CMB-S4 LAT Plenary

Large Aperture Telescopes & Receivers

L2 leads: Mike Niemack and Nick Emerson

LAT Working Group regular members: Amy Bender, Brad Benson, John Carlstrom, Simon Dicker, Patricio Gallardo, Vic Guarino, Ian Gullett, Richard Hills, Matt Hollister, Sherese Humphrey, Jeff McMahon, Don Mitchell, Johanna Nagy, Erik Nichols, John Ruhl, Zhilei Xu, Jeff Zivick

Thanks to many collaborators for contributions!

LAT team: New L2 co-lead

Nick Emerson, University of Arizona

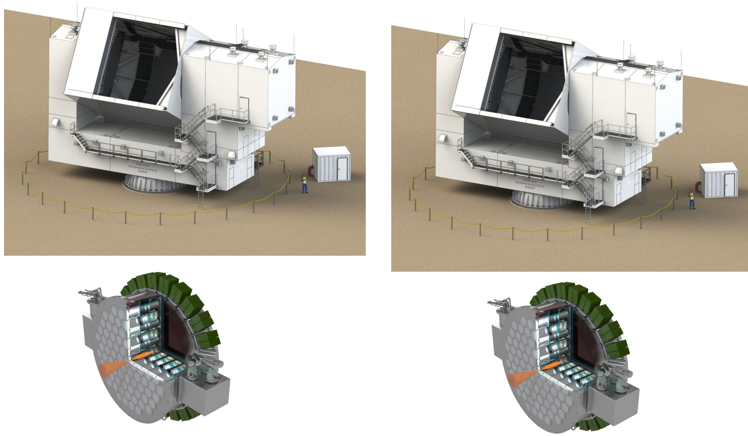
- Large Aperture Telescope and Receiver Projects: ALMA 12m, ARO 12m, SMT 10m, Arizona Array 6.1m (formerly CARMA/BIMA), ARO 4-band receiver
- Experience relevant to CMB-S4: Large telescope design, construction, testing, commissioning and operation
- CMB-S4 role: L2 Co-Lead and CAM for LAT

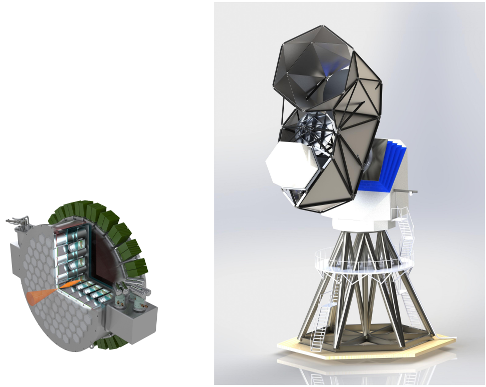
Mike Niemack, Cornell University

- CMB Projects: Atacama Cosmology Telescope (ACT, since 2002), Simons Observatory (SO), and CCAT-prime
- Experience relevant to CMB-S4: Hardware development including detector testing, telescope optics design, data analysis
- CMB-S4 roles: L2 Co-Lead and Scientist for LAT, Governing Board

LAT Deliverables Overview

- Chile
  - Two 6m aperture telescopes in Chile (CHLAT)
  - Two receivers to illuminate detectors on those telescopes (CHLATR)
  - Based on mature design for CCAT-prime and Simons Observatory being built in Chile
- South Pole
  - 5m aperture telescope at South Pole (SPLAT)
  - Receiver to illuminate detectors on that telescope (SPLATR)
  - Inflation cross-validation features: improved beam quality from optics, gapless mirrors & boresight rotation
- Commissioning Receivers
- Calibration Hardware





Parallel Session

12:30 → 14:00 **Large Aperture Telescopes: Parallel**

Join

Convener: Michael Niemack (Cornell University)

LAT Notes

12:30	**South Pole LAT (SPLAT) updates** **Speaker:** Nick Emerson (University of Arizona)	7m
12:38	**Chilean LAT (CHLAT) updates** **Speaker:** Steve Parshley (Cornell University)	7m
12:46	**Chilean LAT Survey Strategy and Sidelobes** **Speaker:** Patricio Gallardo (Cornell University)	7m
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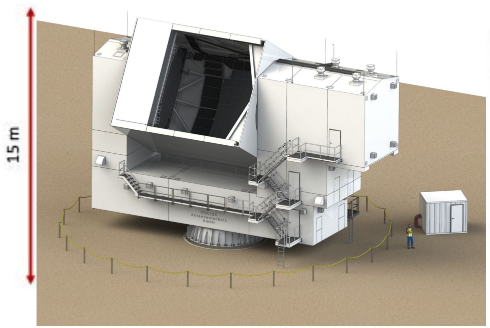
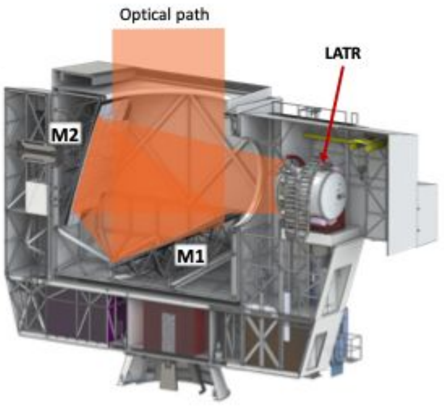
13:02	**S4 LAT Receiver (LATR) updates** **Speaker:** Bradford Benson (Fermilab; University of Chicago)	25m
13:27	**LAT Commissioning Receiver** **Speaker:** Jeff McMahon	7m
13:35	**LAT Calibration Hardware and baffling finishes** **Speaker:** Johanna Nagy (Washington University St. Louis;McDonnell Center for the Space Sciences)	10m
13:45	**Discussion**	15m

