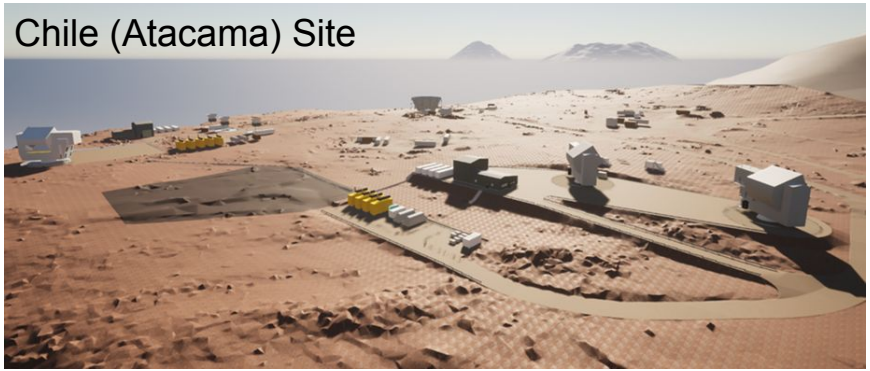


2 Large Aperture (6 m)
Telescopes



New Preliminary Baseline Design (Alternative 1)





This is the optimal configuration (within constraints) because:

- The South Pole offers the best observing conditions for the ultra-deep survey that focuses on the inflation science.
- The combination of small- and large-aperture telescopes observing the same patch of the sky provides unique checks on systematic errors.
- The Atacama site in Chile provides excellent conditions for the deep, wide-field survey with 2 large-aperture telescopes that addresses N_{eff} and many other science goals.

This configuration is being developed for an NSF CDR and DOE CD-1.

South Pole Infrastructure Considerations

The new Preliminary Baseline Design aligns better with the existing logistics and infrastructure constraints at the South Pole, including power, fuel, cargo and people.

The power required at South Pole for this configuration (~170 kW) modestly exceeds that of the existing CMB experiments (~140 kW).

We are pursuing options for ensuring the ability to power the full configuration within the constraints at the South Pole:

- Seek further power efficiency opportunities.
- Use renewable energy and energy storage.

As part of the engineering development of the CMB-S4 Conceptual Design for NSF CDR and DOE CD-1, we are engaging with the NSF Office of Polar Programs to more precisely understand the constraints and incorporate them into our project design.

Renewable Energy at the South Pole

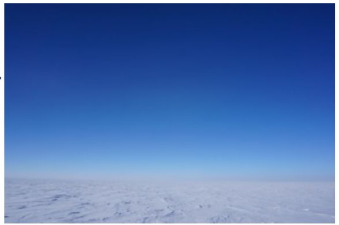
A feasibility study done by Argonne in collaboration with NREL indicates that a combination of solar, wind and energy storage could be a viable way to ensure the ability to power all of the telescopes at the South Pole, while also reducing the carbon footprint and saving on operating and life-cycle costs.

CMB-S4 is investigating including this as part of the project plan.

Specific implementation for CMB-S4 to be coordinated with NSF/OPP.

Details in Amy Bender's talk on Tuesday.

RENEWABLE ENERGY IS VIABLE AT THE SOUTH POLE



- A **significant reduction in carbon footprint and savings of 10s of $M in cost of operations** is possible using mature renewable energy technology.
  - Payback time on capital investment is ~ 2 years
- **Technical risks and developments are identified**
  - Primary risk is durability in extreme environment
  - Risks can be mitigated with engineering development and eventual demonstration
- Implementation can be extremely flexible and staged
  - Even a minimal system can reap economic benefits while retiring technical risks
- We welcome engagement from NSF-OPP!

ENERGY 11 Argonne

Argonne NATIONAL LABORATORY

Susan Babinec (energy storage)
Amy Bender (CMB experiments, S. Pole)
Ralph Muehleisen (solar modeling & system design)
Rik Yoshida (HEP experiments)

NREL Transforming ENERGY

Ian Baring-Gould (wind modeling)
Nate Blair (economics)
Xiangkun Li (system optimization)
Dan Olis (system optimization)
Silvana Ovaitt (solar modeling)

Documenting the AoA

It is important that we document the AoA and its outcome.

