WBS 1.07 Small Aperture Telescopes Status

John Kovac

CMB-S4 Collaboration Meeting
April 3-6, 2023

SAT Team

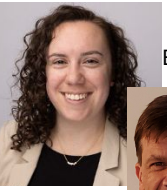
L2: John Kovac
Harvard Univ

CAM: Bobby Besuner
(LBNL)

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

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

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




Bobby
Rebecca

Joe

Akito

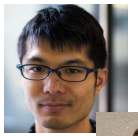
Scott


Abby
Paul

Kirit

Clem

Ben

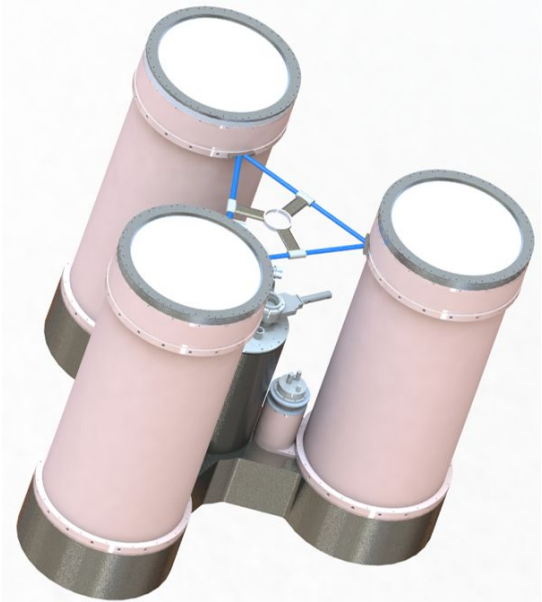


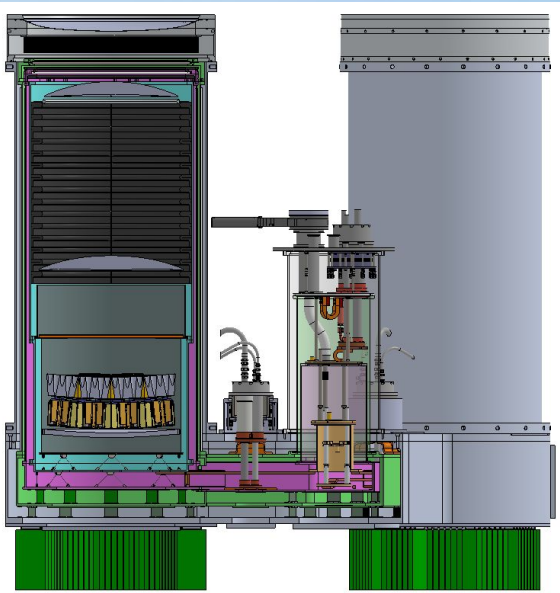

Akito
Marion

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), Nicholas Galitzki (UT), Shaul Hanany(UM), James Cornelison (HU), Tyler St. Germaine (HU), Clara Vergès(HU), Matthew Petroff (HU), David Goldfinger (SLAC), and no doubt many others who have called in...

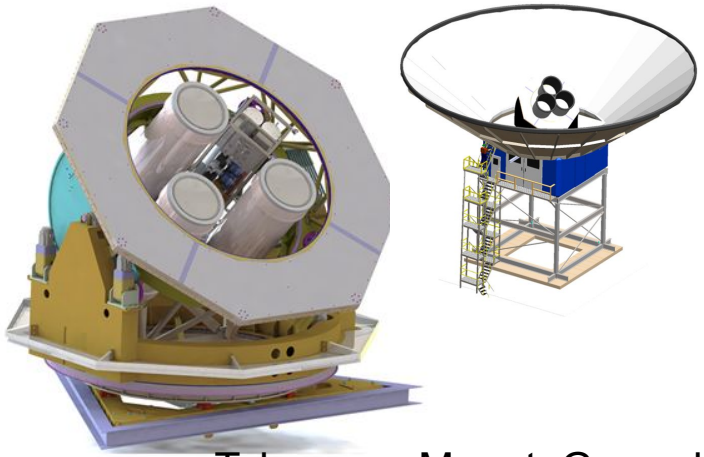
SAT Scope (new baseline)

Cryostat System, Optics Tubes, Integration & Test

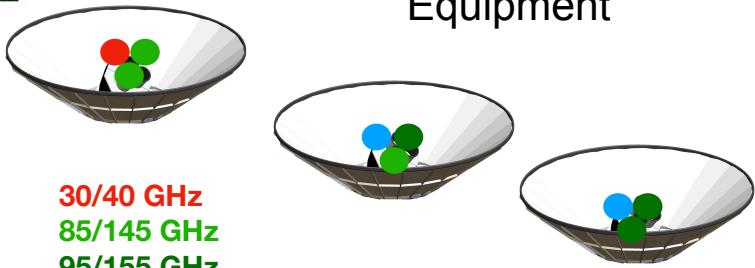




Integration and Test (including modules, readout, DAQ) before shipping to site



Telescope Mount, Ground Shield, Calibration Equipment



30/40 GHz
85/145 GHz
95/155 GHz
220/270 GHz

(note: freq / tube groupings not yet fixed)

SAT Analysis of Alternatives work

Science Requirement on “r” sets extreme experimental challenges for SATs measurement requirements

- Sensitivity and systematics are linked, tradeoffs sometimes steep

Baseline design prioritizes control of science performance risk & readiness

- New features (curved focal plane, dichroic optics, 100mK, etc) offer reasonable path to risk retirement

