Analysis of Alternatives 2: South Pole Alternatives

CMB-S4 Collaboration Meeting
May 9-13, 2022

Outline

- Brief review of rationale for, and overview of, alternative South Pole configurations (John Carlstrom)
- Potential of low-ell measurements with the TMA design of the SPLAT
  - Review TMA justification (Jeff McMahon)
  - New developments in mirror fabrication (Nick Emerson)
  - Estimates for low-ell sensitivity with SPLAT (Tom Crawford)
- Status of r projections for SP configurations (Tom Crawford et al)
- Risks, R&D (John Kovac)
- Site impact (Amy Bender, Erik Nichols)

Rationale for South Alternatives

- NSF has requested that we analyze alternative South Pole options, starting with simply continuing the ongoing SP CMB program, and developing options that fit within the current SP logistical infrastructure, for which a primary, but not sole constraint, is station power generation.
- NSF has premised that the continued funding of CMB-S4 Design and Development effort must be directed toward the development and analysis of these options.
- Future NSF funding and engagement and DOE funding rests on showing there is a supportable path forward for NSF at South Pole, or an all-Chile configuration is viable.

We must therefore develop and analyze alternative SP configurations, and not only the initial DOE AoA options.

Overview of South Pole Configurations

Basis for considerations of SP options

- Programmatic foundation:
  - Configurations to fit within scope of existing/planned logistical capacity (power, transport, lodging)
  - Project implementation risks must be lowered relative to CMB-S4 baseline design
  - Science risks need to be understood and include feasible mitigation plans
  - Operational demands should be of a scale similar to existing facilities
- Scientific foundation:
  - Recent advances in gapless mirror fabrication for SPLAT (NSF funded) & demonstrated improvement of SPT-3G low-ell noise systematics, including understanding and the possible mitigation of variable *polarized* atmospheric signal, indicates data from SPLAT may be able to provide significant low-ell sensitivity for "*r*"
  - CMB-S4 Inflation science goal, "*r*" must be achievable with high probability and low risk
  - Observing duration should be reasonable and short enough to ensure other initiatives do not "beat us to the punch."
  - Build on Stage 3 experiment successes

South Pole Alternatives to be Evaluated

Configuration		Power req'ts	Comments
0	Nothing	None past SPO	None
1a	Maintain SPT-3G & BICEP Array (BA) (including BICEP3)	No change	Current level logistical support
1b	Install BICEP Array (BA) Tower (BART) and BA mount (i.e., CMB-S4 SAT mount); Install CMB-S4 detectors in 1 BA tube, i.e., pathfinder SAT (pSAT)	No increase, roughly neutral	Allows MAPO Lab bldg raise w/o interrupting BA observations; Allows field testing of CMB-S4 detectors and tests to optimize SATs
2a	Install SPLAT/LATR; Turn-off SPT and BICEP3 when SPLAT turns on.	Approximately neutral since SPLAT power ~ SPT + BICEP3 power; High Bay power only for LATR maintenance	Construction: SPLAT, High Bay, and Ice pads Logistics: Minimize airlift cargo with traverse, which is req'd for SPLAT mirrors
2b	Add CMB-S4 SAT on site of current BA tower (MAPO configured with 2 towers as in the past)	Increase of ~37kW from current; fits within *current* SP power generation	Reuse existing BA SAT mount; New BART(or possibly reuse old)
2c	SPLAT/LATR with 3 CMB-S4 SATs (BA replaced with 2 CMB-S4 SATs)	Increase of ~53kW from current; may fit within *current* SP power generation	New CMB-S4 SATs and new SAT mount and tower
3	Instead, two or more smaller aperture SPLATs (smaller than baseline 5 meter design) with or without SATs*	Two or more SPLATs will exceed current power generation capacity	Smaller SPLAT has reduced de-lensing and low-ell sensitivity; will require 2 or more SPLATs; Lack of checks for systematics if not paired with SATs, including SPLATxSAT correlations
4	CMB-S4 Current Baseline Design: 6x3 SATs, Lab Bldg, SPLAT, High-Bay	~368kW SS (~210 kW beyond current CMB usage, assuming SPT and BA turned off)	As described in CMB-S4 Preliminary Baseline Design Report (PBDR)

* Not evaluating smaller SPLATs at this time
* Not evaluating distribution of SATs and LATs between sites until Chile r option better understood

Value Engineering Approach for SP Configurations 1 & 2

- Follows past trend of reusing equipment, while continuing to make progress toward “r”
- Provide continuous stream of science results; engage scientists; addresses OPP’s “capacity building” for Antarctic scientists
- Use of traverse for all but Do Not Freeze (DNF) materials would significantly reduces demand on LC-130 fleet and provide opportunities for increased efficiency in site construction with pre-assembly at MCM
- Does not require a new laboratory building
- Carefully consider methods to increase detector/power of SATs and SPLAT
- Need to investigate further power savings opportunities, as well as alternate power generation, e.g., solar, wind.