- The AoA represents a significant piece of scientific and technical work that should be recorded for our own use and the benefit of others.
- A documented alternatives analysis is a requirement for DOE CD-1.

Partial and preliminary documentation exists:

- Internal Vetting of Analysis of Alternatives (https://indico.cmb-s4.org/event/35/)
- External Review of Analysis of Alternatives (https://indico.cmb-s4.org/event/38/)
- Briefing to DOE and NSF (https://indico.cmb-s4.org/event/44/)
- Revised Preliminary Baseline Configuration of CMB-S4: Conclusions from the Analysis of Alternatives (CMBS4-doc-864) – includes many references to Confluence pages written during the AoA.

P5

The Particle Physics Project Prioritization Panel has been charged [1] by the Director of the DOE Office Science and the Director of the NSF Directorate of Mathematics and Physical Sciences (MPS) “to develop an updated strategic plan for U.S. high-energy physics that can be executed over a 10-year timeframe in the context of a 20-year, globally aware strategy for the field.” “We would appreciate the panel's preliminary comments by August 2023 and a final report by October 2023.”

The 2014 Report [2] from the previous P5 in 2014 was very important in placing CMB-S4 on the US HEP roadmap. The new P5 will be equally important for us.

More info in Hitoshi Murayama’s presentation to the February Town Hall at LBNL[3] and at http://hitoshi.berkeley.edu/P5/.

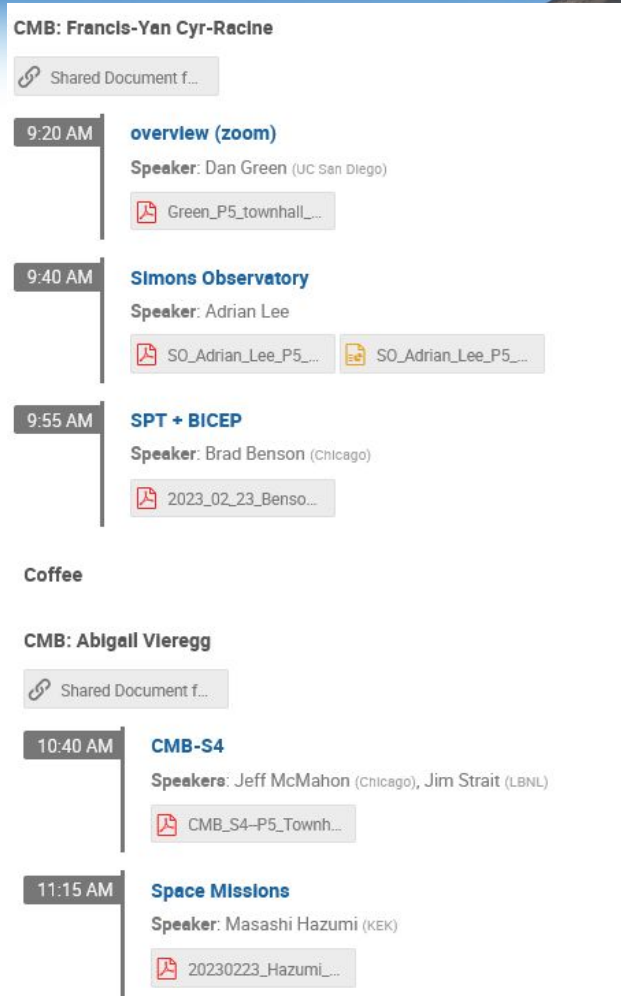
[1] https://science.osti.gov/-/media/hep/hepap/pdf/202212/2022-601_Charge_Letter_P5-2022_AAB_and_SJ_Signed.pdf, https://science.osti.gov/-/media/hep/hepap/pdf/202212/Rameika_P5_Charge_HEPAP_202212.pdf.
[2] https://www.usparticlephysics.org/wp-content/uploads/2018/03/FINAL_P5_Report_053014.pdf
[3] https://indico.physics.lbl.gov/event/2382/contributions/7551/attachments/3728/4984/LBNL.pdf