Preliminary Baseline CHLAT Design



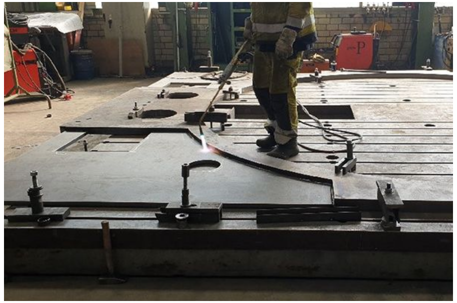


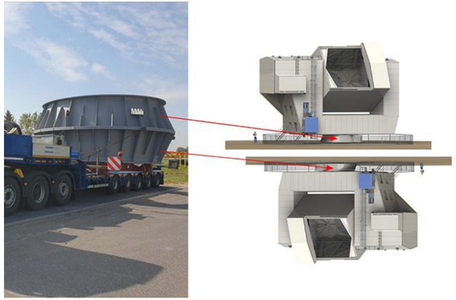
- Two 6m CD needed to satisfy CMB-S4 survey requirements
- Two copies of 6m CD design are under construction in Chile
- Discussions are underway with CCAT-prime and Simons Observatory regarding possibly use of 6m CD telescopes

Chile Design: CCAT-prime & SO
6m Crossed Dragone (CD)

Parshley et al. arXiv:1807.06678
Parshley et al. arXiv:1807.06675
Galitzki et al. arXiv:1808.04493
Gudmundsson et al. arXiv:2009.10138

Photos by Vertex Antennentechnik/ GmbH





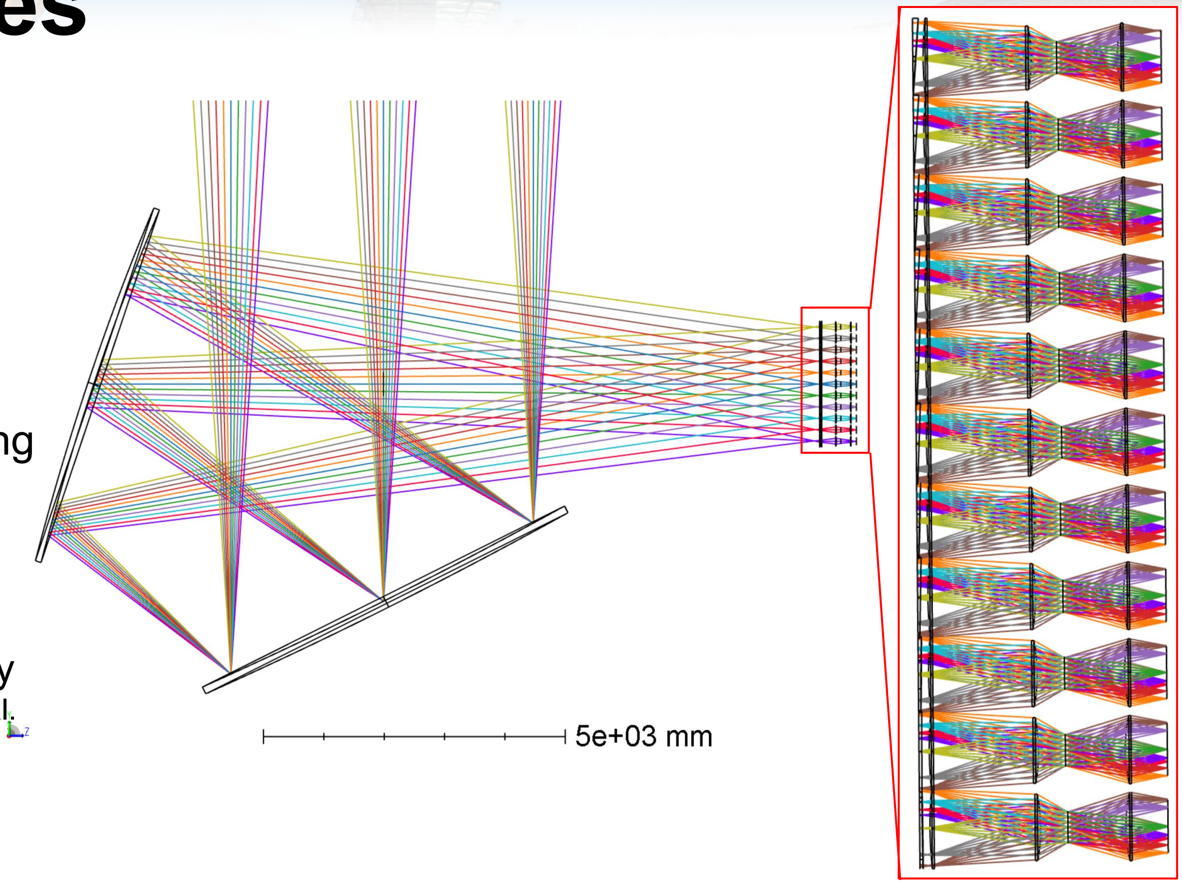
CHLAT updates

Substantial progress on CCAT-prime and Simons Observatory LAT fabrication
(Parshley parallel talk)

New optical designs and analyses for 85-tube LATR using biconic lenses
(Benson/Gallardo parallel talk)

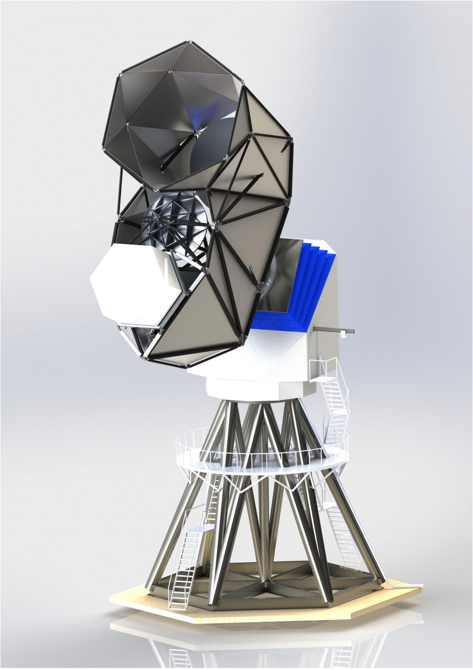
Optical systematics studies published by Simons Observatory
(Gudmundsson, Gallardo, Puddu, Dicker et al. arXiv:2009.10138)

Ground screen option retired (see backup slides)



