WBS 1.07 Small Aperture Telescopes Status

John Kovac

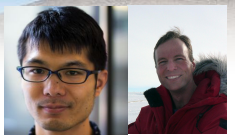
CMB-S4 Collaboration Meeting
May 9-13, 2022

SAT Team

L2: John Kovac
Harvard Univ

1.07 SMALL APERTURE TELESCOPES
John Kovac (Harvard)
*Robert Besuner** (LBNL)

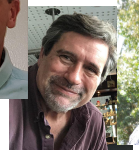
CAM: Bobby Besuner
(LBNL)



+ technical input from
SAT Working Group
(includes all S4 institutions, meets weekly)

- **1.07.01 SAT Management** — *Robert Besuner** (LBNL), Tim Norton (SAO)
- **1.07.02 Cryostat Prototype** — Joe Saba (LBNL)
- **1.07.03 SAT Cryostats** — Joe Saba (LBNL), Akito Kusaka (LBNL)
- **1.07.04 Optics Stack Prototype** — Scott Paine (SAO)
- **1.07.05 Cold Optics** — Abby Vieregg (U. Chicago), Paul Grimes (SAO)
- **1.07.06 Calibration Equipment** — Kirit Karkare (U. Chicago)
- **1.07.07 Telescope Mount Assembly** — Clem Pryke (UMN)
- **1.07.08 Telescope Ground Shield** — Ben Schmitt (Harvard U.)
- **1.07.09 US Integration and Testing** — Akito Kusaka (LBNL), Tim Norton (SAO)

Bobby



Tim

Joe

Akito

Scott

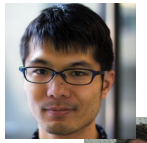
Abby

Paul

Kirit

Clem

Ben



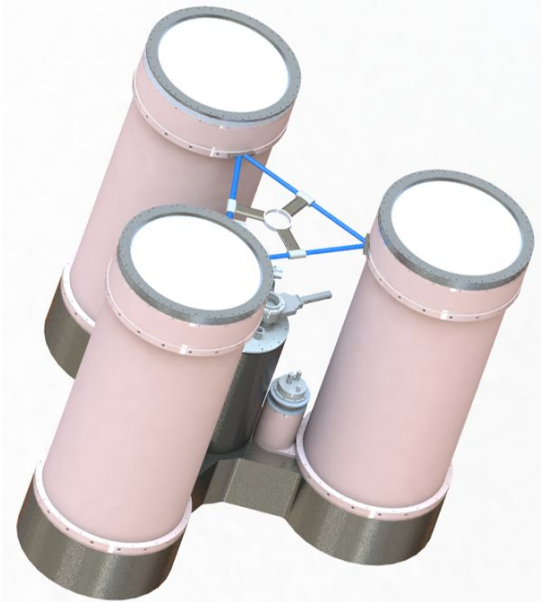
Akito

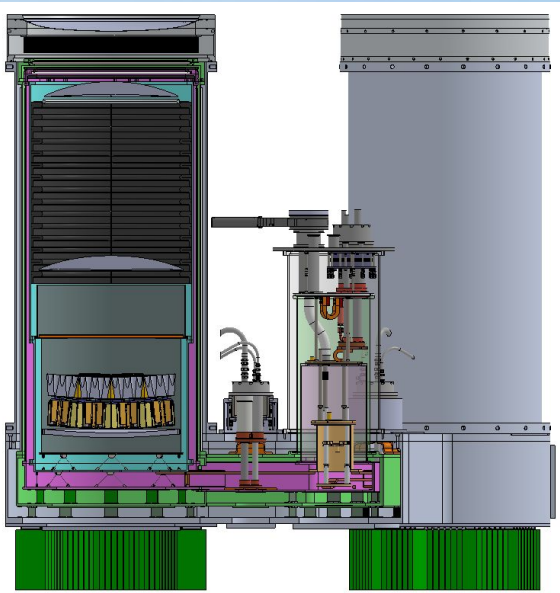
Tim

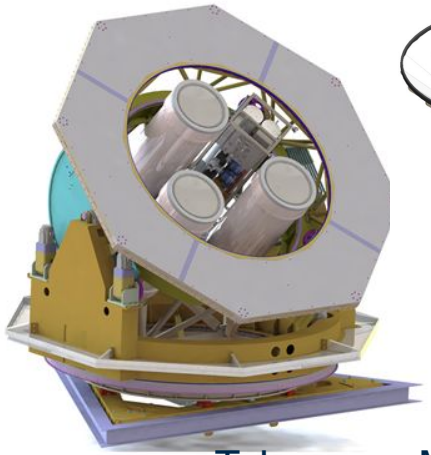
L3 Contributors and Working Group Members: Ken McCracken (SAO), Ed Tong (SAO), Tony Stark (SAO), Fred Matsuda (Kavli IPMU), Keith Thompson (SU), Brad Johnson (UVA),Tomotake Matsumura (Kavli IPMU), Marion Dierickx (HU), Nicholas Galitzki (UCSD), Shaul Hanany(UM), James Cornelison (HU), Tyler St. Germaine (HU), Clara Vergès(HU), Matthew Petroff (HU), David Goldfinger (HU), and no doubt many others who have called in...