Potential of low-ell measurements with the TMA design of the SPLAT (South Pole Large Aperture Telescope)

Review TMA Motivation (Jeff)

SPLAT measurement drivers:

Everything we can to support the B-mode measurement

- delensing for the ultra deep survey
- 20 GHz channel for the ultra deep survey B-mode foregrounds
- Margin for B-modes

And to support the CHLAT science cases

- 10% contribution to the Neff measurement
- Transients

Table 1: Summary of high level instrument and survey parameters

Telescope	SAT	SPLAT	CHLAT
Minimum Limiting Aperture Diameter[a] (m)	0.40	5	6
Minimum Main Beam Efficiency[b] (%)	95	95	95
Number of Detectors (count)	147,936	129,024	275,992
Number of Detector Wafers[c] (count)	216	85	170
Frequency Coverage (GHz)	22-300	18-300	22-300
Number of Frequency Bands[d] (count)	8	7	6
Receiver Unit Fractional Bandwidth[e]	2.2:1	2.2:1	2.2:1
Survey Area (deg^2)	1200	1200	28000
Frequency Coverage Uniformity[f] (%)	97	97	97
Boresite Rotation	required	required	unnecessary
Scan Speed (deg. s^{-1})	4	3	3
Turnaround Efficiency (%)	95	95	95
Side-lobe Suppression to the Ground[g] (dBi)	-60	-60	-30
Side-lobe Suppression to the Galaxy[h] (dBi)	-30	-30	0
Mimimum Operating Temperature (C)	-80	-80	-20

Important footnotes: (b) beam efficiency is expressed in ell space at angular scales relevant for each measurement, **(g,h)** are expressed after band pass filtering the sidelobe structure for scales relevant to each measurement, for example 0.5-10 degrees for the SATs and SPLAT. **These parameters are subordinate to the instrument requirements and should be regarded as a helpful explanation of the reasoning behind the instrument configuration**

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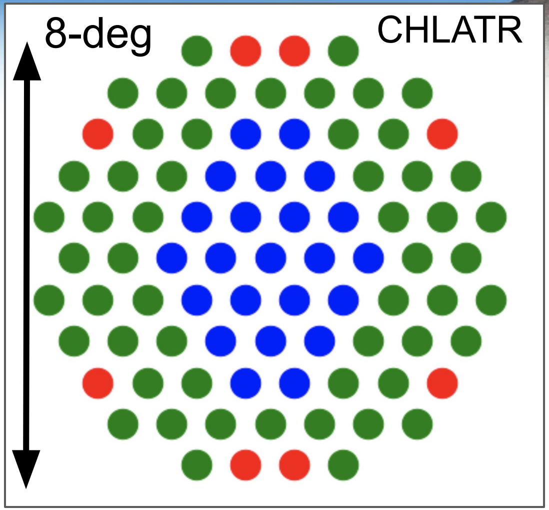
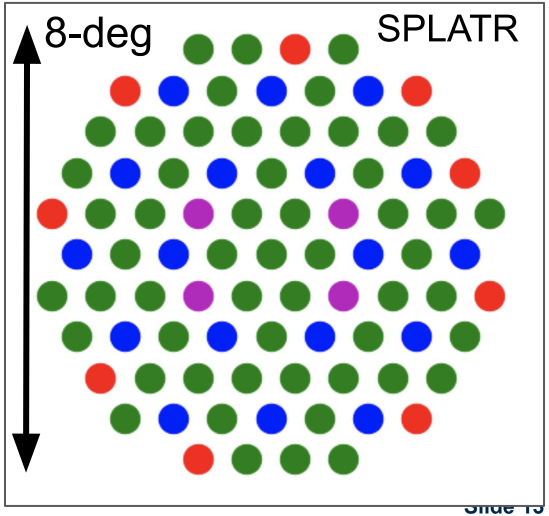
Survey Uniformity and CD versus TMA optics design

- Survey comparisons
  - South Pole Survey covers ~3% of sky
  - Chilean Survey covers > 50% of sky
- FOVs of both LATs are ~8 deg diameter
- For a small survey uniform frequency distribution across the FOV is critical to achieve full overlap between frequencies
- CHLAT two mirror optics have best image quality in middle, so all high frequency optics tubes must be in middle
- **SPLAT three mirror optics correct astigmatism, such that high frequency tubes can be distributed uniformly across FOV to achieve required survey uniformity → crucial for maximizing frequency coverage uniformity**

CHLATR Frequency Band Layout by Tube
- 8 LF
- 54 MF
- 23 HF

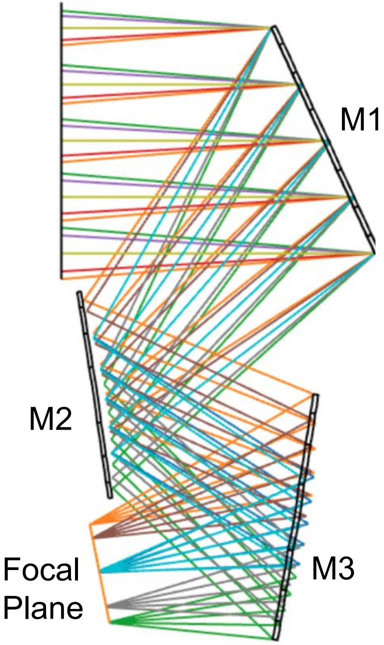


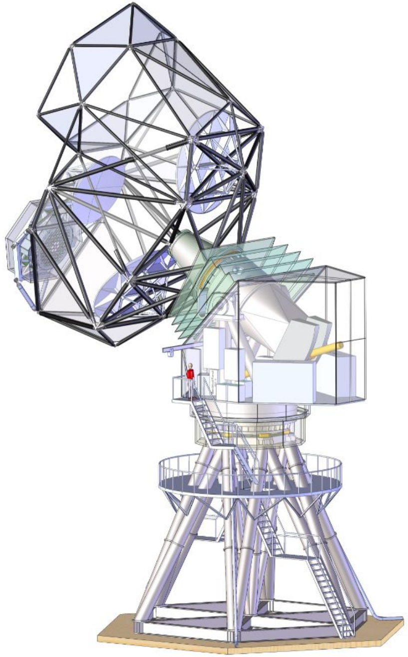
SPLATR Frequency Band Layout by Tube
- 4 ULF
- 9 LF
- 54 MF
- 18 HF