P5 Town Hall at LBNL

Feb 22-24, 2023

The meeting [1] concentrated on the Cosmic Frontier: Dark Matter, Dark Energy, CMB, Cosmology, …

- 2-hour session on CMB made a coherent and powerful case for CMB science as a crucial part of HEP and that CMB-S4 is the right way to pursue it.
- We requested that P5:
  - Reaffirm the recommendation of the 2014 P5 report to “Support CMB experiments as part of the core particle physics program.” and the recommendation of Astro2020 that NSF and DOE “should jointly pursue the design and implementation of … CMB-S4.”
  - Endorse the importance of the broad and unique contributions to particle physics to be made by CMB-S4 and support its timely construction and operation.



[1] https://indico.physics.lbl.gov/event/2382/

P5 Interactions

Interactions with P5 members have been generally quite positive. In the formal Q&A and informal discussions with P5 members, topics of interest included:

- renewable energy
- operations costs
- international contributions
- technology spin-offs
- schedule for needing MREFC funds.
- logistics and infrastructure constraints
- when we need access to the South Pole
- reasons for the particular configuration of telescopes
- NSF vs DOE funding.

NSF made a closed-door presentation to P5 on South Pole logistics after the open Town Hall sessions.

- This has generated concerns within P5, which we are addressing so far through personal contacts and informal discussions.
- We have requested an opportunity to address the concerns to P5 in a more formal way.

P5 Cost Subcommittee

The formation of a Cost Panel was announced at the LBNL Town Hall.

This should be good for CMB-S4, since our cost and schedule estimates are well advanced and can stand the scrutiny as well or better than any of the other initiatives.

Costs

- One lesson from the previous P5 was some of the costs were off by a factor of ~π
- Need to understand maturity of cost estimates better
- We are putting together another expert panel to look into costs, risks, schedule
- Chair: Jay Marx (STAR, LIGO)
- That panel will ask for inputs from collaborations in March
- We will receive their assessment by May

Jay Marx

Funding and Budget

Funding

- DOE funding for FY23 = $11M ($10M from the Inflation Reduction Act)
- DOE request for FY24 (part of the President's Budget Request) is $9M
- No formal decision yet on the 3-year NSF Continuing Design Proposal, but there is good reason to expect that 1st year funding ($3.7M) is imminent.

CMB-S4 budget and plans for FY23

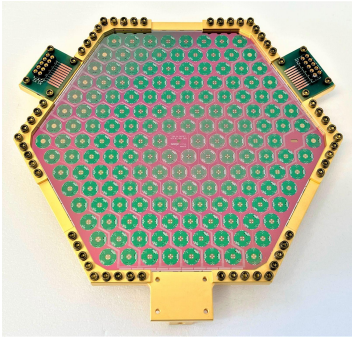
- Funds are being allocated to collaborating institutions to support the highest priorities, i.e. work needed to be ready for an NSF CDR and parallel DOE pre-CD-1 progress review.
  - Project controls
  - Project documentation
  - Internal reviews
  - Engineering to support review scope
  - Readout electronics and modules to permit full detector wafer testing
  - Keeping other efforts moving as possible and maintaining support for key people

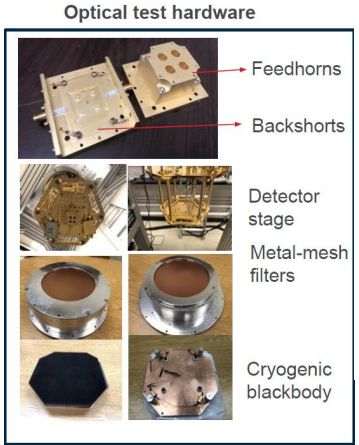
Technical Progress

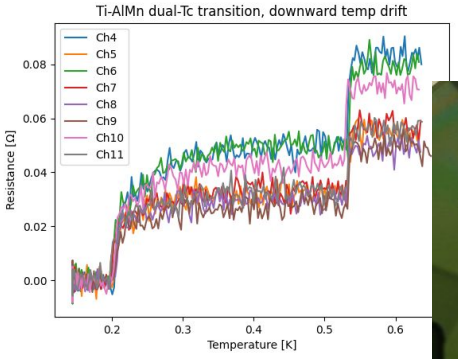
Beyond all of the politics, there has been a lot of technical progress. The following are a few (quasi-random) highlights drawn from tomorrow's talks.
This is far from a comprehensive review of progress!!