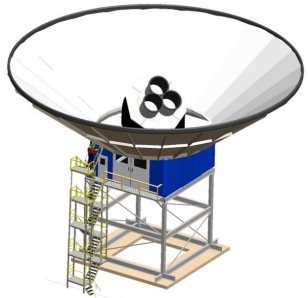
SAT Scope

Cryostat System, Optics Tubes, Integration & Test







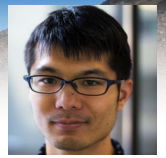


Telescope Mount, Ground Shield, Calibration Equipment

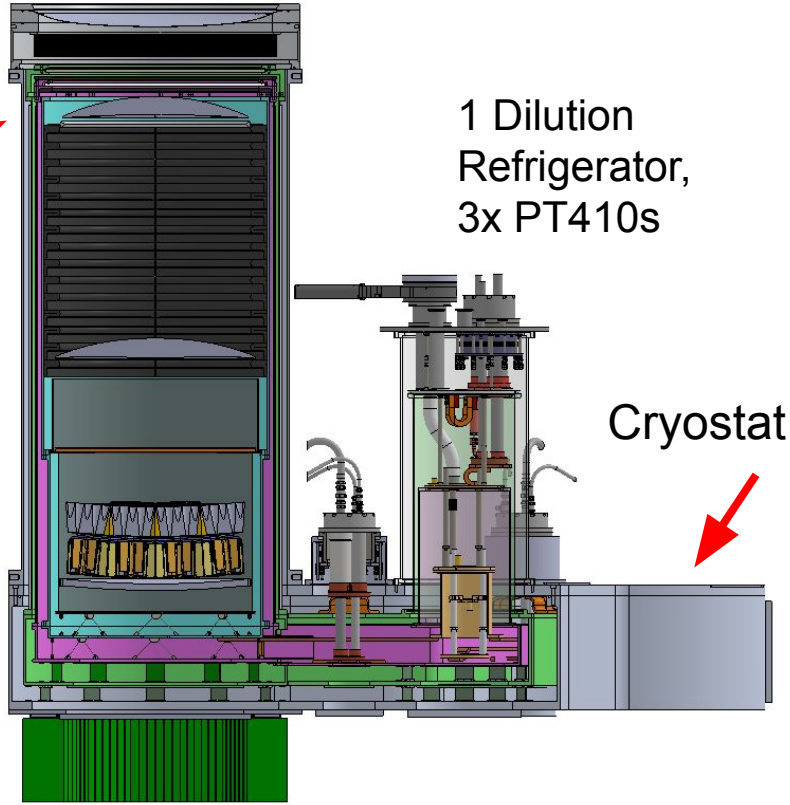
Integration and Test (including modules, readout, DAQ) before shipping to site

SAT Receiver and Cryostat Design Overview


Joe


Akito

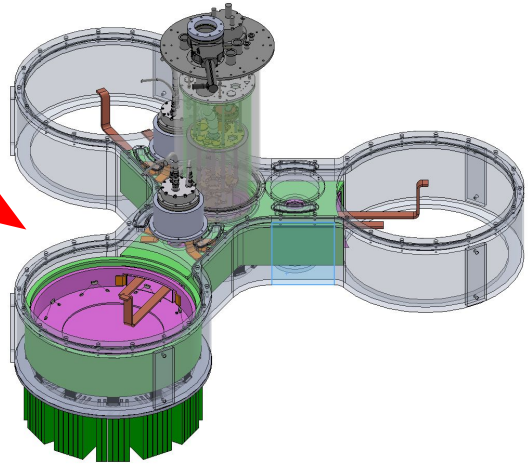
3x Receiver Tubes (each with an optics tube and focal plane)



1 Dilution Refrigerator, 3x PT410s

- SAT design draws directly on design heritage from BICEP3, BICEP Array, and Simons Observatory Small Aperture Telescope Receivers
- Design is maturing this year, driven by prototype test schedule
- Baseline cryostat power: 27 kW