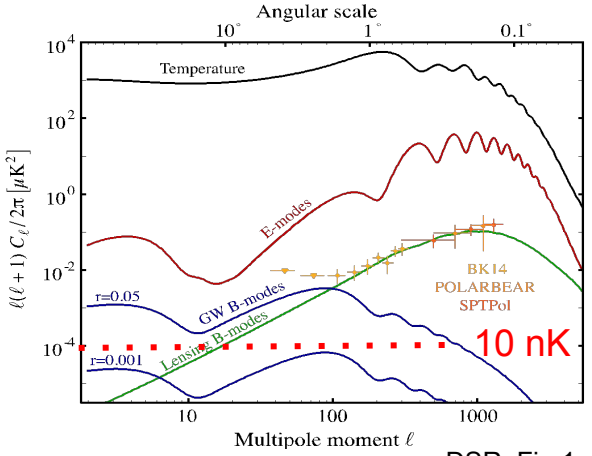
Alternatives carry additional science risk (field demo) or engineering risk (lab R&D)

- Lots of alternatives studied: see SAT AoA slides for full summary
- Considered: sites, shields, optics, cryostat configurations

  For example, revisited cryostat configuration selection DocDB-737 with new focus on power consumption, optics developments

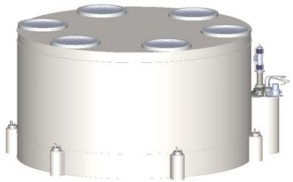
Opportunities for SAT systems engineering identified:

- Aggressiveness in optics illumination: field prototype testing
- Reducing SAT power consumption: lab prototype validation



DSR, Fig 1

“BIG SAT”

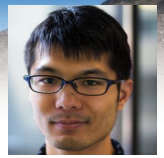


6-Tube SAT

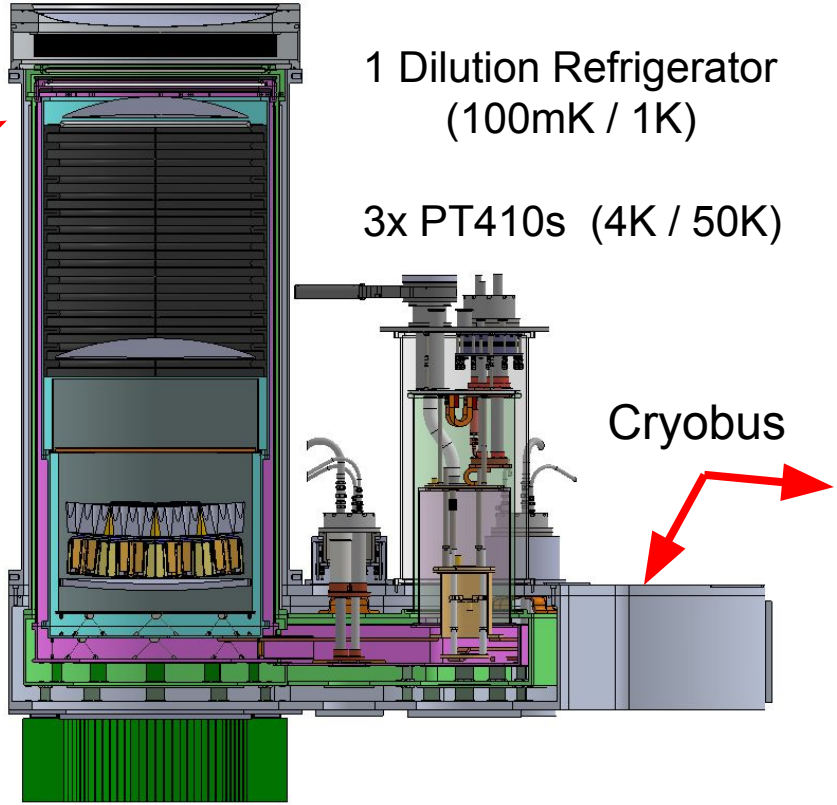
Baseline SAT

Baseline SAT Cryostat Design

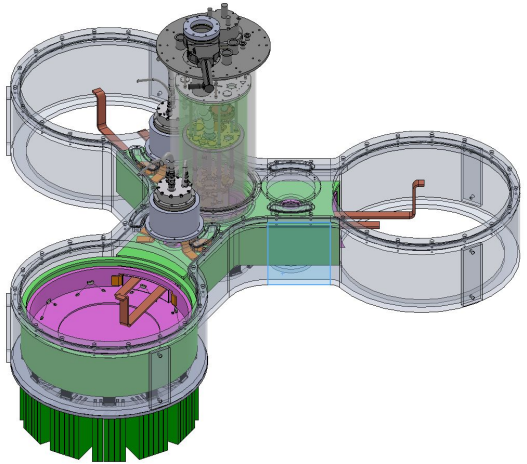

Joe


Akito

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

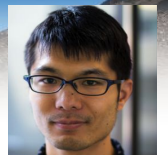


- SAT cryostat draws on design heritage from BICEP3, BICEP Array, and Simons Observatory Small Aperture Telescope Receivers
- Design matured a lot this year!
- Baseline cryostat power: 27 kW
- **Risks are mainly engineering**, to be retired by prototype lab test plan.