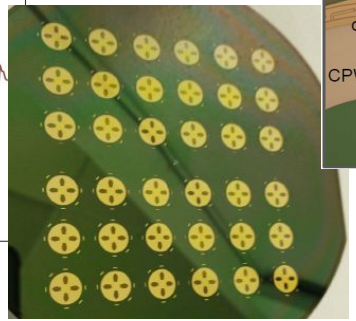
Detectors

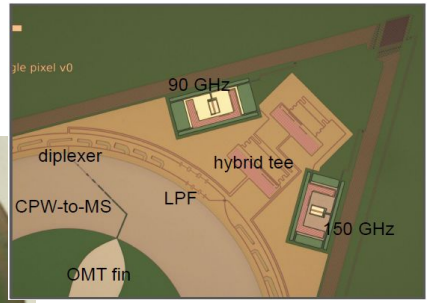
- First SAT MF2 wafers delivered by SeeQC, awaiting testing. Argonne (LAT MF), JPL (SAT MF2), NIST (LAT MF), UCB (LAT LF), all of whom have made arrays for other experiments, are moving toward fabricating CMB-S4 arrays.







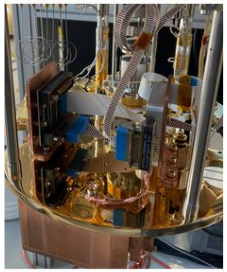




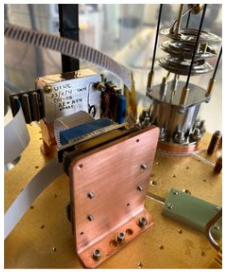
Technical Progress

Readout:

100 mK and 4K readout electronics for module testing delivered from SLAC to FNAL and UIUC

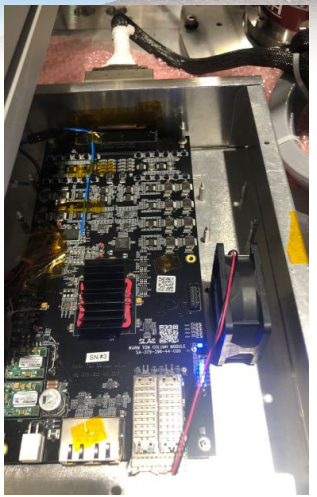


100 mK Readout in FNAL cryostat

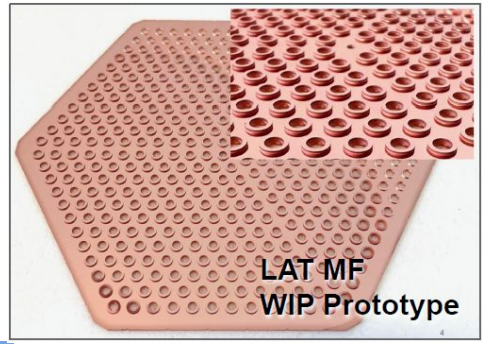


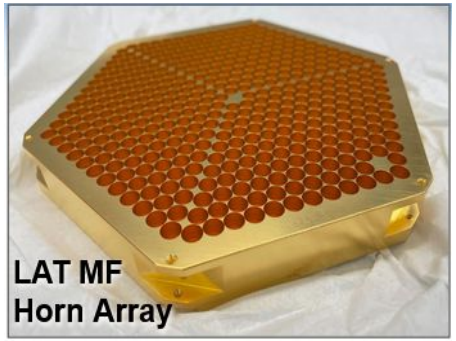
100 mK Readout in UIUC cryostat

Prototyping 300 K electronics



Modules: LAT MF horn array and 1st prototype coupling wafer sets delivered to Fermilab; dummy assembly of flat module