Cryostat Bus



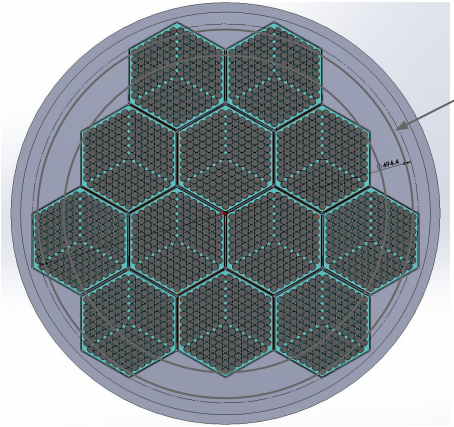
SAT Optics Design

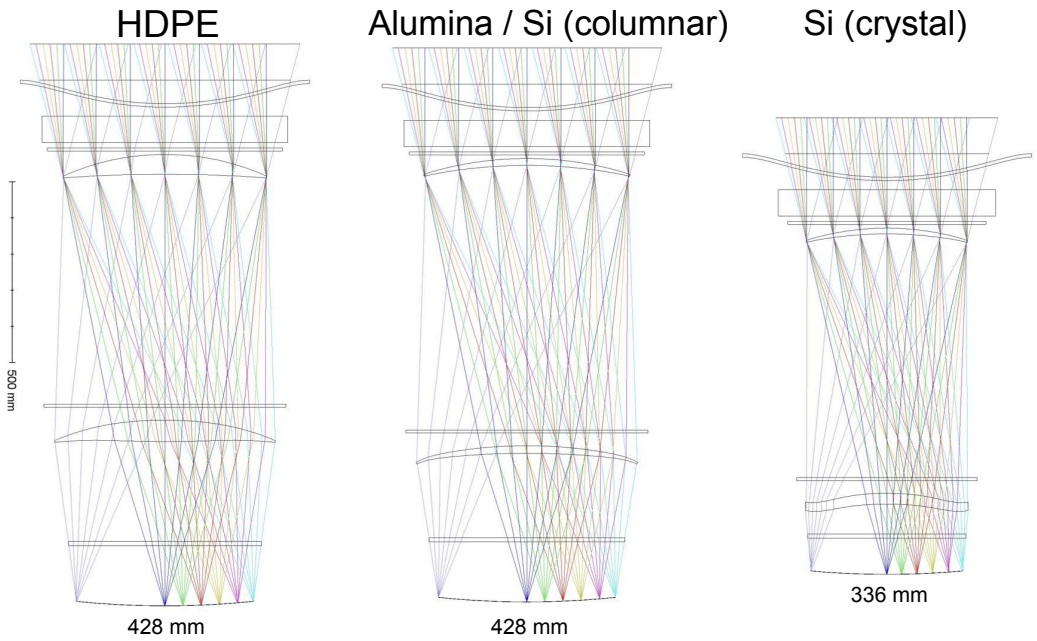

Scott

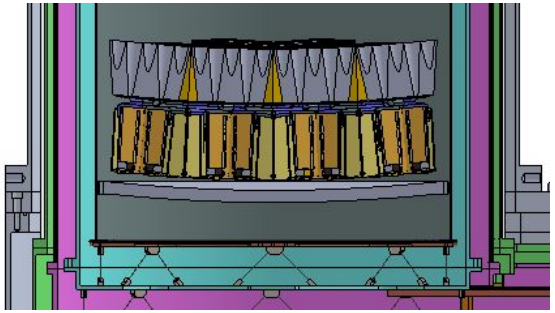

Abby


Paul

- Baseline **controls science risks** → clean, compact, extremely high throughput
  - builds on **only** proven approach for deep *r* measurements
- Recent developments:
  - **slightly curved focal surface** (r = 2.4 m) dramatically improves performance of two-lens designs
  - **MF optics / pixel layout study** defined baseline coupling for MF1/MF2
  - **initial material measurements** have bounded loss / birefringence in HDPE
- HDPE now baselined for all frequencies; alternatives to be evaluated



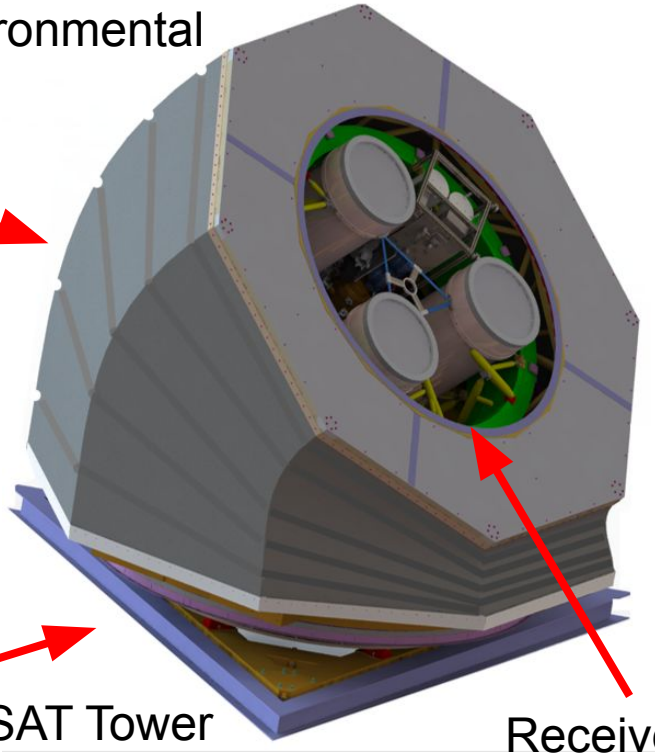




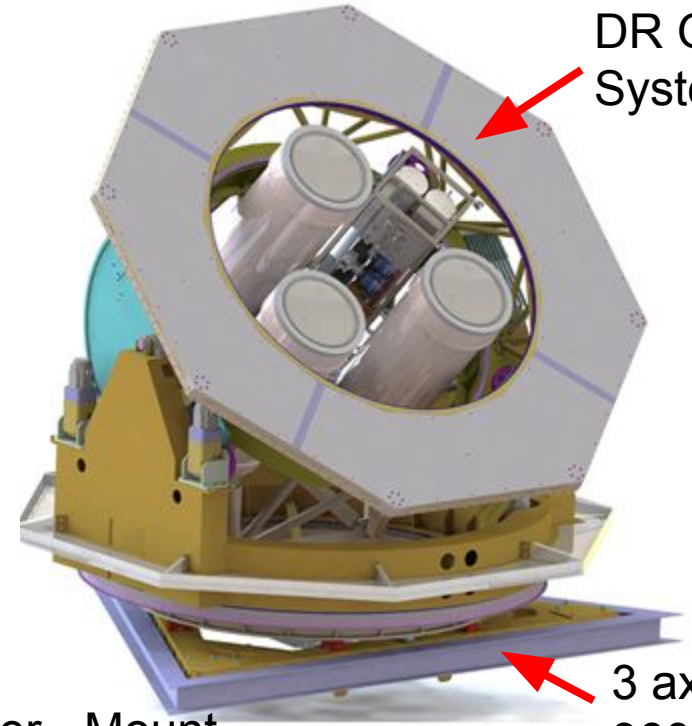
SAT Mount Overview

Clem

Flexible Environmental Enclosure



DR Gas Handling System



Interface to SAT Tower
(Pole Site ICD CMBS4-doc-348)