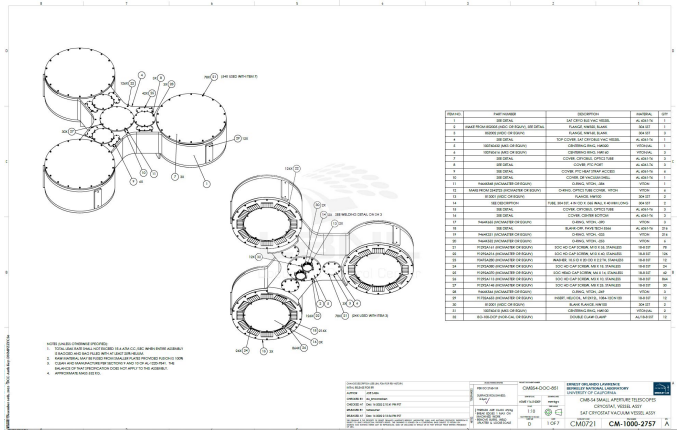


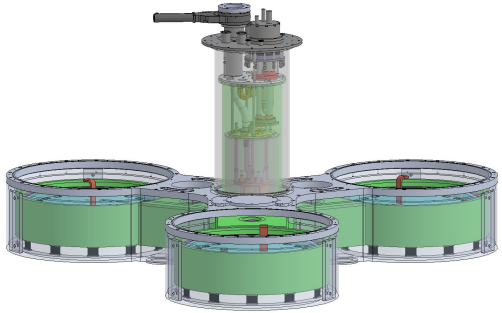
SAT Cryostat - Technical Progress

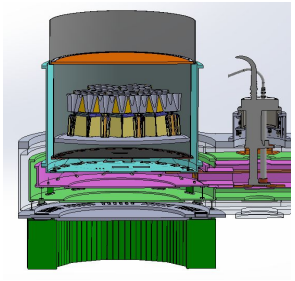

Joe

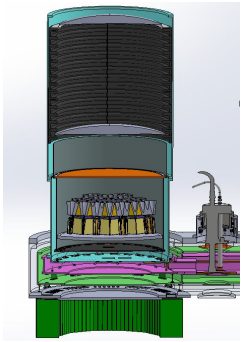

Akito

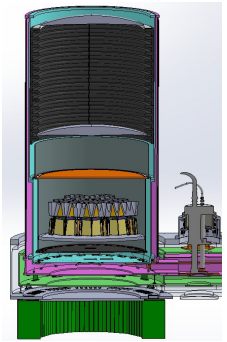
- Cryostats thermal analysis supported AoA configuration studies – 27 kW per cryostat, pending prototype testing
- SAT cryobus vendor Request for Information (RFI)
  - Live Feb/March, compiling vendor feedback now
- Cryostat assembly sequence, shipping units, and design detail have been matured (with input from SAT WG!)
  - E.g. see these slides for recent work

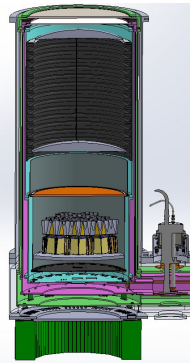








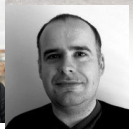




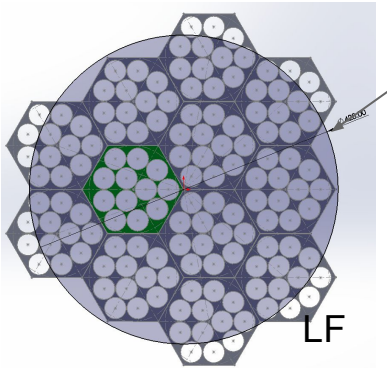
Baseline SAT Optics Design


Scott

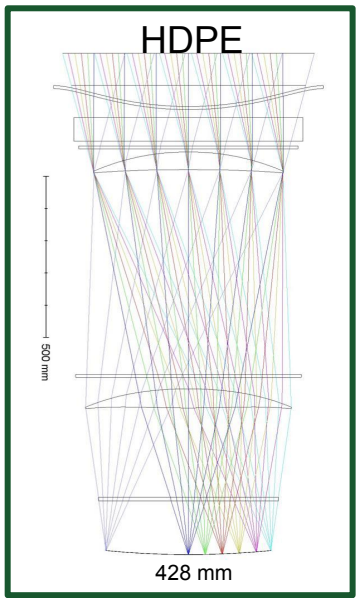

Abby

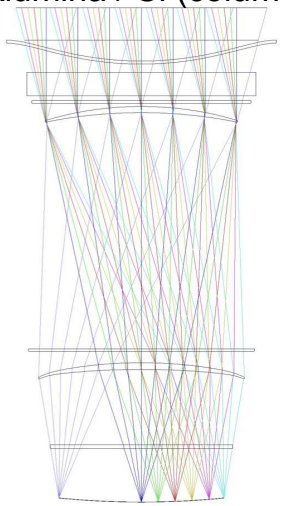

Paul

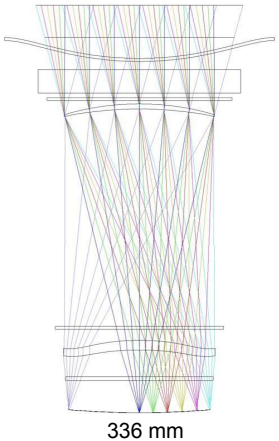
- Baseline **controls science risks** → clean, compact, extremely high throughput
  - builds on **only** proven approach for deep *r* measurements
- Developments, improvements, and new risks vs. those designs:
  - **curved focal surface** (r = 1.6 m) dramatically improves performance of two-lens designs
  - **dichroic tubes** increase throughput but make systematics harder
  - **aperture coupling** specified to stay close to experience
  - **colder optics temperatures planned: 1K / 100mK**
  - **optimization of materials and AR** through comparative testing
- HDPE now baselined for all frequencies; alternatives to be evaluated