Preliminary Baseline SPLAT Design

- 5 meter aperture meets requirements for lensing (resolution and detector count), transients, and support of the N_eff measurement but is small enough to enable gapless mirrors.
- The design meets the requirements for operation in the South Pole environment
- Key features achieve survey uniformity and mitigate systematics for Level 1 B-mode measurement science goals
    - **TMA design** provides better image quality, which is critical for uniform frequency coverage of smaller field from South Pole
    - **Monolithic mirrors** eliminate panel gap sidelobes to prevent B-mode contamination
    - **Boresight rotation** to mitigate B-mode systematics by rotating polarization (Q ⟷ U)





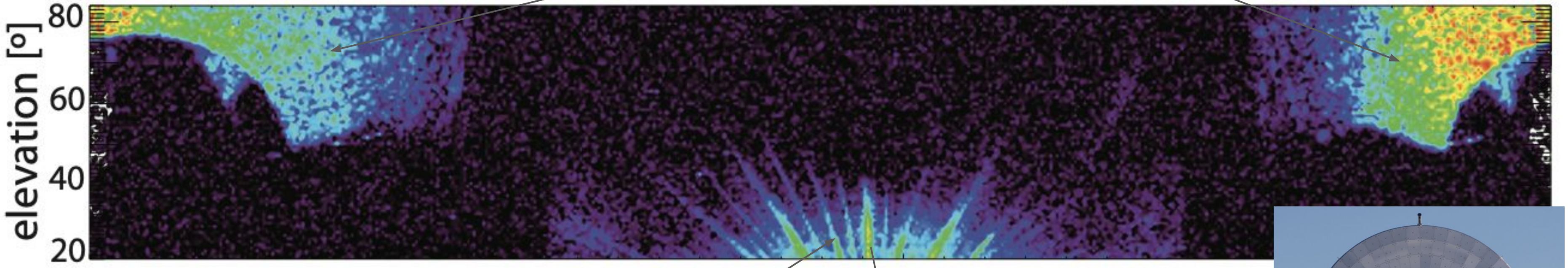
South Pole Design:
5m Three Mirror Anastigmat (TMA)

Padin Applied Optics 2018, 57(9), SPTMA Wiki

Gallardo et al. 2022 in prep.

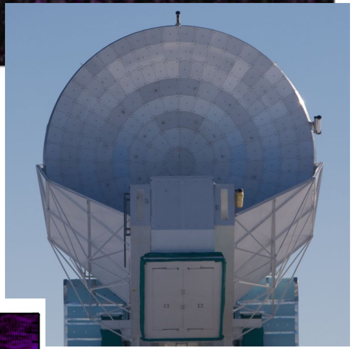
Sidelobes on Existing Instruments: SPT

Scattering from the receiver, hits the ground

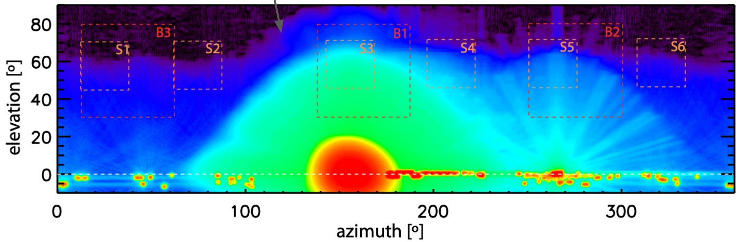


Panel gap diffraction, hits the ground

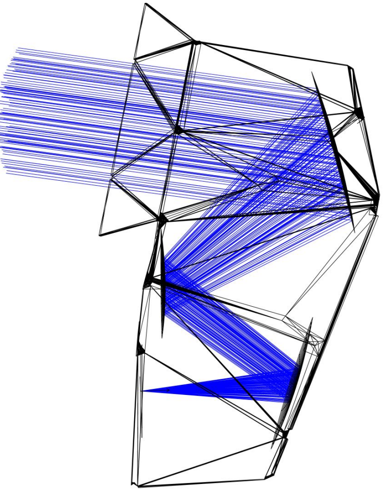
Convolved with ground to estimate scan synchronous signals



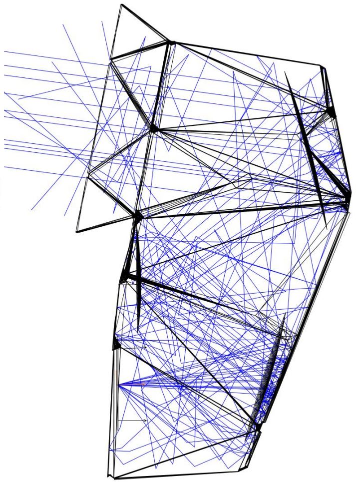
Measurements of the SPT-SZ far sidelobes