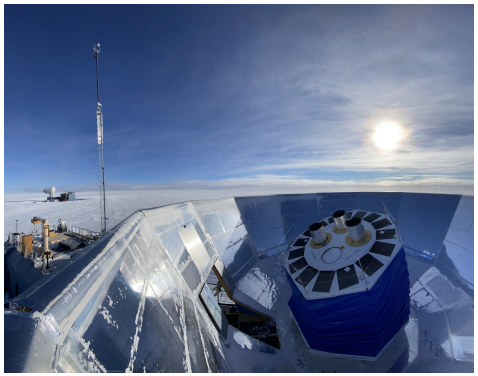
Receiver - Mount Interface Struts

3 axis balanced 360-boresight

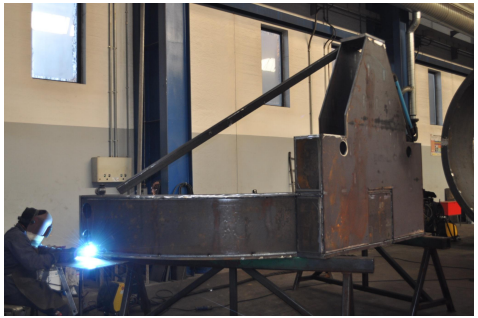
Heritage: BICEP Array Mount Integration, Deployment, Site Interface

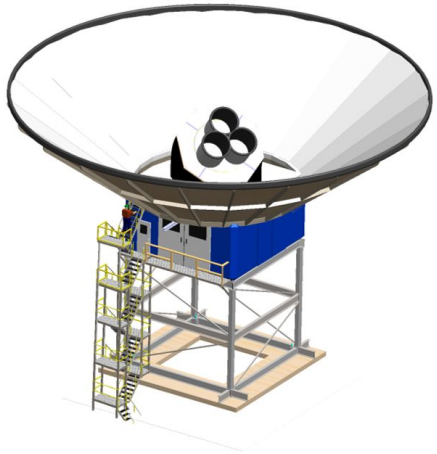
BICEP Array Mount
@ UMN (Aug 2020)

BICEP Array Mount
@ Pole (2021)



Mount #2
under fab now





S4 SATs mount
and groundshield
(total 6 planned)

- BART (BICEP Array Replacement Tower) – design adopted, confirmed to meet CMB-S4 baseline rqts.

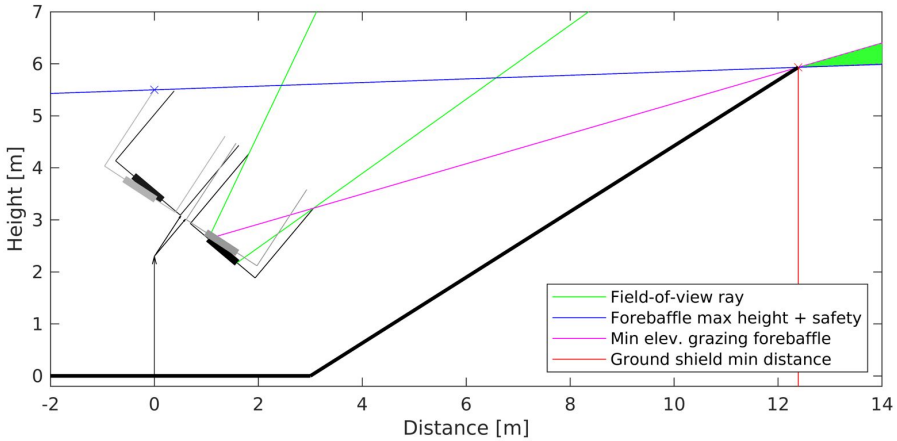
Ground Shields

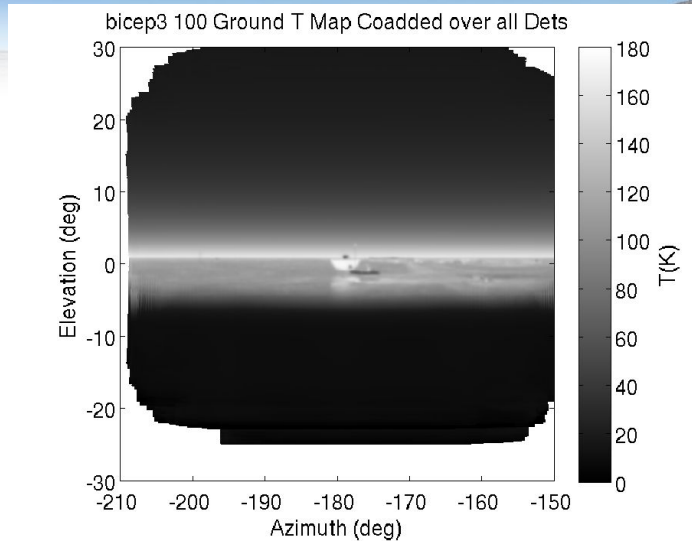
Key elements of proven approach to systematics control:

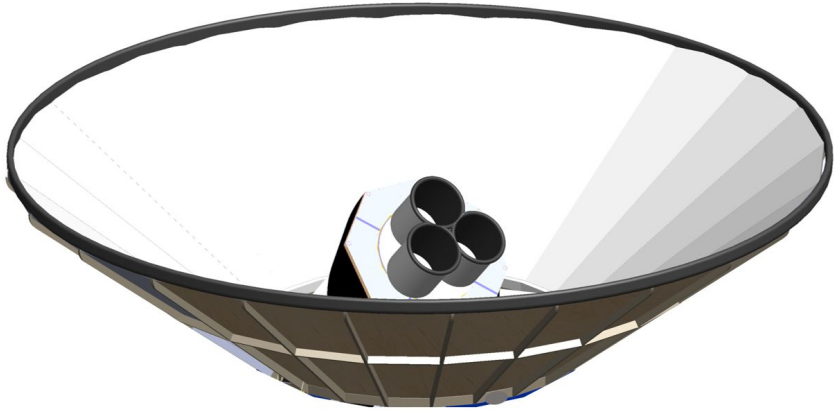
- Cylindrical warm forebaffles
- Reflective outer groundshield

Under double-diffraction criterion, at 50 degrees minimum elevation, geometry study found SAT 3-tube receiver can be shielded with:

- **Forebaffle**: 1.75 m tall, 0.8 m radius
- **Ground Shield**: 5.9 m tall, 12.4 m radius

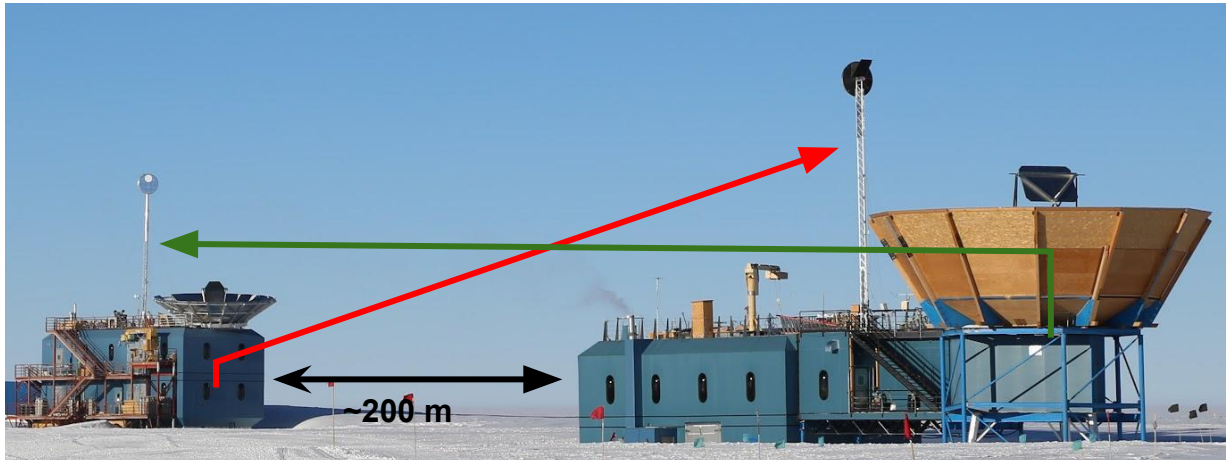




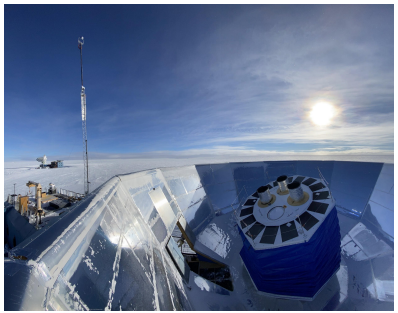


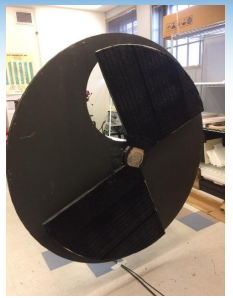
Ben

SAT Calibration Apparatus



- Far-field measurements using a redirecting flat mirror, sources on masts
- Some apparatus also needed for prototype test and I&T validation
- Major effort on standardizing definitions and refining requirements (Kirit/Clara)

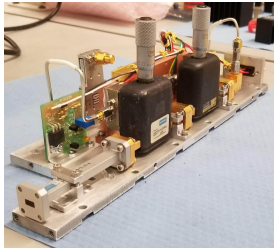




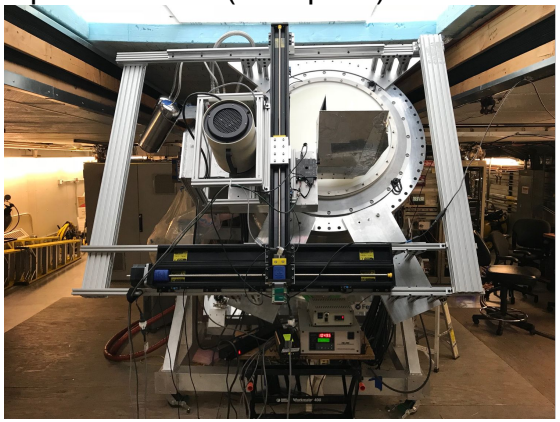
Thermal choppers
24” aperture
(precision beams)

Kirit

Broad-spectrum noise sources (polarization, sidelobes)



Spectrometers (bandpass)



SAT current focus:

- Maturing the baseline design
  - **Cryostat** advancing toward readiness for prototype build
  - **Optics** component-level prototype measurement and alternatives assessment
  - **Calibration** plan oriented toward validation/acceptance goals
    - **I&T plan** is sufficiently mature for present (thanks to Tim & Akito + Joe, Ben)
    - **Mount and Tower** design mature (mount #2 under construction!)