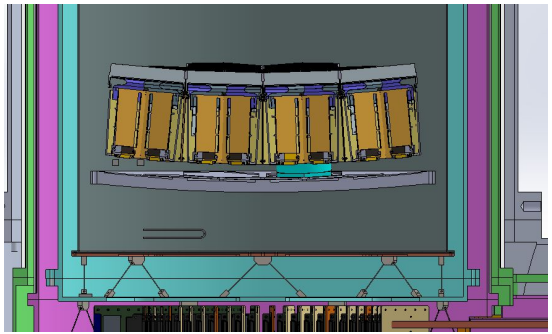


baseline for all SATs





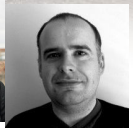




SAT Optics - Technical Progress


Scott

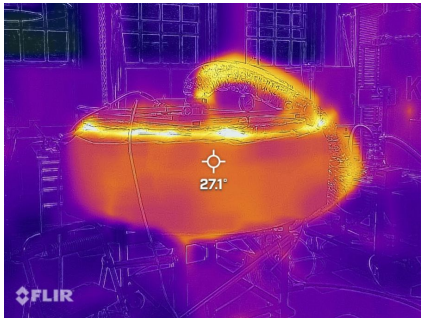

Abby

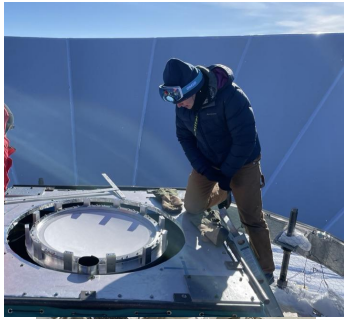

Paul

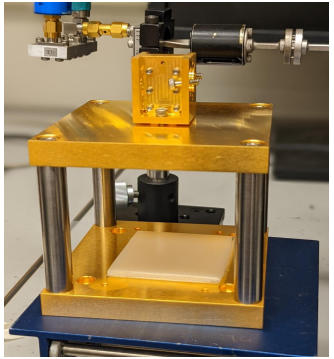
- 2 Ultra-thin windows have been deployed on BICEP/Keck (95 GHz & 150 GHz receivers)
  - Reduces loading, promising to become baseline technology for CMB-S4 in coming months
  - See Miranda Eiben, et al. Proc. SPIE 12190:121902L (2022) for details

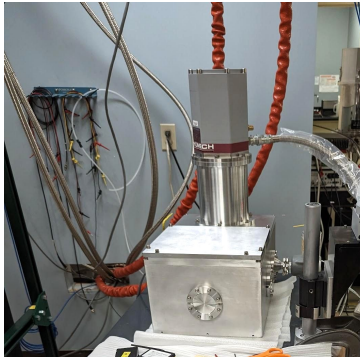
- Materials measurement capability expanded with quasi-optical test cavity and dedicated test cryostat.
  - Evaluate material loss at low temperature
  - Obtain precise refractive index data for design
  - Support materials QC in production

- pSAT (prototype SAT receiver) project initiated
  - 100mK optics tube in BICEP Array cryostat
  - enables validation of cold optics design / I&T