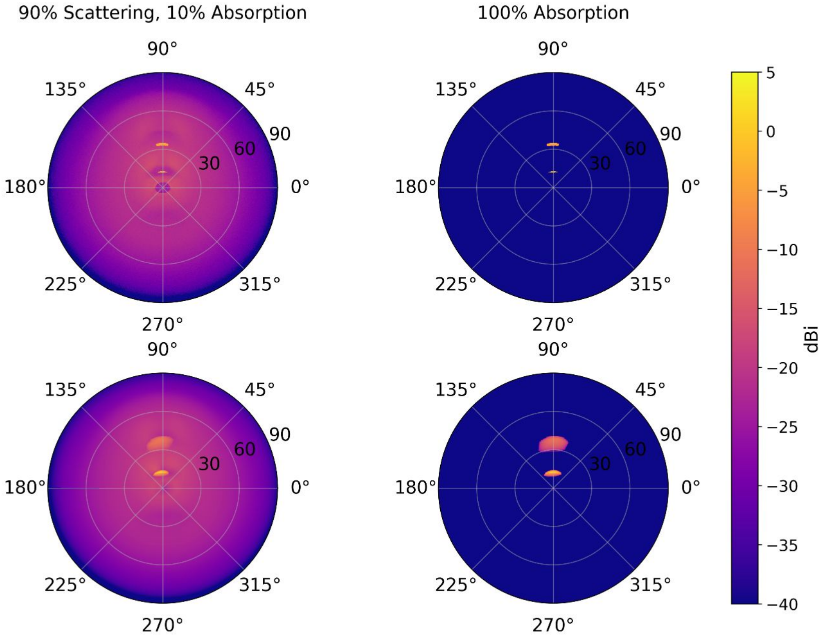
Stringent Sidelobes control with the SPTMA



Clean



Scattering @ Window



Monolithic mirrors → no panel gap diffraction spikes

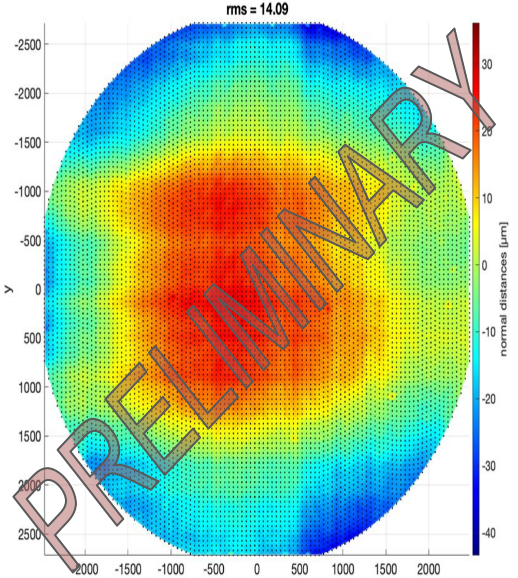
Baffling controls remaining scattering lobes to meet tight requirements on the amplitude and smoothness of sidelobes

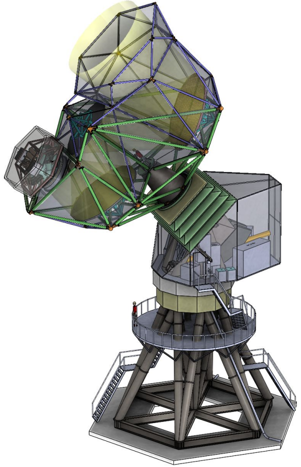
Use ray tracing sims to map sidelobes with different cabin wall treatments
Reflective walls → Sharp features, Scattering walls → Blurry sidelobes

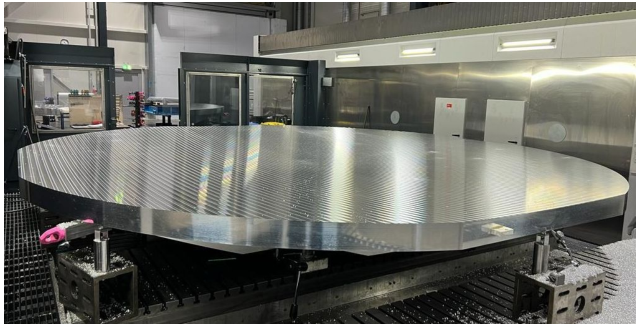
CMB-S4

New developments in mirror fabrication

- Final machining of monolithic 5m prototype SPLAT mirror is now complete
- Preliminary in-house measurement by vendor very promising, with initial result of 14μm rms (goal < 20μm rms)
- Additional measurements, inspection with project team at vendor facility next week to characterize potential measurement systematics and validate support system concept
- Final independent measurement and characterization to take place after delivery to Chicago
- SPLAT Design activities have been focused on designs of the 3 mirrors, mirror support systems