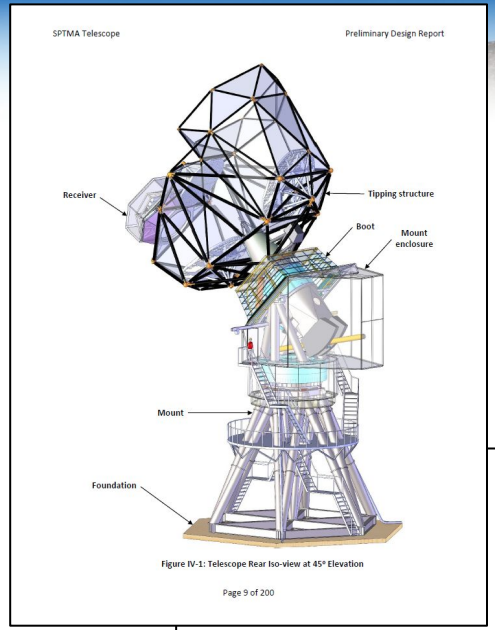


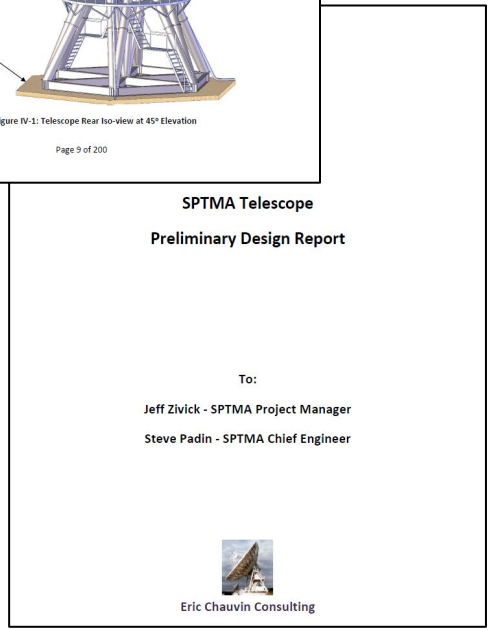


Technical Progress

SPLAT / TMA: Preliminary Design Report completed and several papers are in preparation or have been submitted for publication:

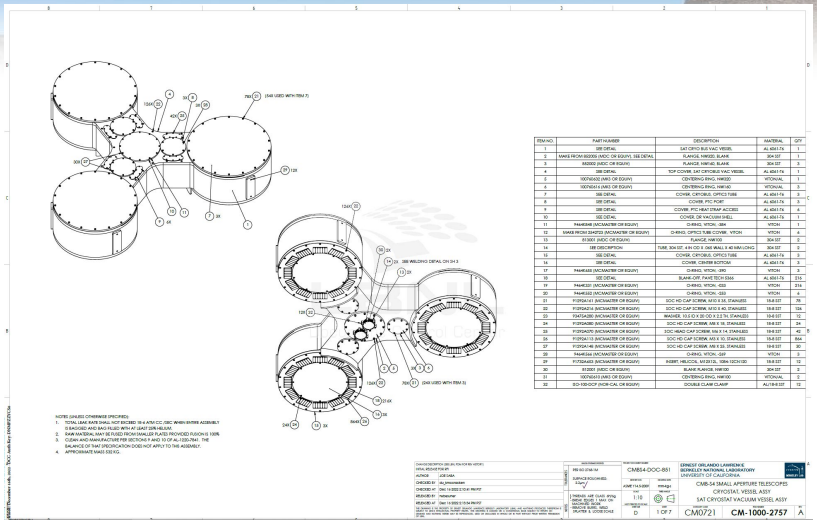
- Preliminary Design Report, CMBS4-doc-790-v3, Sep 2023
- LAT overview - Gallardo et al. 2022 SPIE Proceedings
- Gapless mirror prototype - Natoli et al. in review at Applied Optics
- TMA sidelobes and baffling prototype - Gullett et al. 2023 arXiv:2302.10971
- SPLAT TMA and LATR Optics design - Gallardo et al. 2023 in collaboration review