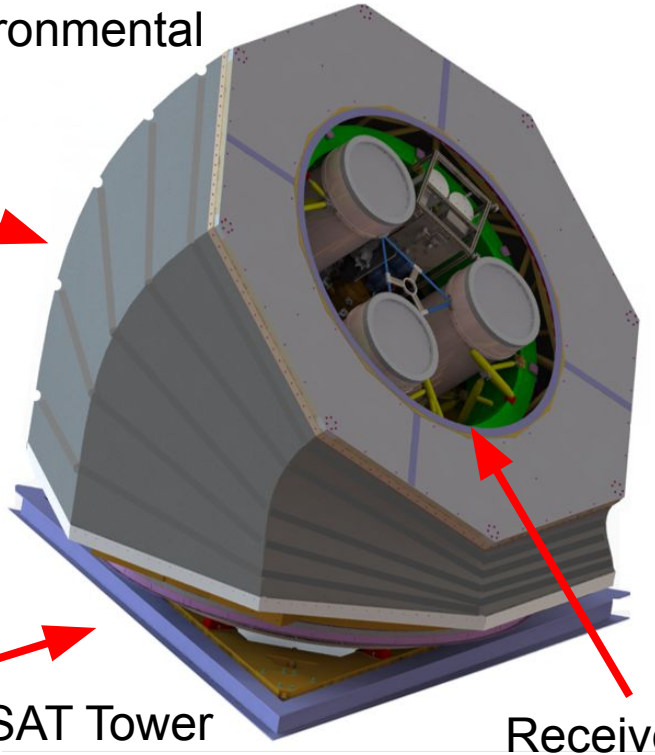




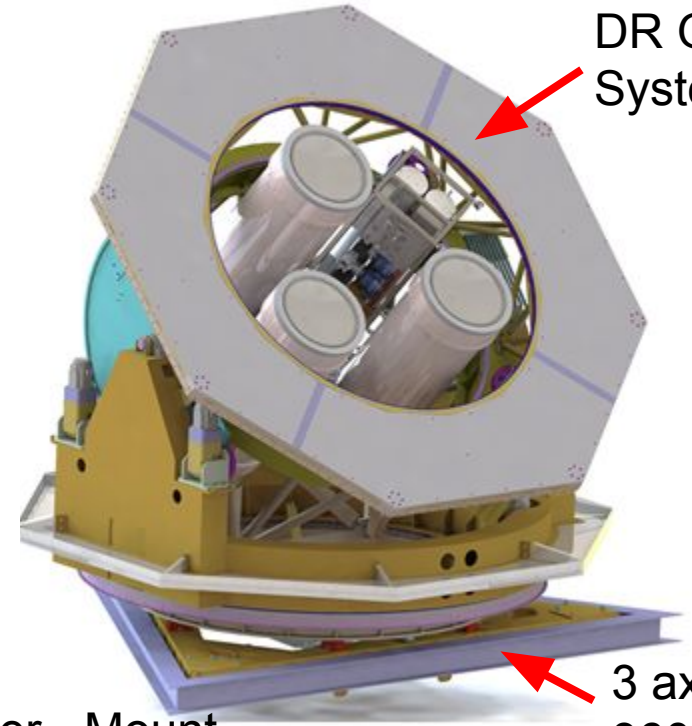
SAT Mount Overview

Clem

Flexible Environmental Enclosure



DR Gas Handling System

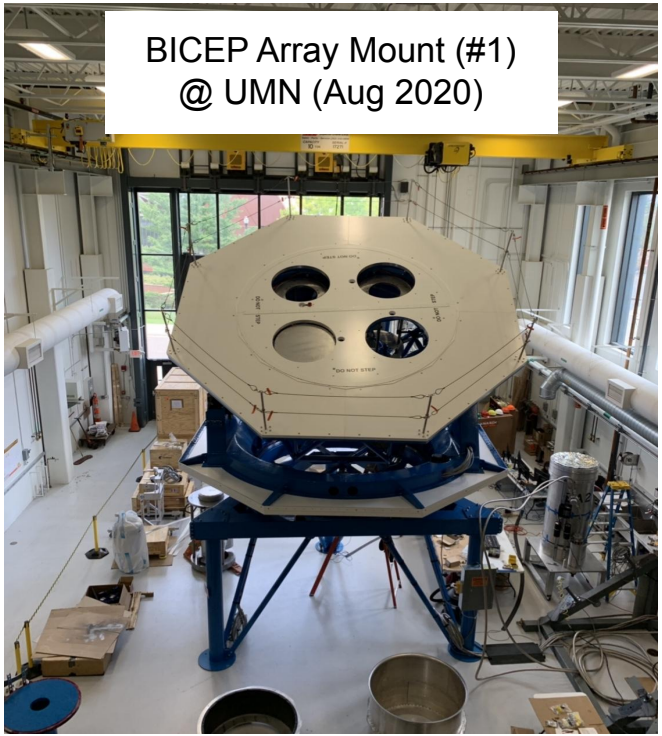


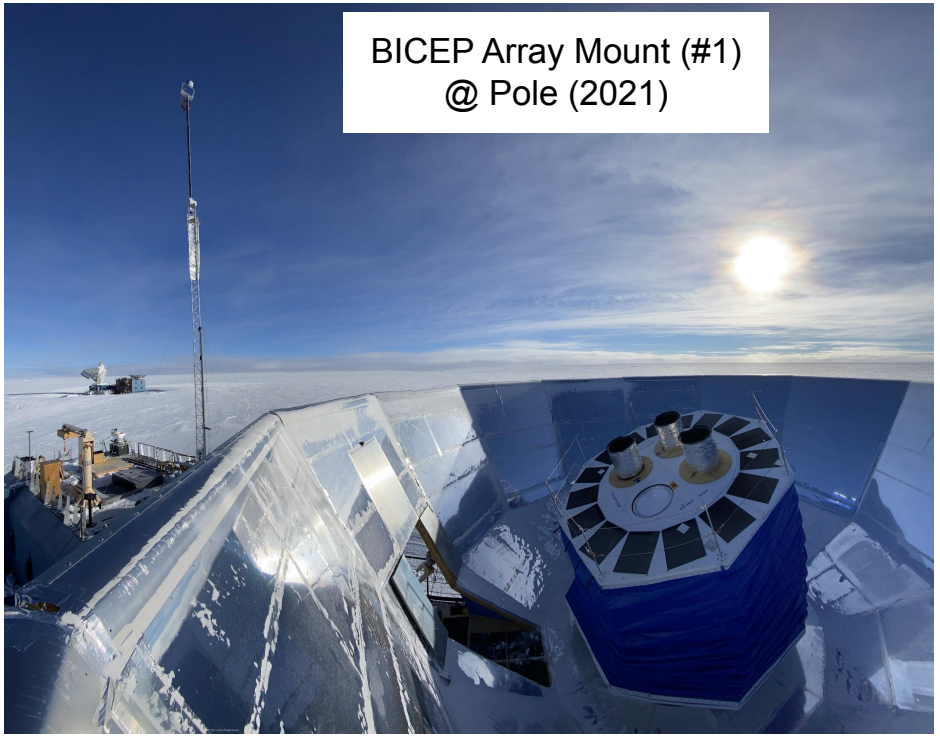
Interface to SAT Tower
(Pole Site ICD CMBS4-doc-348)

Receiver - Mount Interface Struts

3 axis balanced 360-boresight

Heritage: BICEP Array Mount Integration, Deployment, Site Interface





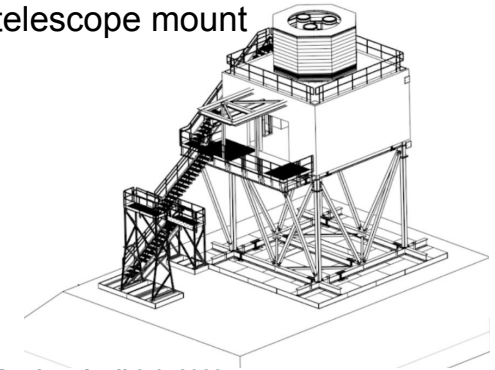
CMB-S4 SAT/Sites Progress supported by BART Project: Tower, Mount, Ground Shield, Control Room Design

- Design of the BA mount was modified for compatibility with the CMB-S4's "3-tube" cryostat, as we built the BART mount (#2)
- Fabrication now complete, mount #2 shipment on its way to UMN.