Preliminary Baseline SPLAT Design

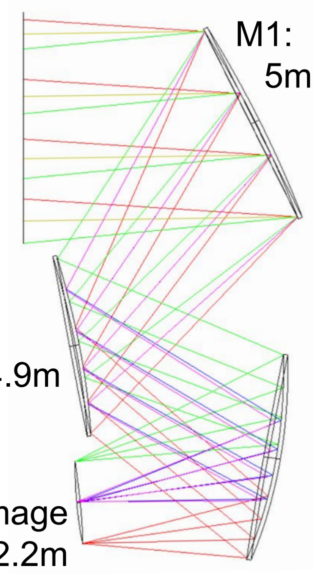
- 5 meter aperture meets requirements for delensing LAT **(Emerson parallel talk)**
- 5 meter aperture with TMA design provides sufficient throughput and allows monolithic (gapless) mirrors
- Additional features mitigate systematics, enabling cross-checks and verification for primordial gravitational wave (PGW) Level 1 science goals
  - **TMA design** provides better image quality
  - **Monolithic mirrors** eliminate panel gap sidelobes for recovery of degree scale signals
  - **Boresight rotation** to mitigate systematics

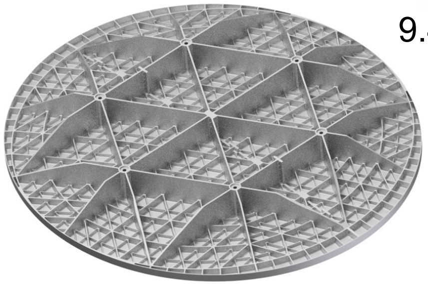


South Pole Design:
5m Three Mirror Anastigmat (TMA)
Padin Applied Optics 2018, 57(9), [SPTMA Wiki]

SPLAT updates

- Optics design has evolved from S. Padin concept to achieve lower f/# to match 85-tube LATR design
- Ongoing optimization of tipping structure design to accommodate new optics while maintaining required performance
- Ongoing discussions with mirror vendors in preparation for prototype mirror fabrication
- Mount design studies performed to optimize telescope stiffness and validate elevation drive system concept (7m drive screw)

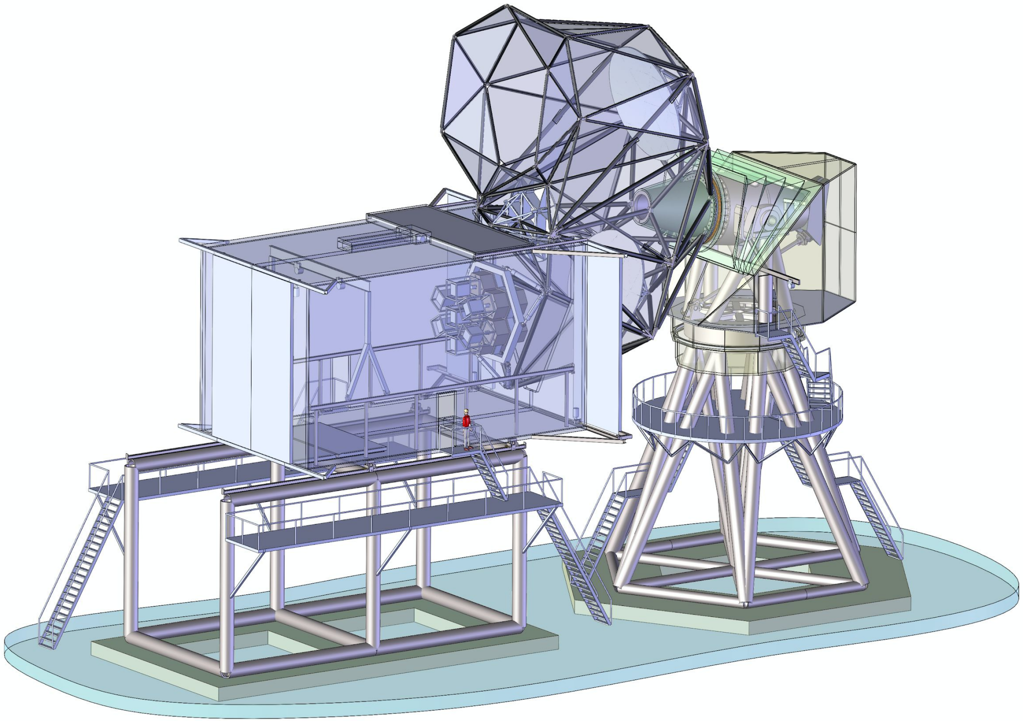




SPLAT Maintenance High Bay (sites WBS)

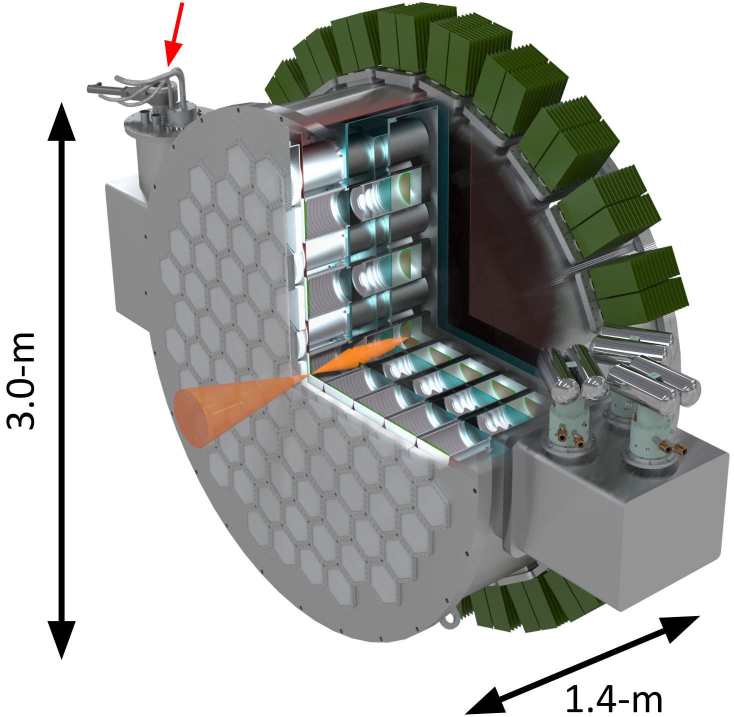
A concept for a high bay maintenance structure that mates to the TMA to provide warm access to the receiver and supporting components is illustrated here.