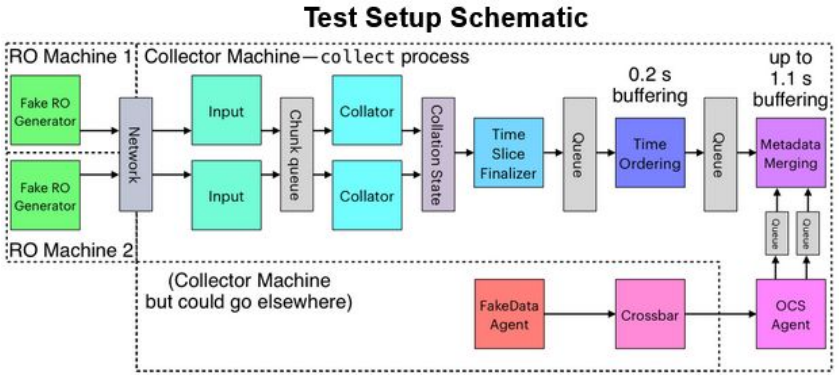


Technical Progress

SAT: RFI (Request for Information) for SAT Cryobus submitted to potential vendors. Discussions with potential vendors are under way and one bid has been submitted.



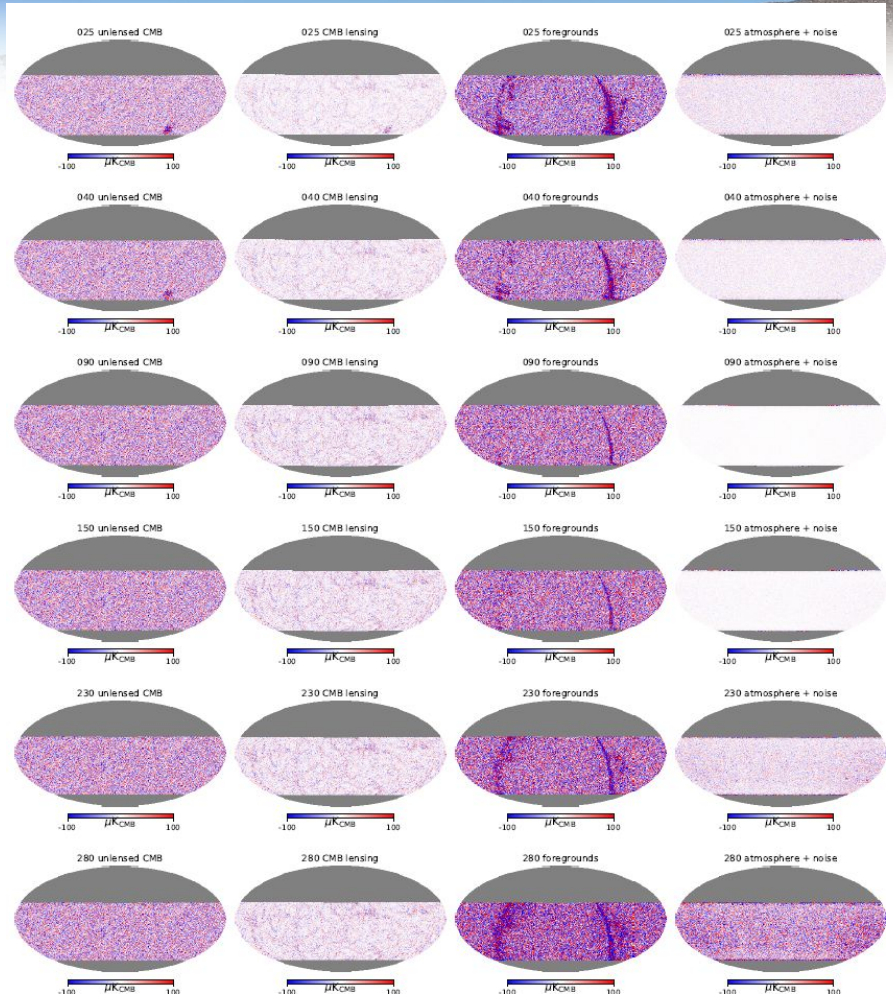
DAQ: High-speed data collector prototype