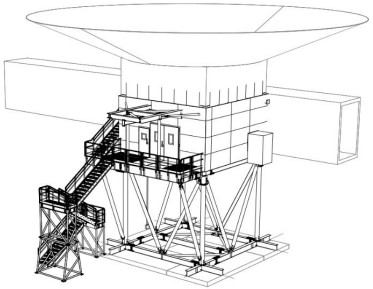
BART Mount (#2)
Fab complete (Mar 2023)

- BART (BICEP Array Replacement Tower): design adopted, confirmed to meet code and CMB-S4 baseline requirements
- Final design will be submitted for OPP acceptance this spring

S4 SAT tower and telescope mount



Conceptual ground shield and walkway attachment



Ground Shields – technical progress

Ben

Key elements of proven approach to systematics control:

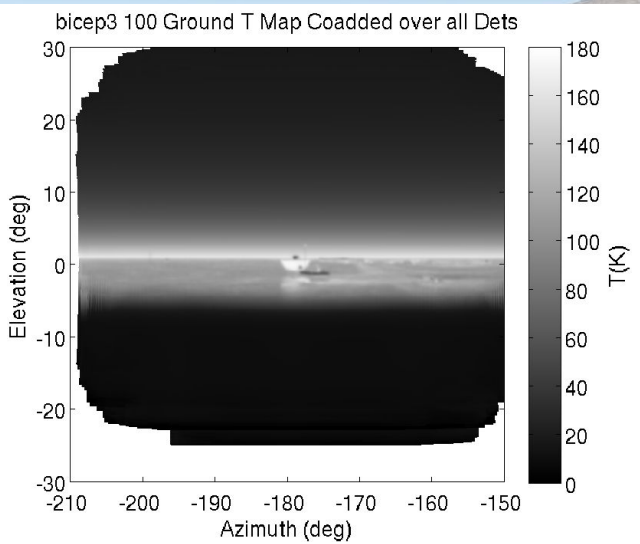
- Cylindrical warm forebaffles
- Reflective outer groundshield

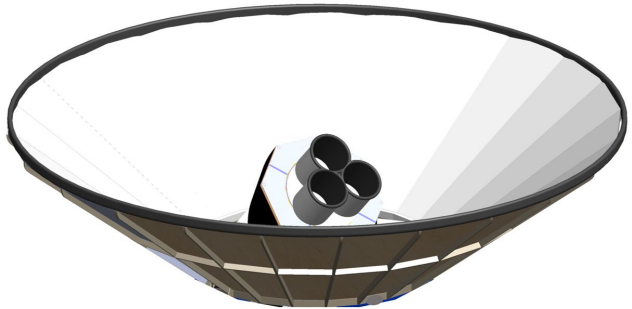
Under double-diffraction criterion, at 50 degrees minimum elevation, geometry study found SAT 3-tube receiver can be shielded with:

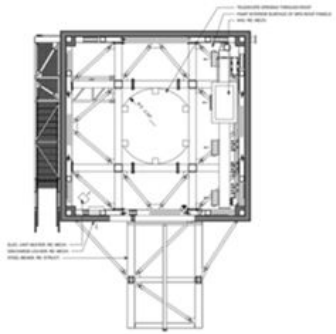
- **Forebaffle**: 1.75 m tall, 0.8 m radius
- **Ground Shield**: 5.9 m tall, 12.4 m radius

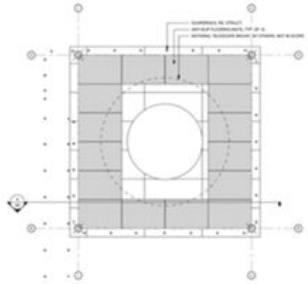
Data on ground maps has been improved: can inform systematics studies

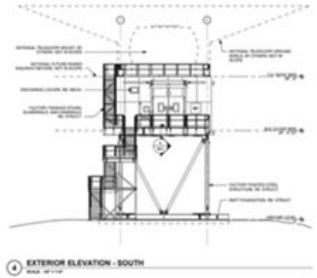
Design effort has focused on coordinating interfaces between CMB-S4 SATs, South Pole Sites infrastructure, and BART's design subcontractor, Ditesco.