The final design will be done in concert with the larger CMB-S4 site plans to ensure all observatory requirements are satisfied.



LATR Cryostat

1x PT420 cooler backed DilutionFridge



85 tube Cryostat Design:

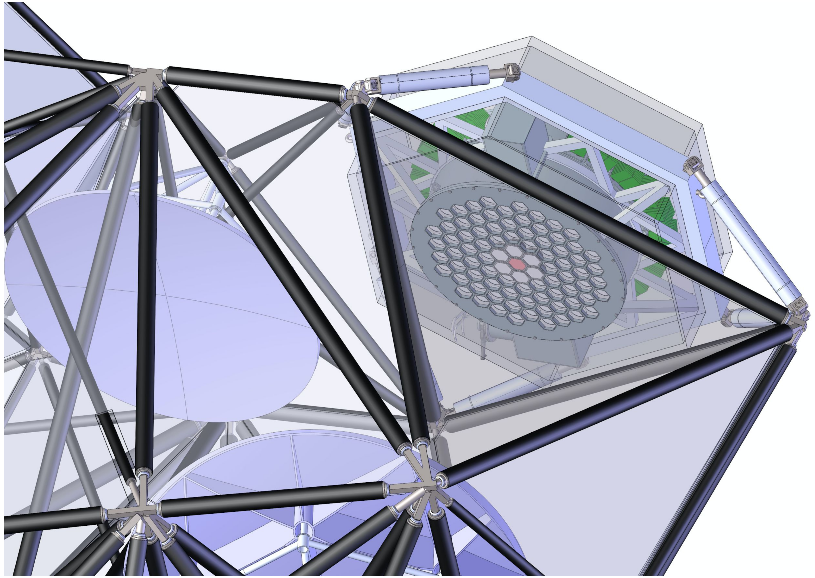
- Each optics tube consists of a 3-lens (20-cm diameter) design that couples to a single HEX-shaped detector wafer.
- Two primary advantages compared to DSR cryostat reference design:
  - **More Sensitive:** 1.25x higher mapping speed meets science requirements.
  - **Reduced detector module complexity**: Only 1x detector module per tube, with a single HEX-shaped detector wafer and module geometry (i.e., no “Rhomboid shaped wafers”).

(Benson et al. parallel talk)

LATR details and updates

Compared to DSR

- LATR now uses 85x ~20cm optics tubes versus 19x ~40cm optics tubes in DSR
- Infrared filters changed to zotefoam stack from metal mesh in DSR
- Only one hexagonal detector module geometry versus two in DSR



LATR in preliminary SPLAT mount

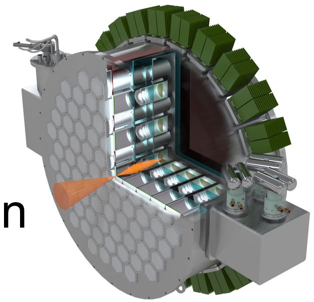
LATR details and updates

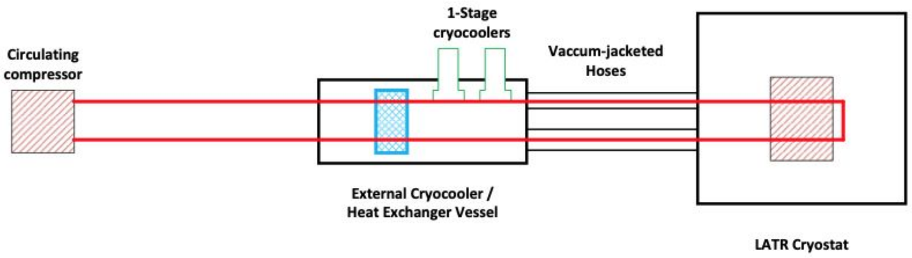
Mechanical design has advanced considerably **(Mitchell parallel)**

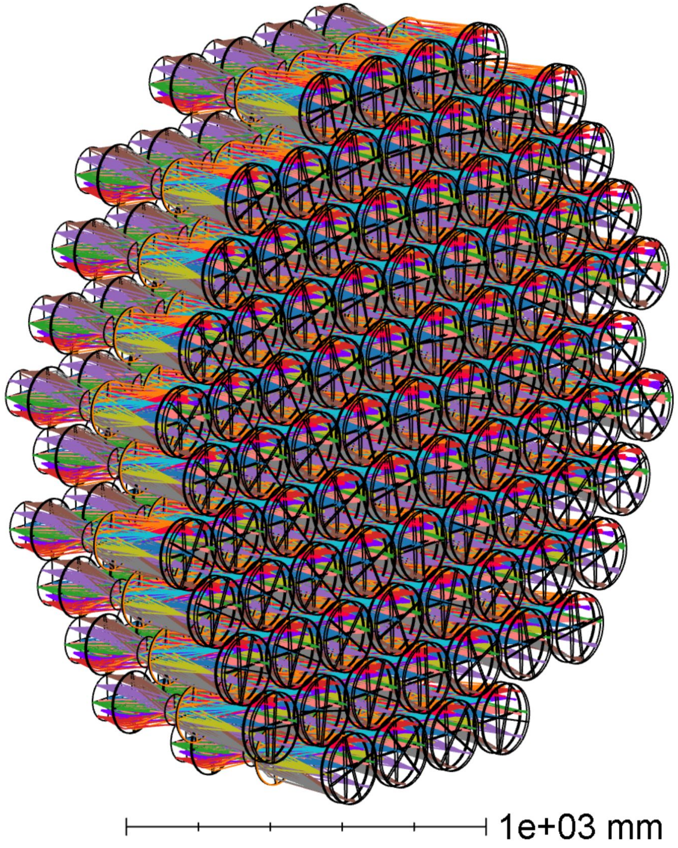
Design goal is identical cryostats on both CHLATs and SPLAT