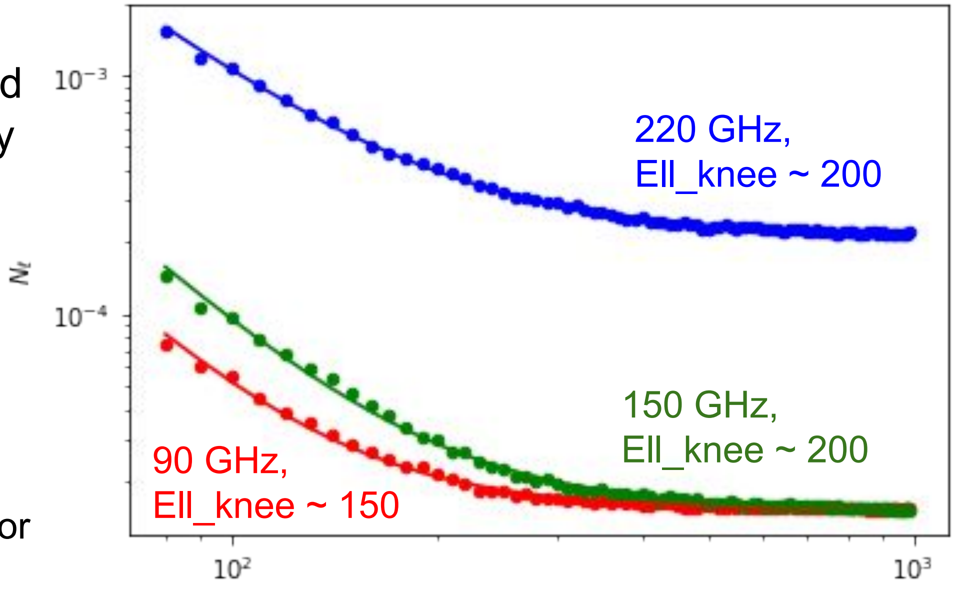




Low-ell performance from LATs (Tom)

Current SPLAT low-ell noise specs (ell_knee and alpha) from analysis of SPT-3G Q and U data by Jessica Avva, Raphael Flauger, and TC.

- Note: This is achieved performance from a segmented mirror with no boresight rotation.
- Noise-wise, this is conservative to use for the SPTMA.
- But who knows about degree-scale B-mode systematics, so most conservative assumption is that we can use no information from the SPLAT for degree-scale B modes.
- “Optimistic” projections will assume we can use this low-ell information, with the parameters shown at right.
- “Goal” case discussed on next slide.



Parameters used in forecasting, extrapolated from above:

Freq	ell-knee	alpha
27	150	-2.7
39	150	-2.7
93	150	-2.7
145	200	-2.6
225	200	-2.2
278	200	-2.2

Low-ell performance from LATs

Possible mitigation of low-ell noise increase at 90/150 GHz (particularly 150) by exploiting strong correlation of low-ell noise between bands.

- Simply put, subtract 220 GHz noise times some coefficient from 90/150 GHz signal+noise data.
- Seems to work very well: significant reduction in noise with no bias to signal (and does not throw out 220 GHz data).
- Particularly useful on days when Q noise is much higher than U noise, consistent with polarized Rayleigh scattering of ground emission off of ice crystals in the air. (cf. work by Satoru Takakura—now postdoc at Colorado—with Polarbear data, arXiv:1809.06556).
- Work led by Jessica Avva, Anna Coerver, Neil Goeckner-Wald at UCB under supervision of Bill Holzapfel.
- Should have reasonably final achieved noise spectra to use in next rounds of AoA forecasting. **NO “GOAL” FORECASTS DISCUSSED TODAY.**

Forecasting alternative South Pole configurations

- Led by Victor Buza (primary author of CMB-S4 r forecasting paper and creator of primary low-ell BB analysis working group forecasting code). Kimmy Wu providing delensing forecasts. Raphael Flauger and Colin Bischoff vetting results against previous results and Chile AoA pipeline.
- Details of pipeline discussed earlier by Colin (see Chile AoA slides). For full details, see forecasting paper: https://iopscience.iop.org/article/10.3847/1538-4357/ac1596/pdf .
- **WORK IN PROGRESS** - we will not report quantitative results until we have vetted them and made sure they are consistent with other pipelines and previous results.

Forecasting alternative South Pole configurations

- **MAIN QUALITATIVE TAKEAWAYS (none of these are surprising)**:
  - Alternatives 1a (BICEP Array + SPT-3G) and 1b (same plus “pSAT”) are not viable: CMB-S4 r goals not reached in 50 years of running.
  - These alternatives are **delensing**-limited: Need SPLAT upgrade to reach CMB-S4 r goals.
  - With upgraded SPLAT, we are **foreground**-limited. Need more degree-scale sensitivity. With only BICEP Array and “pSAT” (power-neutral alternative 2a), we would need to use low-ell info from SPLAT (which increases risk) and much longer integration time to reach goals.
  - Nearly power-neutral alternative 2c (replace SPT with SPTMA, turn off BICEP3 and BICEP Array, install three 3-tube SAT assemblies, would add ~50 kW to power budget) achieves CMB-S4 r goals in <14 years with no SPLAT low-ell information and without folding in BK information.
    - This is by construction, as it is the same LAT effort and ½ the SAT effort as the PBDR, so it can’t take more than twice the time.
    - Faster if folding in BK and running full SPLAT for more than 7 years.
    - Faster yet if able to demonstrate clean SPLAT low-ell performance.