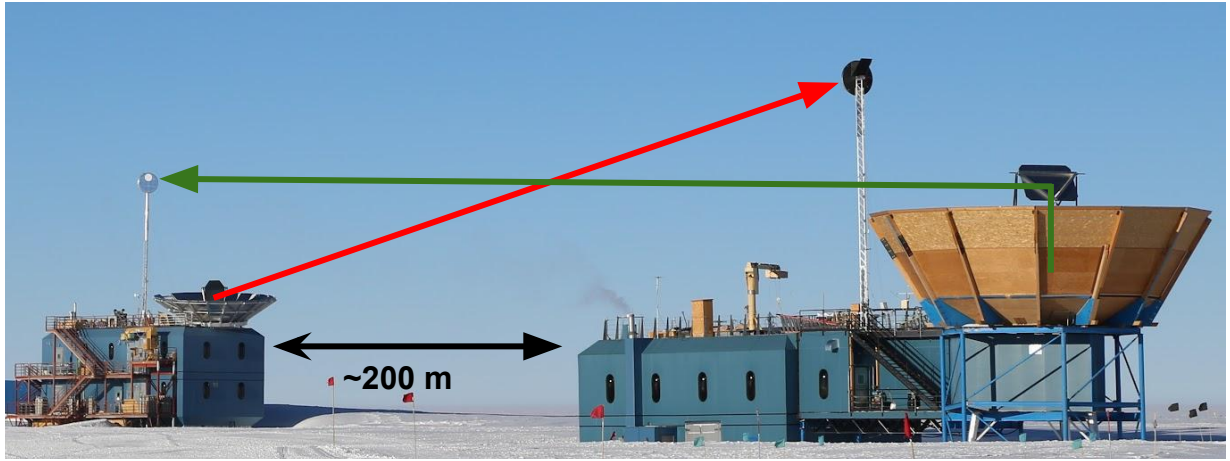


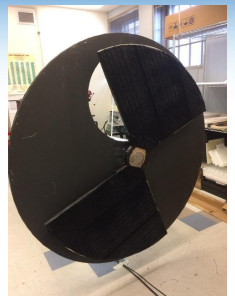






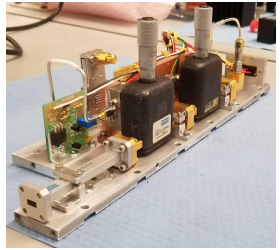
SAT Calibration Apparatus





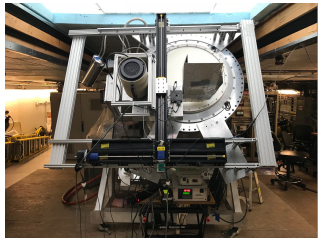
Thermal choppers
24” aperture
(precision beams)

Kirit



Broad-spectrum noise source
(polarization, sidelobes)

Spectrometers (bandpass)



Near-field
beam mapper

Technical progress:

- Major effort to refine systematics/calibration measurement requirements
  - publication planned based on *r* forecasting framework (Clara/Kirit/Colin)
- Prototype near-field beam mapper built (Brodi) and cold load designed (Matthew). To be validated/tested on BA/pSAT receivers in NA and at Pole
- CMB-S4 SAT Far-field flat mirror / mast design now underway (evolutionary)
- Upcoming: FTS design and systematics exploration (SLAC)

SAT summary and current focus:

- Maturing the baseline design
  - **Cryostat** working detailed design activities and soliciting vendor feedback
  - **Optics** component-level prototype measurement and alternatives assessment
  - **Calibration** plan oriented toward validation/acceptance goals
  - **Mount and Tower** design mature
    - BART mount fab is complete, shipping to UMN
    - Near-term use for CMB-S4 integration / prototype testing

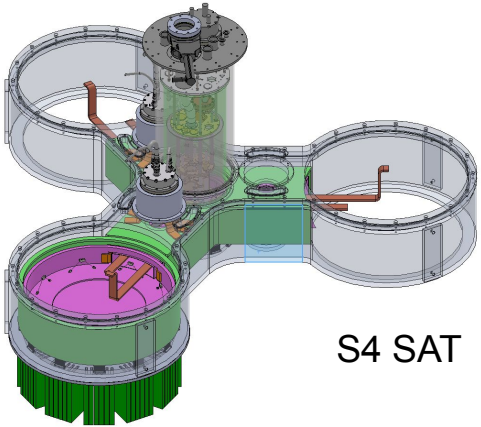
- SAT Systems Engineering, R&D to build Margin and Mitigate Risk
  - Reducing SAT power use – cryostat thermal design and lab prototype testing
  - Sensitivity increases – aiming for more science per SAT
    - “Easy” optics optimizations: thinner window, less scattered forebaffle loading, other “no-downside” improvements

- Other SAT Opportunities
  - SAT systematics project – solid, comparative basis for requirements development
  - pSAT (pathfinder SAT) – (single tube 100mK SAT prototype using existing BA cryostat)
    - avenue for cold optics subsystem testing, designed to retire science performance risk
    - Could be used to explore sensitivity / systematics tradeoffs
      - Enables comparative testing of aggressive vs baseline pixel densities, aperture illumination, etc.

BACKUP SLIDES

SAT Cryostats Design and Heritage

- Cryogenic Bus Assembly is based on BICEP Array Heritage
- Leveraging integration & test experience with arrays of SAT cryostats from multiple Stage 3 projects