- SAT Opportunities
  - BART mount and tower designs now confirmed to meet CMB-S4 requirements
    - LOI states plan for reuse by CMB-S4; working on how to fold into project plan and AoA

- SAT Systems Engineering, R&D to build Margin and Mitigate Risk
  - Power savings – reducing cooling needs per SAT (baseline 27kW)
    - Baseline design: use of inverter compressors (CPA286i) and load reduction could get to ~18 kW
    - Alternative designs: “Big SAT” rather than 3-shooter, possibly < 18 kW
  - Sensitivity increases – aiming for more science per SAT
    - Optics optimizations (thinner window, less scattered forebaffle loading, etc.)
    - Pushing to higher pixel densities, either with more aggressive optics or alternate DRM technologies
  - pSAT (pathfinder SAT) – (single tube 100mK SAT prototype using existing BA cryostat)
    - Proposed avenue for cold optics subsystem testing, designed to retire science performance risk
    - Could be used to explore sensitivity tradeoffs

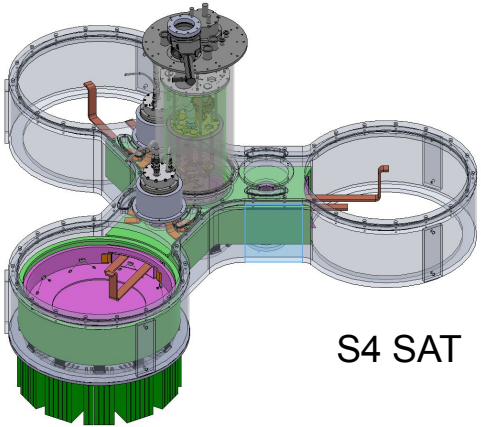
Summary

- SAT has an experienced team in place
- The SAT Baseline Design has been developed to meet its uniquely challenging measurement requirements
- Risks / hazards and mitigations are guiding our R&D and design effort
- Analyses of alternatives are being used effectively, collapsing design space
  → consider additional **engineering** and **science risks** for alternatives beyond baseline
- The SAT team has a clear path to readiness for CD-1

BACKUP SLIDES

SAT Cryostats Design and Heritage

Cryogenic Bus Assembly is based on BICEP Array Heritage



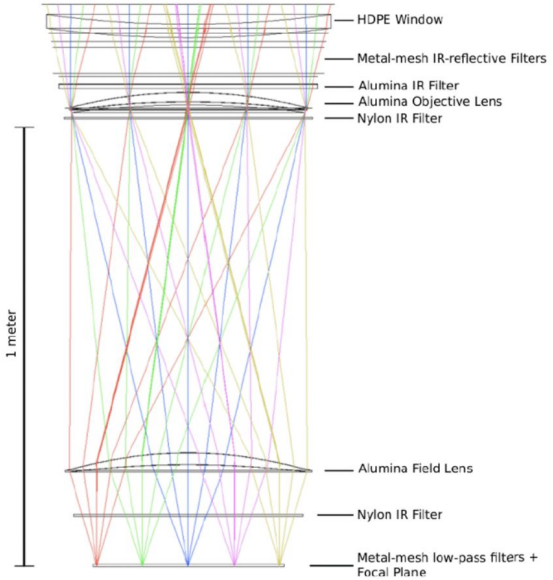
S4 SAT

BICEP Array SATs

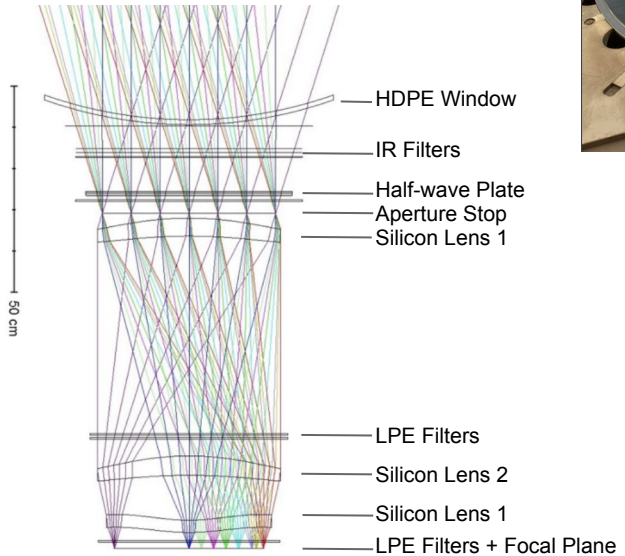
Leveraging integration & test experience with arrays of SAT cryostats from multiple Stage 3 projects

Cold Optics Heritage

BICEP3

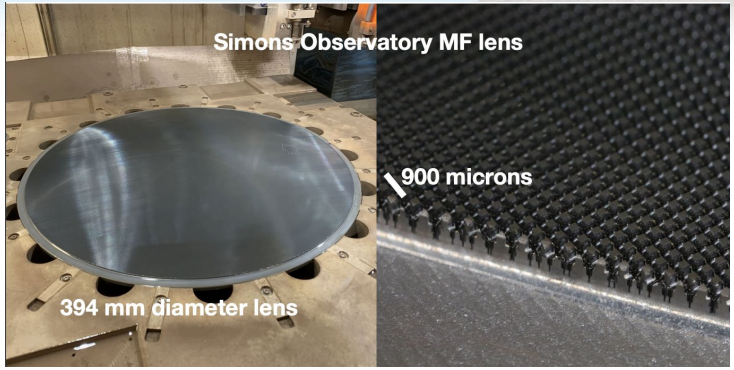


Simons Observatory

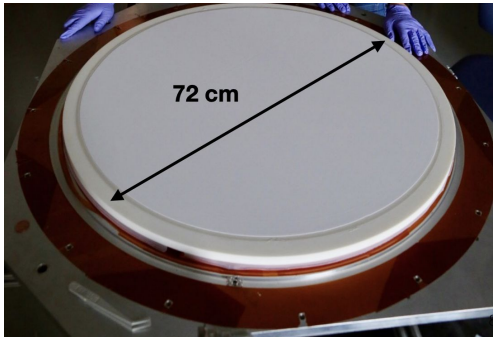


Optics design based on matured approach, but experience shows for every design, prototype testing is essential.