Lens shapes will differ between CHLAT and SPLAT **(Gallardo parallel)**

Rapid cooldown system will be integrated into LATR **(Hollister parallel)**







LAT Commissioning Receivers

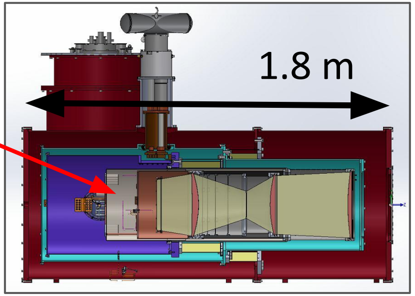
Three LAT Commissioning Receivers (LATCRs) will be constructed **(McMahon parallel talk)**, and will be used to characterize the following:

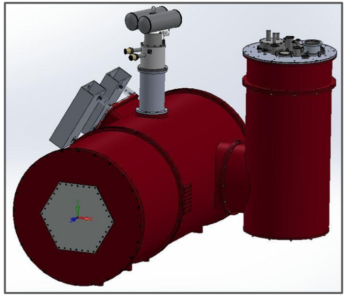
1. Telescope performance, beam size, and pointing using point source measurements in all frequency bands
2. On-sky detector performance, including noise and system efficiency
3. Optics tube performance, including the above and excess loading

First LATCR will be shared for the CHLATs, the second will be used for the SPLAT, and the third will be used as a Testing Receiver

The LATCRs will include a telescope interface flange and dummy mass, to mimic the full LATR weight, for acceptance tests of telescope servo performance.

Example: *Commissioning receiver for CCAT-prime, which could support ~3x CMB-S4 optics tubes*





LAT Calibration Equipment

Includes both pre-deployment and on-site validation and calibration equipment
(Nagy parallel talk)

Bandpasses: *FTS measurements* required for instrument performance verification and component separation

Beams: Pre-deployment measurements of LATCR and LATR beams with *chopped artificial sources* and on-site as well as measurements of planets/sources with receivers on telescopes and far-sidelobe measurements of the moon and *artificial sources*

Gain: Astronomical sources and bias steps will be used, and *artificial sources* are being considered

LAT Calibration Equipment (continued)

Mirrors: *Tower holography* will be used to characterize mirror alignment as well as *photogrammetry and/or laser trackers*

Optical efficiency: Pre-deployment measurements of *LATR beam filling blackbody sources*

Optical time constants: Bias step measurements and possibly a *chopped thermal source*

Pointing: Measurements of astronomical sources and *optical star cameras*

Polarization angle efficiency: Pre-deployment measurements of *chopped polarized sources* and on site measurements of astronomical sources and possibly *artificial sources on a tower or drone*

LAT Path Forward

- **Address Chilean Survey Strategy specifications**
- Monitor progress on CCAT-prime and SO fabrication, installation, and commissioning and continue engaging on MOUs.
- Monitor progress on SO receiver fabrication **(Zhu parallel talk)**, installation, and commissioning to inform 85-tube LATR design.
- Evolve detailed South Pole TMA design and construction plans (UChicago); Prototype TMA monolithic mirror and CFRP struts (UChicago, NSF SPO funded)
- Continue investigation and optimization of LAT sidelobe mitigation
- **Detailed engineering design of 85-tube LATR**

Next ~6 months

- Chilean survey strategy covers 68% f_{sky}, which requires observing at 35 deg elevation or lower. Past experience suggests 40 deg or higher is preferred
  - Observing this low degrades sensitivity and introduces systematics (e.g. ground pickup)
  - ACT observes at 40 deg elevation or higher, which would lead to ~65% f_{sky} for CHLATs
  - **Can we reduce Chilean survey area from 68% to ~65% f_{sky}?**
- Prepare for NSF MSRI review in ~April
- **Develop LATR design (see next slide)**
- Develop LATCR design and testing plan; evolved from similar commissioning receiver designs and informed from matured LATR design
- LAT
  - Shielding, panel treatment for reflection/absorption
  - Monolithic mirror development / prototype
- Schedule and prepare for internal project review of CHLAT, SPLAT, and LATR

Next 6 months: LATR

- **Develop LATR design at level appropriate for DOE CD-1 / NSF PDR**
- Define cryo and mechanical interfaces to telescope
  - Define mount to telescope, volume of LATR package (incl. readout), cryogenic plumbing interfaces to telescope (Helium lines, DR pump, etc.)
- Cryogenic design
  - Implement fast-cooldown into design
  - Update heat budget with new lens design, readout, IR filtering design
- Lens design and manufacture
  - Finalize lens optical design and optics tube volume
  - Prototype biconic silicon lens and AR treatment with dicing saw
- Readout
  - Define readout interfaces and volume needed at 300K (warm connectors and boxes), 4K/1K (SQUIDs), 1K wire routing

LAT Summary and Parallel Session

LAT Preliminary Baseline Design is well developed and we have a clear path forward