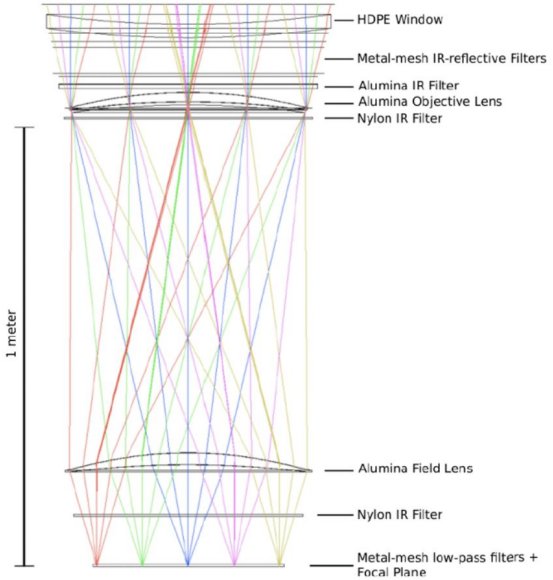


S4 SAT

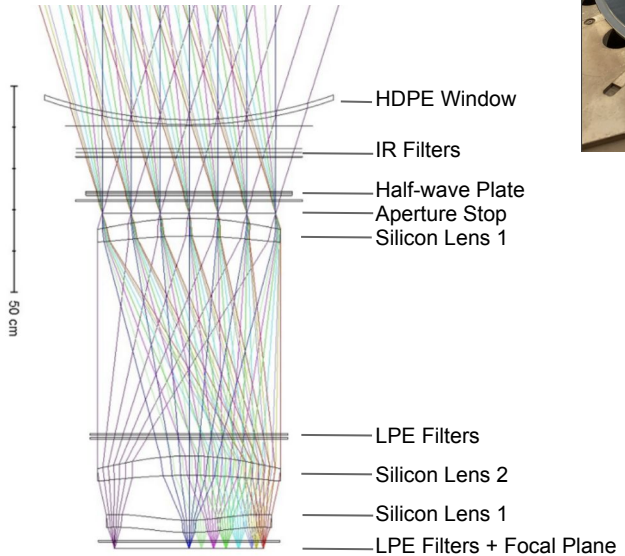
BICEP Array SATs

Cold Optics Heritage

BICEP3

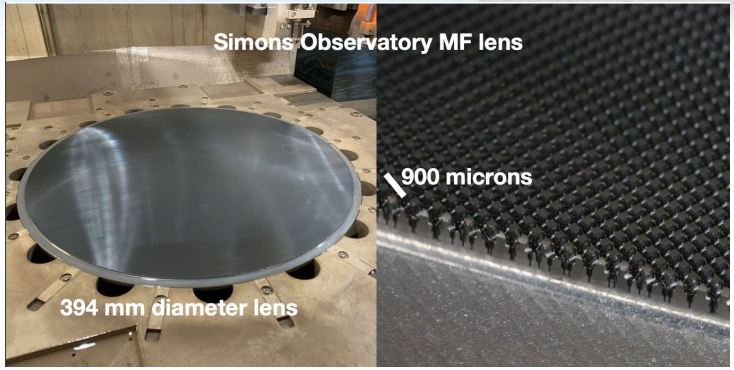


Simons Observatory

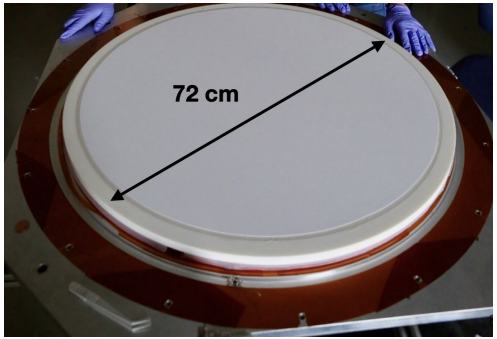


Optics design based on matured approach, but experience shows for every design, prototype testing is essential.

Silicon AR Example (Michigan/Chicago)



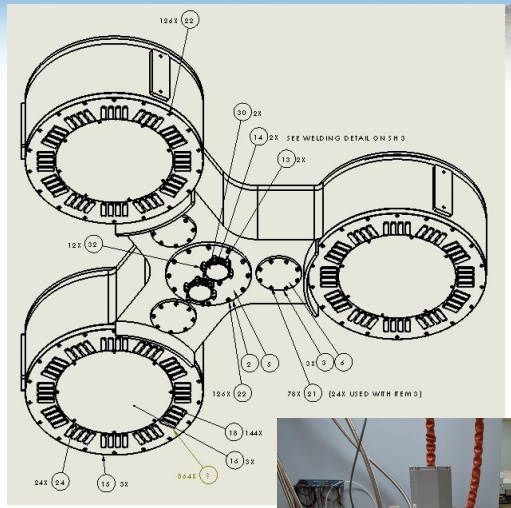
Alumina AR Example (Illinois)

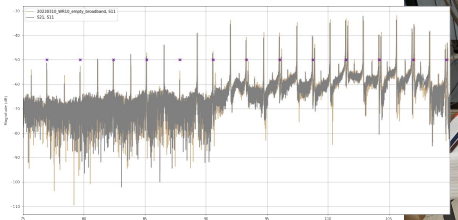


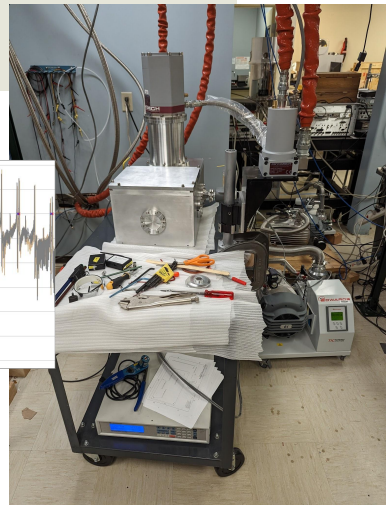
AR coating is a major R&D item. Technology shared with LAT.

Recent SAT L2/L3 Highlights (March 2023)

- **Management**
  - Collecting and submitting comments on the draft SAT SOW modifications for both SAO and Harvard for FY23/FY24
  - Review of SAT P6 schedule and providing recommendations to L1 project controls
- **Cryostat Prototyping/Cryostat:**
  - Received and reviewed the results of the cryobus RFI (Request for Information)
  - Considering design feedback from the RFI process
- **Optics Stack Prototyping/Cryostat:**
  - Quasi-optical cavity test cryostat has been fully assembled and is undergoing its first cool down
  - Performed measurements of Dyneema thin window laminates and DeWal expanded teflon material to reduce thermal loading relative to thick window







Recent SAT L2/L3 Highlights (March 2023)

- **Calibration Equipment:**
  - Continued developing analysis framework for defining calibration requirements. Paper proposal for forecasting framework approved by SAT and systematics working groups.
- **Telescope Mount Assembly:**
  - The BART mount assembly is being prepared for shipment to UMN from Colombo (Milan, Italy)
  - Cospal has completed the insulation paneling for the top of the BART mount assembly - working on arranging shipment for this item as well
- **Telescope Ground Shield:**
  - The BART Ditesco 90% Interior Design review period has started 3/13 and will last the next two weeks
  - This includes the review of interfaces to the telescope mount and the ground shield
- **US Integration and Testing:**
  - Communicating with Detector/Module team to re-organize and re-coordinate the integration and testing schedule