Silicon AR Example (Michigan/Chicago)



Alumina AR Example (Illinois)

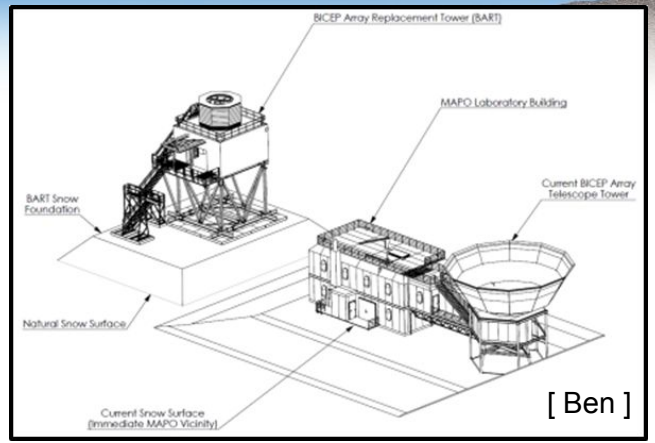


AR coating is a major R&D item. Technology shared with LAT.

Recent SAT L2/L3 Highlights

Management:

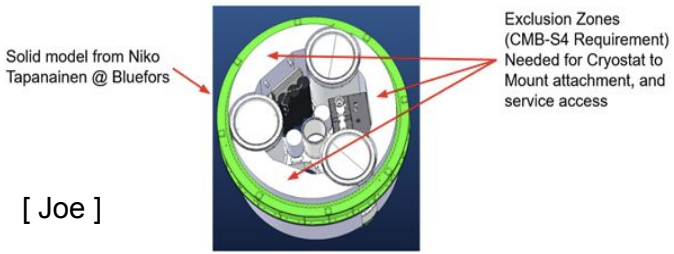
- Working with South Pole Sites L2, ensured SAT Tower and related requirements updated in the South Pole Sites - SATs ICD to a level that allowed requirements to be input to Jama:
  - Process documented BART compliance with current state of South Pole Sites and SATs operations plans.
  - Allowed BART structural and civil designs to move forward to fabrication, deemed in compliance with S4 requirements.
- Cost, schedule, and BOEs developed further in P6 and Confluence tools.
- Interface development going on throughout SAT L2, both inside and outside of SATs.



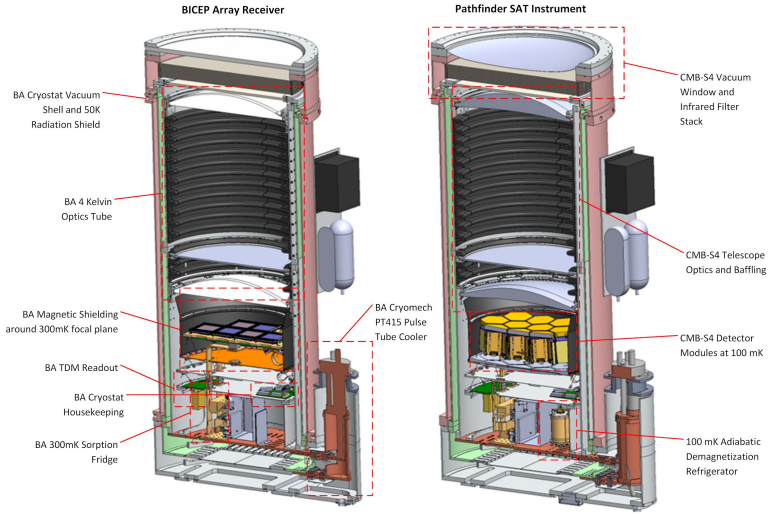
[Ben]

Cryostat Prototyping/Cryostat:

- Met with representatives of three potential dilution refrigerator manufacturers (Bluefors, Janis, Oxford).
  - Progress has been made with vendors focused on packaging options for their gas handling system on the SAT mount.
- Developed pSAT project as an NSF-MRI proposal.
  - The pSAT project would adapt an existing BICEP Array receiver to house CMB-S4 prototype optics, detectors, and readout for lab testing and field deployment to South Pole.



[Joe]



[Scott/Paul/Ben]

Recent SAT L2/L3 Highlights

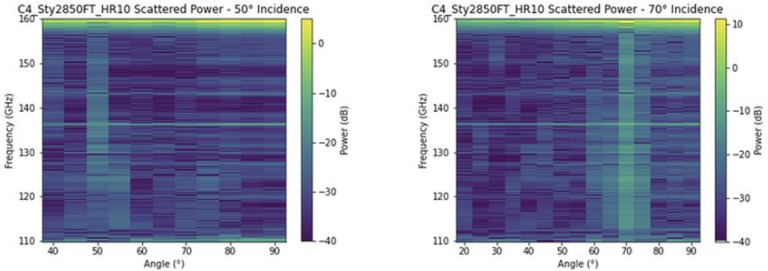
Optics Prototyping/Cold Optics:

- Worked with John Ruhl on modelling the SAT Optics system for L1 system design - formulating process for maintaining/documenting sensitivity model for the SAT optics, identifying uncertainties and opportunities for building margin in various configurations (baseline, alternatives).
- Completed design of open cavity resonator for cryogenic materials testing of index and loss, and sent out for manufacturing.
- Continued optical testing of cryogenic baffling material configurations.
- Testing and use of full-scale AR layer lamination press at Harvard.
- Continued development of the Optics Assessment Plan.