12:30 → 14:00 Large Aperture Telescopes: Parallel

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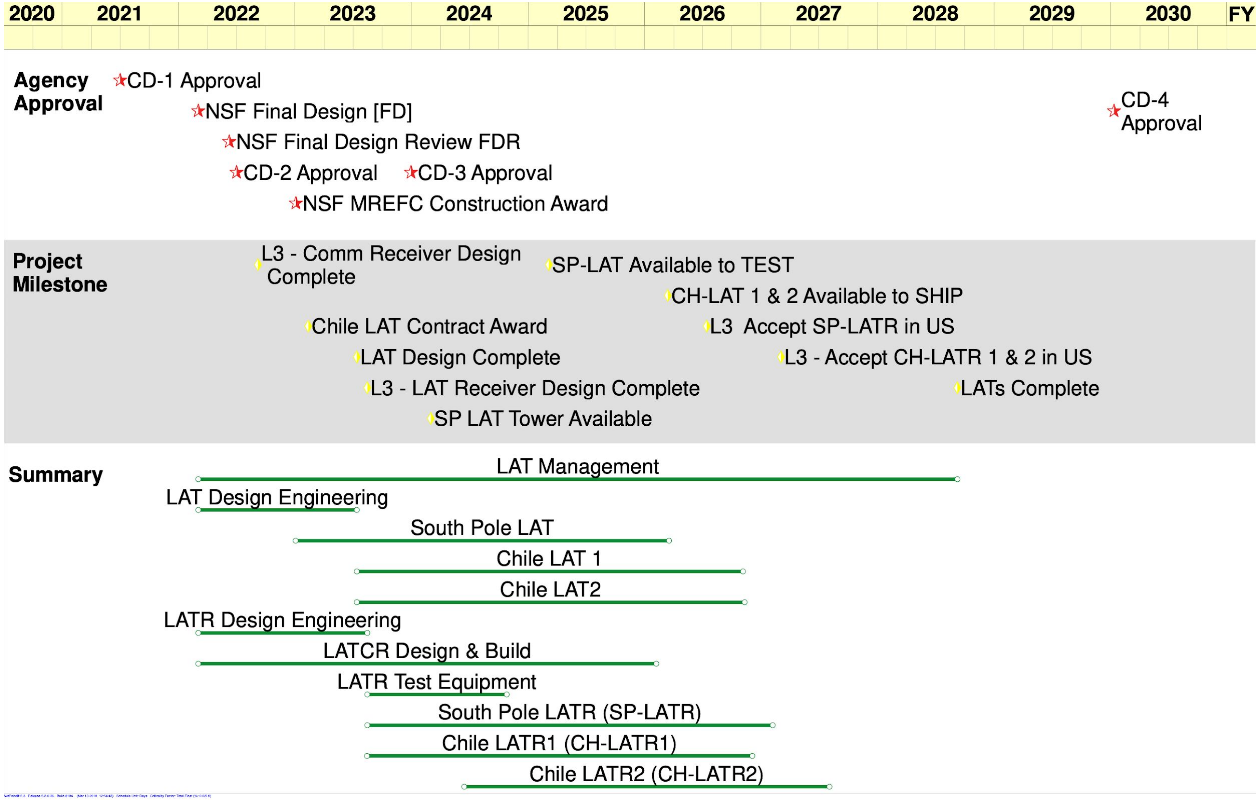
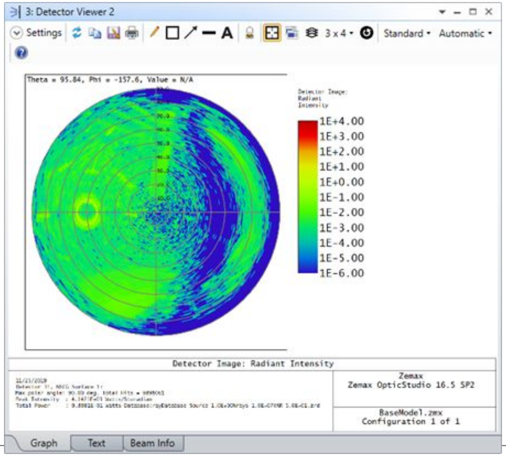
Back-up slides (will probably remove these)

LAT Schedule from 2020

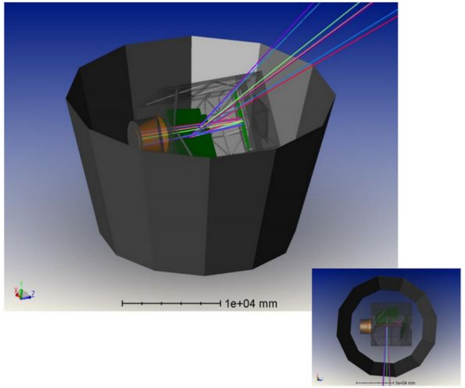


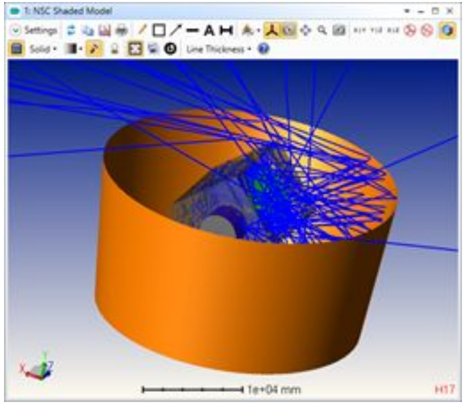
R&D: CHLAT Ground Screen Studies (CQ3)

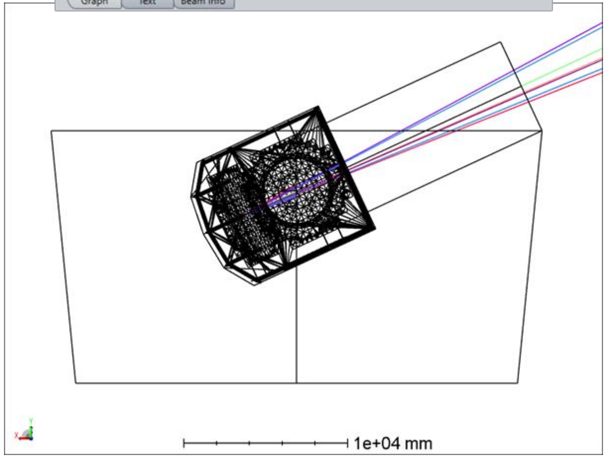
- <u>Minimal model</u>: Cone section <u>Faceted model</u>: 12 facets
- Clears 25 deg elev, 15m radius & 15.4m height
- Sims run for arbitrary elevations & produced half sky sidelobe pattern & ground pickup
- Conclusion: Ground screen does not provide sufficient benefit to be worth implementing, without impacting science
- Simulations underway to investigate alternative sidelobe mitigation methods, to improve LAT performance



CD Faceted ground shield concept







Scale Comparison of TMA & SPT

(CQ3)

Scale of two structures is similar.

Experience constructing and operating SPT informs design of TMA.

TMA tower is taller to allow for its tipping structure to clear snow drift levels when pointing close to horizon.