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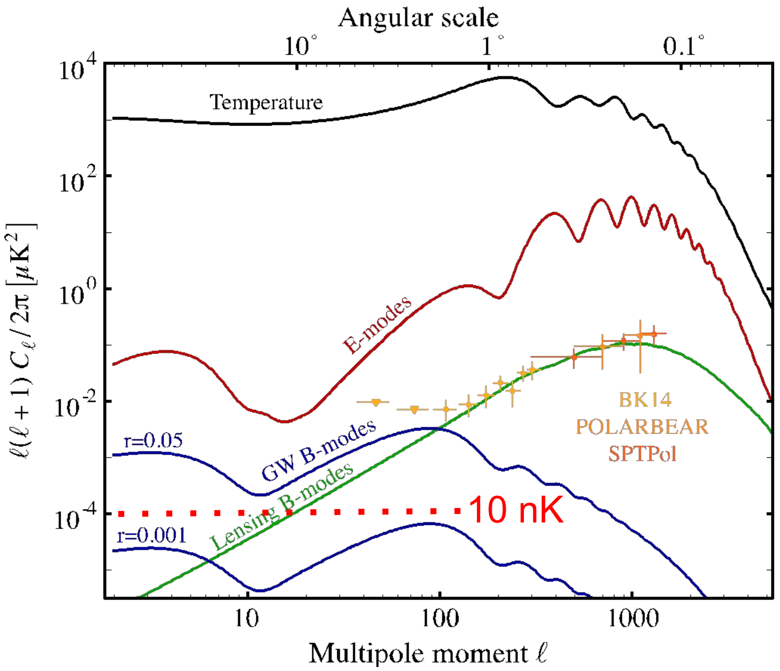
Risks, R&D (John Kovac)

SAT/low-ell Design Drivers (slides from 2018-2020 & DSR)

- Science Requirement driving SATs:
  - r < 0.001 at 95%, or detect r = 0.003 at high confidence (DSR ch. 2)
- this means < 10 nK (!!) uncertainties at degree scales:
  - raw sensitivity
  - systematic control
  - foreground separation

…all made harder at degree scales by

1/ell noise & red-spectrum confusion signals



DSR, Fig 1

Extreme experimental challenge – paper studies alone cannot retire risks.

→ Our design approach is to build on what's been proven to work in deep r measurements for Stage 1, 2, 3…

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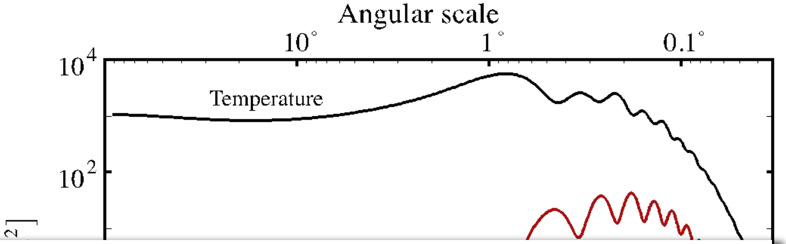

from DSR p. 115

In making design choices we have distinguished between *engineering issues*, those that can be fully developed and demonstrated in the lab to retire risk, and *science issues*, those whose impact on successfully meeting the measurement and science requirements must be judged with comparison to direct experience of making deep *B*-mode maps. For example, cryostat design is primarily an engineering issue because we are confident our design choices can be fully validated in the lab. Examples of science issues include beam and sidelobe optical performance, polarization modulation approach, ground pickup and shielding, and other systematic effects, and for design choices that impact these issues we have endeavored to stay close to and to build upon proven experience.

1/ell noise & red-spectrum confusion signals

Extreme experimental challenge – paper studies alone cannot retire risks.

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DSR, Fig 1

Risks, R&D (John Kovac)

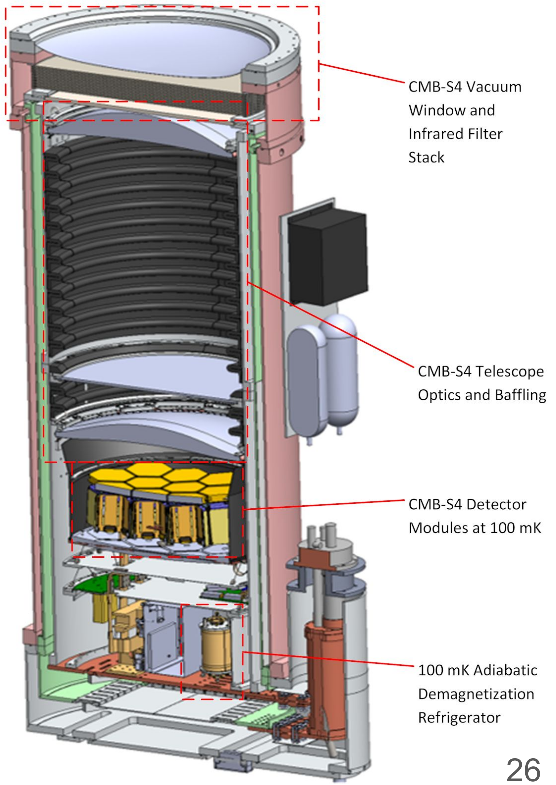
- Baseline Design prioritizes control of science performance risk + readiness
- Alternatives will carry additional science risk (field demo) or engineering risk (lab R&D)
- Chile SATs, 3 alternative optical configurations considered
  - each carry different additional science risks
  - Can place lower bound on number SATs needed vs Pole, upper bound is harder (requires field demo)
- Pole alternatives to baseline can be considered, with different timelines to retiring risks
  - Reducing SAT power consumption is most straightforward “engineering risk” alternative
    - On paper, a path to ~18kW per SAT cryostat
  - Big-SAT idea: use much larger aperture to increase detector count per kW
    - Trying to keep shielding and systematics risks the same
  - Pushing to higher pixel count per SAT by using:
    - more aggressive optics illumination (e.g. Ruhl’s slide w/ Chile #3 level, gaining ~50% per tube)
    - alternate detector (planar antenna) or readout (RF mux for HF) technologies
    - relaxed shielding requirements

pSAT: Risk retirement and design optimization for CMB-S4

pSAT = single tube, 100mK MF-2 prototype testbed in spare BA cryostat aims to offer CMB-S4 :