[John]

Calibration Equipment:

- Continued analysis of BK beam map data to determine noise scaling with beam map schedule count.
- Worked with South Pole sites group to ensure that roof can accommodate anticipated equipment.
- Worked with South Pole Integration and Commissioning to outline a list of calibration activities and delineate responsibilities.
- Worked to quantify sidelobe map depth with Colin and Rito.
- Working on the initial conceptual design of early calibration equipment systems (cold load, near field beam mapper, etc.).



[Paul]

Recent SAT L2/L3 Highlights

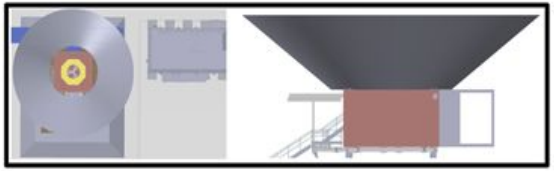
Telescope Mount Assembly:

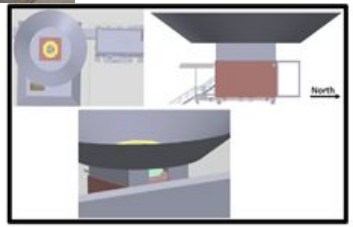
- Steel part fabrication and assembly welding process ongoing at Colombo Carpenteria for the first SAT-compatible telescope mount assembly (to be deployed on BART tower).
- Gear reducer alternative vendor study completed:
  - Considered cost/benefit of Micron ($28k cheaper per mount) vs. Parker (original) reducers.
  - Conclusion: Parker is preferred on basis of better service access and stronger intrinsic design with lower risk.

Telescope Ground Shield:

- Coordinated on interface development between South Pole sites and SAT telescope mount, cryostat, and calibration hardware L3s.
- Coordination of planned SAT walkway and roof level activities with South Pole sites laboratory building development effort.
- Developed six conceptual SAT Ground Shield geometric variants, and with input from SAT WG conducted a downselect to two variants:
  - Will further consider a monolithic ground shield design and a vertically-segmented design in more engineering detail.

[Clem/Eric]



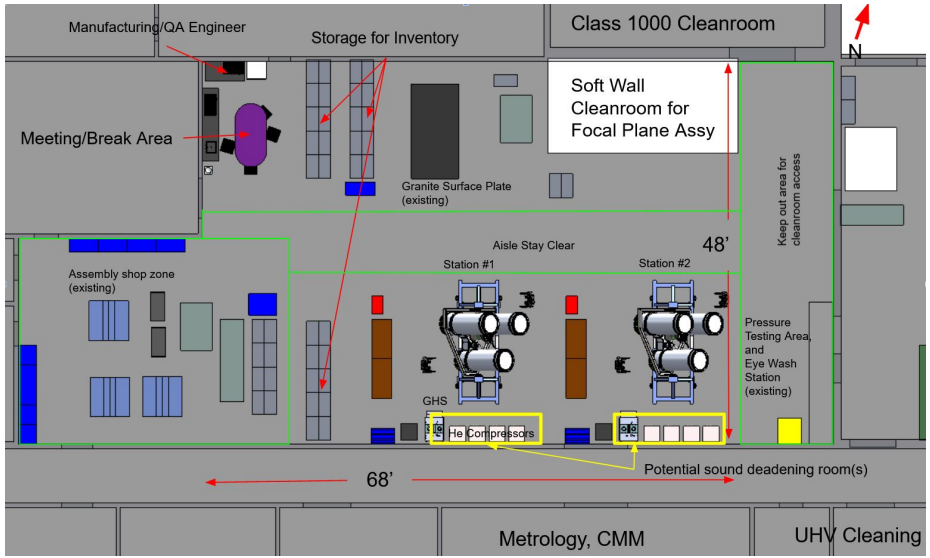


[Ben/Ken]

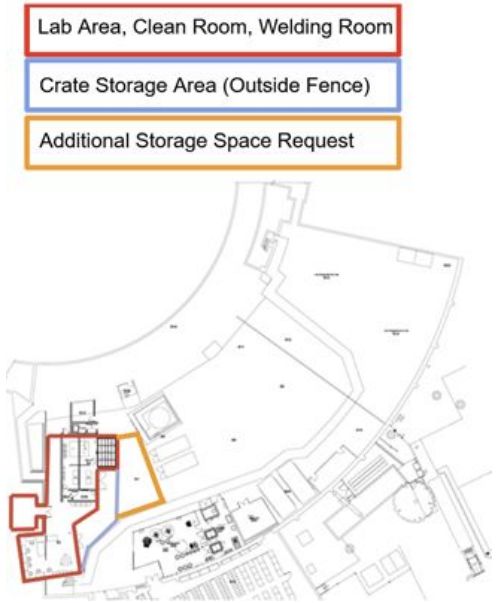
Recent SAT L2/L3 Highlights

Integration and Testing Plan Development:

- Developing facility layouts for integration and testing of SAT receivers in LBNL Building 77 (left) and Harvard high bay facility (right).
- Continued interfacing with detector L2 team regarding detector delivery schedule and coordination with SAT integration and testing schedule.



[Joe]



[Ben]