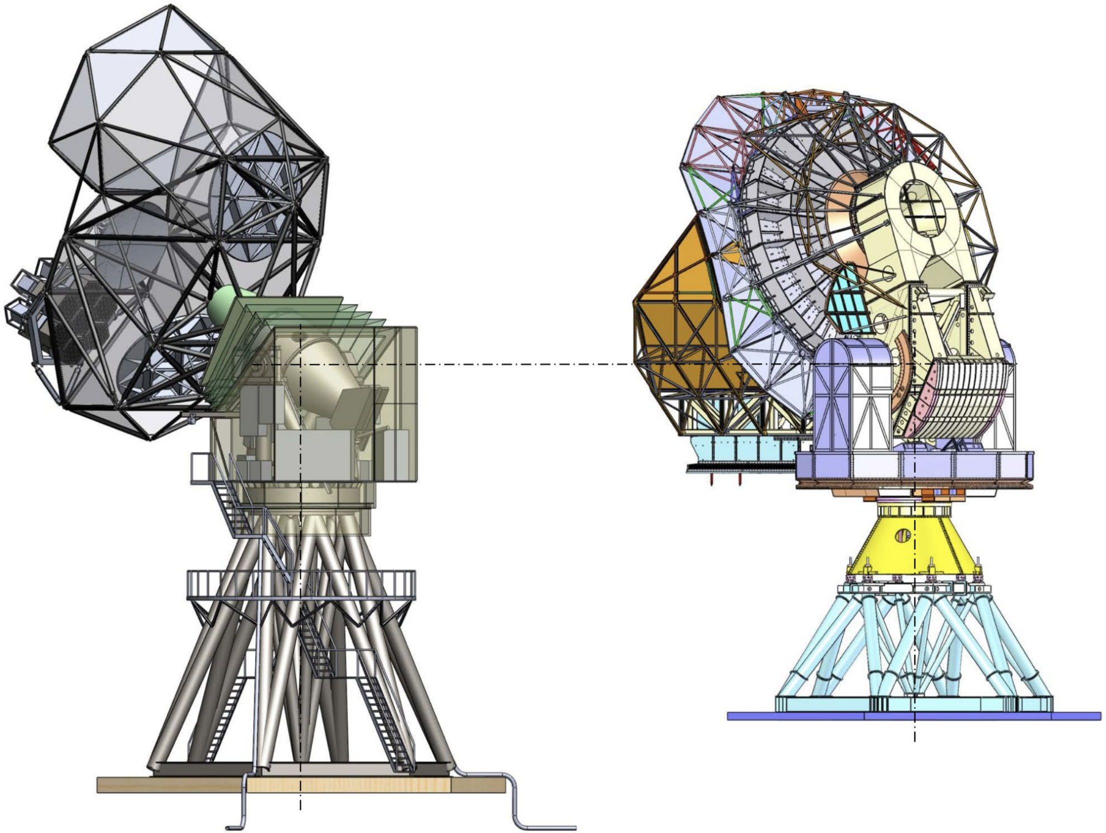
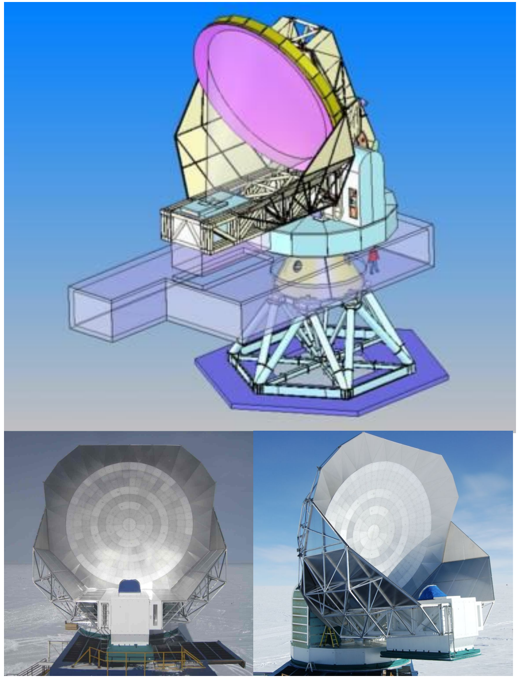


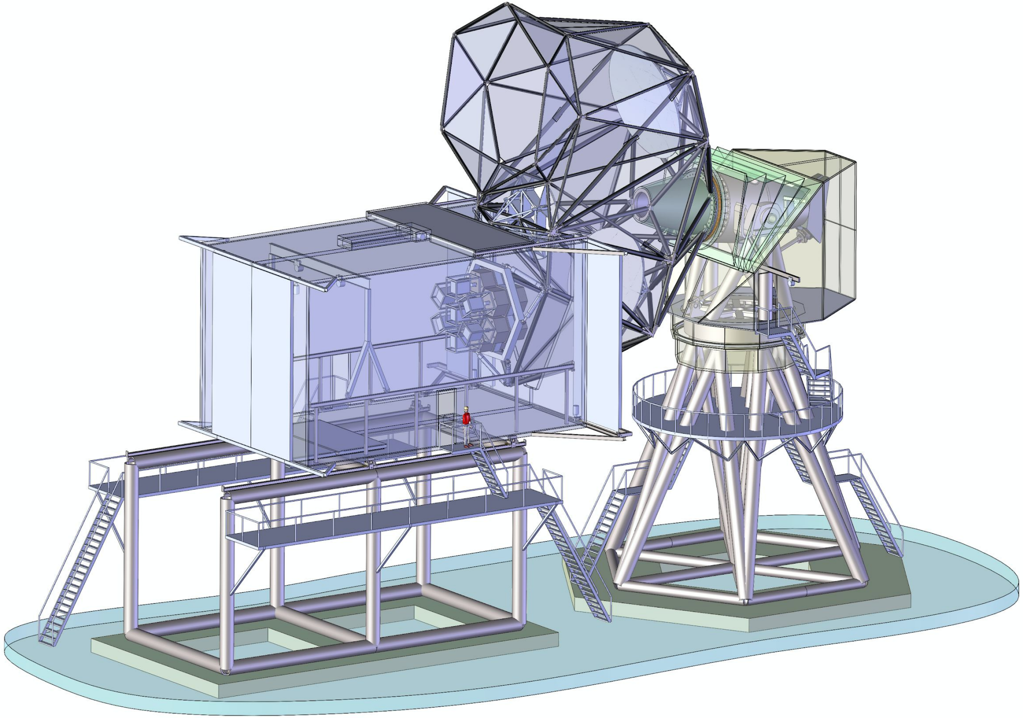
Figure 3: SPTMA vs SPT-3G Rear Views (same scale with elevation-axis aligned)