- “Direct correlation of laboratory component-level performance measurements with deployed system performance”
- Risk retirement on in-field sensitivity and systematics resulting from new S4 design features; comparative testing vs. previous choices:
  - Dichroic optics (sensitivity, optics performance)
  - Curved focal plane and other S4 baseline optics refinements
  - Horns (crosstalk, beam systematics)
  - Subsystem performance of prototype modules, readout, potentially DAQ, cal
- Updated estimates for end-to-end map depth per detector
- Potential for design optimization studies
  - Optics Tube throughput (horn density, aperture)
  - External Shielding geometry – informs # tubes possible for given footprint
- “Experience gained in integrating, deploying, and calibrating CMB-S4 hardware during the pSAT effort will help inform CMB-S4’s commissioning, calibration, and operations planning, well in advance of construction of the CMB-S4 production hardware.”

Pathfinder SAT Instrument



“Science Risks” for low-ell BB to worry about:

- Shielding from time-variable scan-fixed pickup from ground /sun
  - Ground subtraction limits BK filtering and low-ell information recovery
  - Chile environment is dramatically different in terrain and diurnal stability
  - SPLAT shielding may not include absorbing forebaffle or outer groundshield
- Boresight rotation
  - 360-deg boresight rotation tests/mitigates effects @ 90- and 180-deg (table 2 arXiv:1502.00608)
  - SO and SPLAT may have more limited rotation (45-deg Q→U)
- Correlated polarized 1/ell from atmosphere
  - Measurable effect on current BK 1/ell in higher bands (~partially factored into forecasting)
  - Not well understood how scales between sites or angular scales
  - Impact of concentrating lines of sight with many more detectors needs to be understood
- Correlated polarized 1/ell from instrument
  - Control of common-mode polarized pickup from mirrors, baffles (everything outside window)
- Unknown unknowns
  - for any new measurement approach, we can expect new problems to emerge.

Site Impacts to Explore

Amy Bender & Erik Nichols

- Electrical power
- Fuel
- Site layout
- On-site personnel
- Safety, flexibility, complexity, risks of site operations

Electrical Power Considerations

Guidance is to fit in ‘existing footprint’.

- Power currently supporting SPT-3G, BICEP3, BICEP Array would be used to support CMB-S4
- Estimate (**average consumption**) is based on a combination of measurements and manufacturer specifications
  - SPT-3G: 58.6 kW (telescope drives, compressors, cooling loop, compute, electronics)
  - BICEP3: 18 kW (mount, compressor, electronics)
  - BICEP Array: 62 kW (telescope, electronics, tower support systems)

CMB-S4 power consumption is factorized by element. Focus on steady-state consumption.

SPLAT	82.2 kW	Telescope, glycol system, heaters, compressors, DR, readout, DAQ [current design]
High Bay	7.5 kW	HVAC fans, lights, monitor system, misc science equip (assumes not moving/using cranes). Heat supplied by boiler & fuel.
SAT	31 kW	Mount, compressors, DR, readout, DAQ [current design]
SAT tower	4 kW	air handler, glycol system, lights, misc equipment. No other source of heat.
1x SAT support building (MAPO or lab building)	15.5 kW	MAPO: HVAC, lights, misc science equip.. Heated by furnace and fuel. **MAPO is currently supported within station footprint.** Lab building options also exist, need to explore matrix of power/fuel efficiency.
DM System	4.2 kW	**Reduced** alternative: 2x copies of 1 month spinning data storage, 5 compute nodes for DQ processing

Electrical Power Summary

Configuration		Power Compared to Current CMB Consumption at South Pole
1b	Install BICEP Array (BA) Tower (BART) and BA mount (i.e., CMB-S4 SAT mount); Install CMB-S4 detectors in 1 BA tube, i.e., pathfinder SAT (pSAT)	No increase - neutral
2a	Install SPLAT/LATR; Turn-off SPT and BICEP3 when SPLAT turns on.	+9.8 kW for SPLAT/LATR +17.3 kW for SPLAT/LATR + high bay
2b	Add CMB-S4 SAT on site of current BA tower (MAPO configured with 2 towers as in the past)	+36.7 kW for SPLAT + BA + S4 SAT (no high bay)
2c	SPLAT/LATR with 3 CMB-S4 SATs (BA replaced with 2 CMB-S4 SATs)	+52.8 kW for SPLAT + 3x S4 SAT
3	Instead, two or more smaller aperture SPLATs (smaller than baseline 5 meter design) with or without SATs	Further design information required to estimate, 2x SPLAT would be significant power consumption
4	CMB-S4 Current Baseline Design: 6x3 SATs, Lab Bldg, SPLAT, High-Bay, Full DM system	+210 kW for all

- Station current electrical power usage headroom ~ 50 kW
  - Within current CMB usage, enough power for **SPLAT + DM + BA + S4 SAT**
  - **Increase to 3x S4 SAT and/or inclusion of high bay** is on scale of current capability
  - If we can further optimize CMB-S4 design (SPLAT or SAT or infrastructure) for power efficiency, …. *More CMB-S4 SATs could be possible*.