Technical Progress

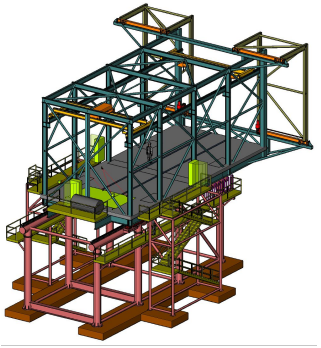
Data Management: Data Challenge 0 CHLAT data delivery – 4 components x 6 frequencies for the CHLAT.

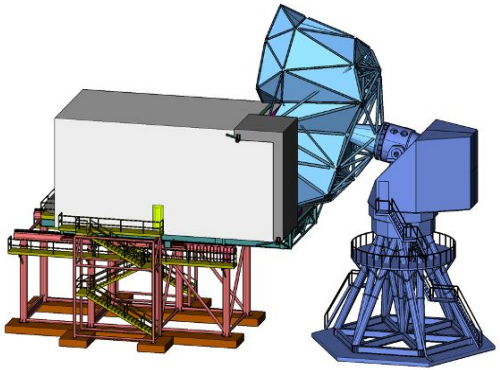
See Simulations and Data Challenge session on Wednesday



Technical Progress

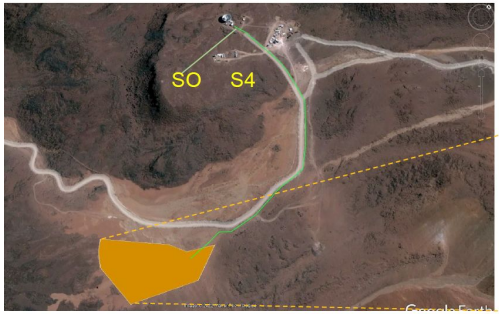
South Pole Site: LAT High Bay
Preliminary Design complete