SP LAT Maintenance High Bay

(CQ3)

Following experience gained from SP telescopes, e.g. SPT





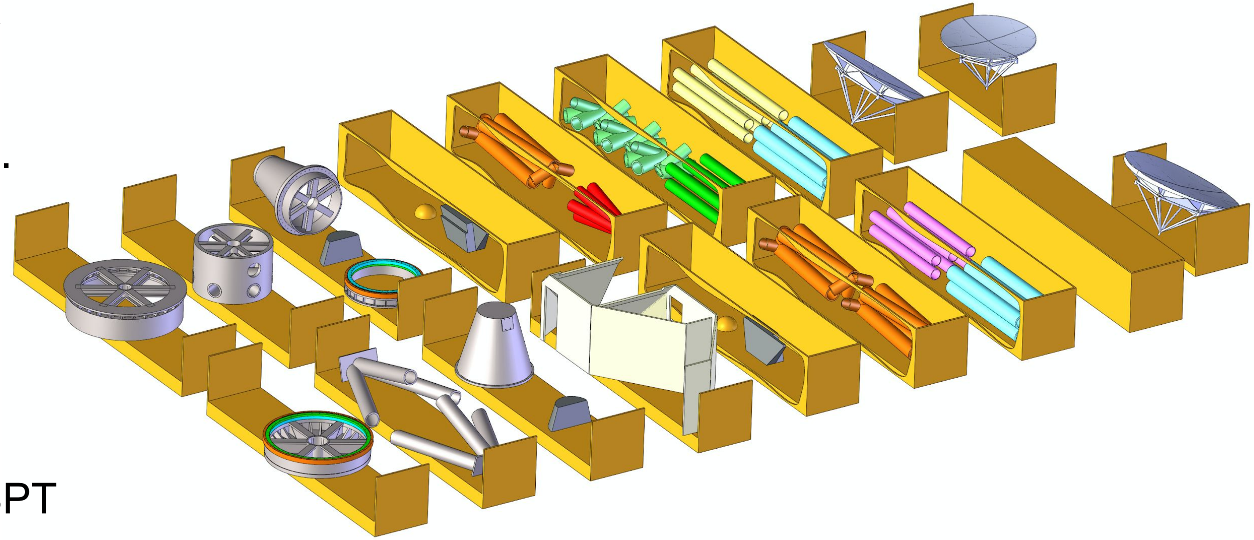
SP LAT Shipping Considerations (CQ3)

Preliminary shipping layout of major telescope components arranged in containers and flat racks

18 containers/flat racks in total.

Sized to stay within 14’ wide restrictions to avoid night travel/police escort conditions.

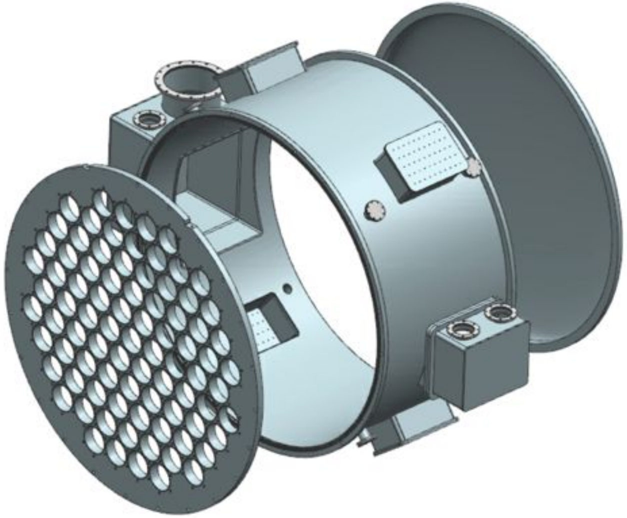
Current total telescope mass estimate is 416 kg, similar to SPT



LATR Cryostat

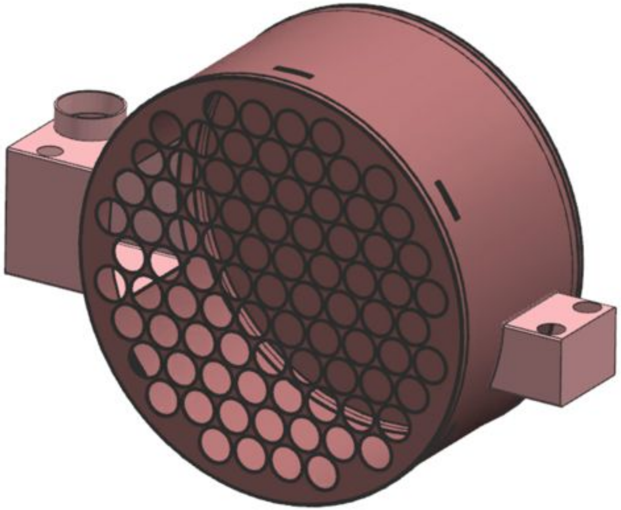
(CQ3)

300K Vacuum Jacket



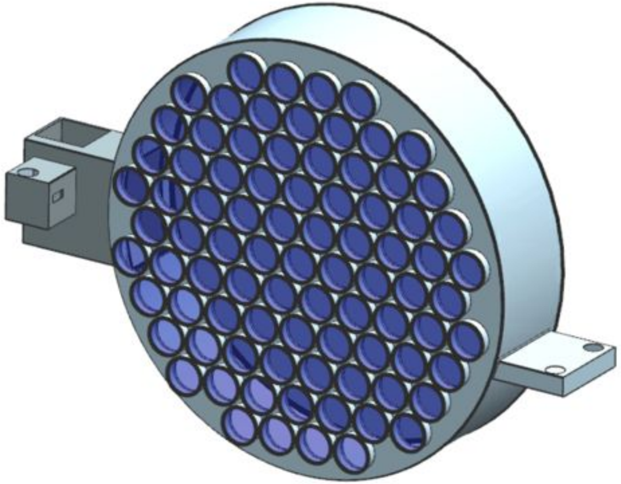
8100 lbs
Stainless Steel

50K Shield Assembly



340 lbs
Aluminum

4K Shield Assembly



340 lbs
Aluminum

Total Cryostat Weight Expected to be ~10,000 lbs