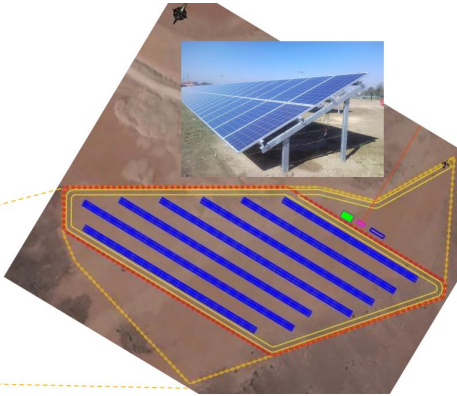




Chile Site: Planning Photovoltaic Array

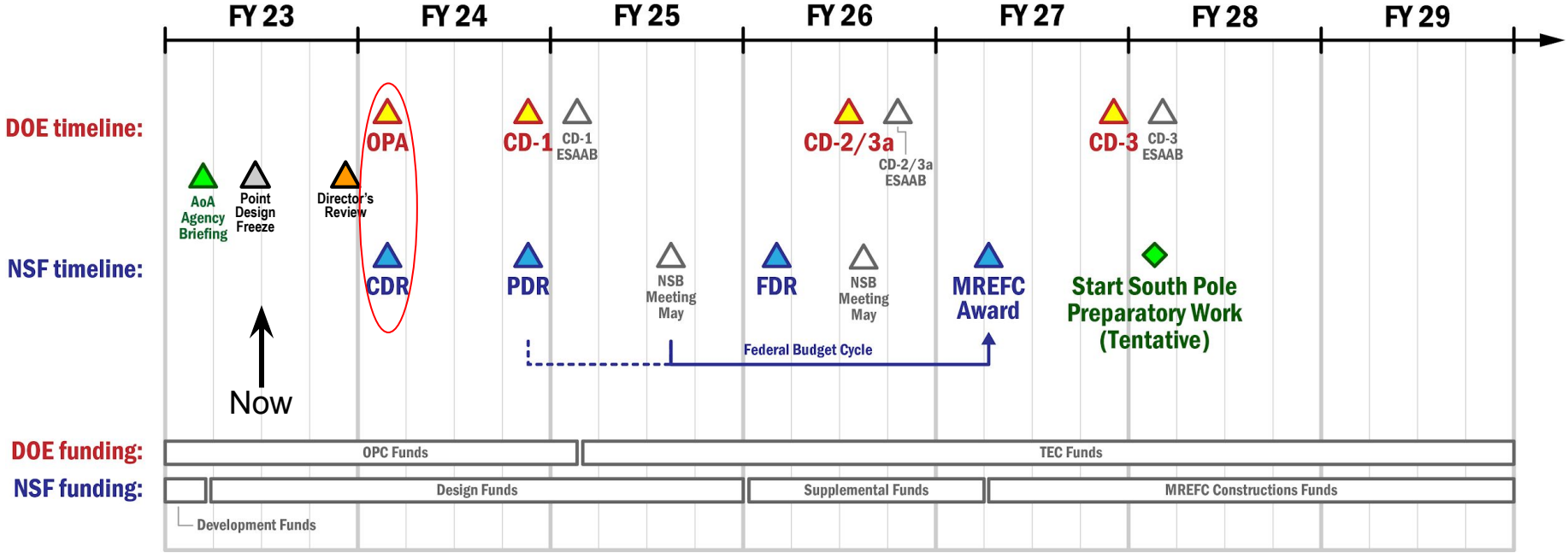
SO = 340 kW
S4 = 314 kW





Moving Forward

We aim to maintain the timeline shown last summer. The major target is to be ready for an NSF Conceptual Design Review and parallel DOE Progress Review whenever they are scheduled by the Funding Agencies.



More timeline details in Matthaeus' talk on Wednesday "Status of New Project Baseline Development"

Moving Forward

We have most of the information needed for the upcoming reviews, but there is plenty of work to be done to be fully ready and to finalize documents required for NSF CDR and draft documentation for DOE CD-1, e.g.,

- Validate point design for CDR/OPA review
- Update resource loaded schedule and basis of estimate documents
- Update and release Requirements, ICDs, other technical specifications
- Update and release a new version of Preliminary Baseline Design Report
- Update the Risk Analysis and QA/QC Plans
- Conduct L2 Subsystem Conceptual Design Reviews
- Pass a Director's Review (1-2 months ahead of the CDR/OPA Reviews) to ensure readiness for the Funding Agency Reviews

Moving Forward

Wednesday sessions will discuss work needed to prepare for upcoming reviews

Preliminary Baseline Design and Next Steps

Convener: Jeff McMahon (University of Chicago;)

Session notes

08:20 **PBDR & Science Book overview**

08:45 **Low ell BB**

Speaker: Colin Bischoff (University of Cincinnati)

New Project Baseline Development

Conveners: Jeff Zivick (University of Chicago;) , Matthaeus Leitner (Lawrence Berkeley National Laboratory)

Session notes

12:00 **Status of New Project Baseline Development**

Speaker: Matthaeus Leitner (Lawrence Berkeley National Laboratory)

12:25 **Status of Technical Documentation Deliverables**

Speaker: Bobby Besuner (Lawrence Berkeley National Laboratory)

Technical Documen...

12:50 **Status of Risk Management**

Speaker: Jeff Zivick (University of Chicago;)

13:05 **Preparations for Upcoming Reviews**

Speaker: Jeff Zivick (University of Chicago;)

13:15 **Quality Assurance**

Speaker: Jessica Aguilar (Lawrence Berkeley National Laboratory;)

(Times listed are PDT.)

Moving Forward

Exciting times ahead.

Let’s go for it!