Fuel Considerations

- Fuel is used to generate electrical power, building heat, and for vehicles.
  - Note that they can interchange depending on design decisions.
  - Assume personnel vehicle fuel usage is comparatively small and same in all scenarios. Focus on telescopes & buildings
    - Plan to incorporate heavy equipment in next update (crane etc)
- Estimate fuel consumption for 1 year when component is in a 'full usage' mode

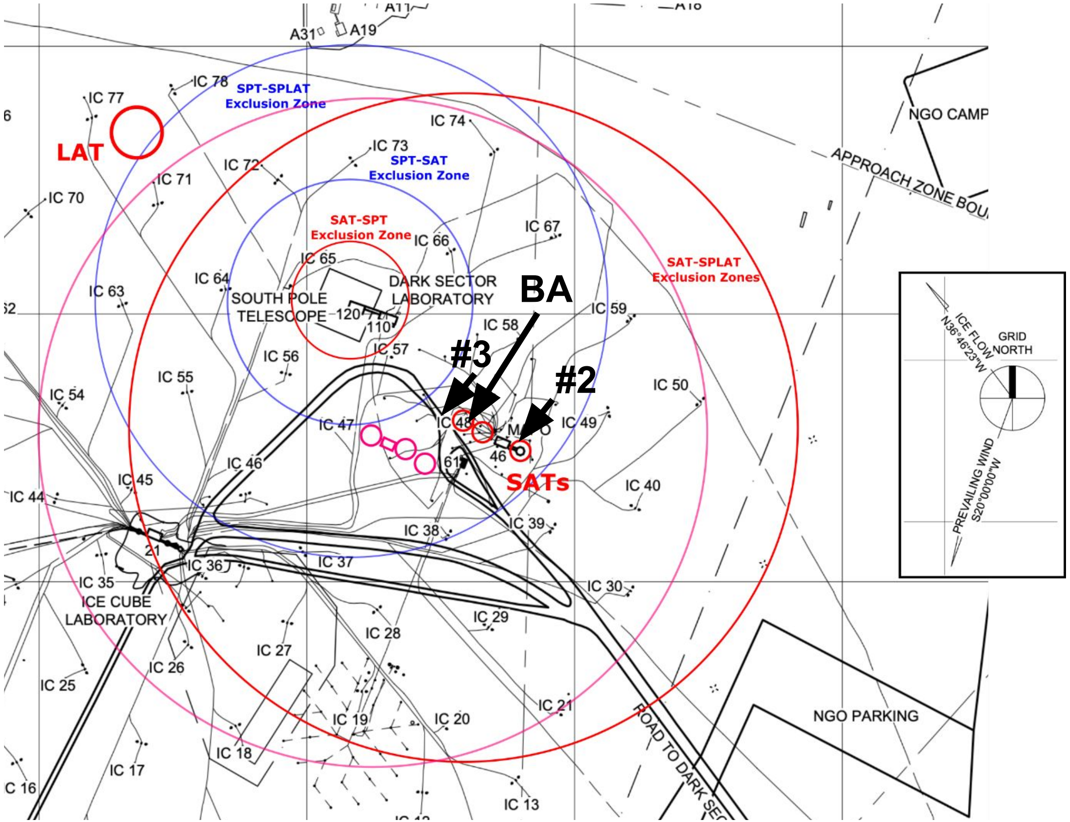
Configuration	Heating Fuel	Notes
SPLAT	N/A	Waste heat from compressors
High bay	~18,500 gal	Boiler for heat
SAT + Tower	N/A	Waste heat from compressors
MAPO	~18,500 gal	**Already supported** furnace & electrical
Lab Building	N/A	Either electric heat or DM waste heat
DM System	N/A	Full or alternate DM system can generate usable heat

Fuel Summary

- Significant contribution from highbay leads us to explore alternate configurations to support the SPLAT (more later)
- Additional electrical power consumption also increases fuel consumption
  - Efforts to optimize for electrical power will similarly reduce fuel
- Need to consider both transportation and storage capabilities as AoA continues
  - Transportation: primarily via overland traverse that runs 3x in an austral summer
    - For example: Case 2c (no high bay) corresponds to 20% more fuel on one of the traverses

Site Layout Considerations

- BA will still be next to MAPO to allow use as support building
- Current plan is to **keep SATs 1-3 in same position** as baseline
  - Limits impact of ground pickup requirement & enables shared use of tools/equipment between SATs
- Combination of ground pickup, site restricted zones and Icecube drive baseline position of SPLAT
  - Suggest retaining baseline location to continue to meet requirements
  - Also preserves possibility of future expansion back to baseline
- Without the lab building, a new home for the DM system will need to be identified



On-site personnel

- On-site summer and winter population depends not only on what is being built but also the schedule
  - Current schedule assumed ‘technically limited’ pace
  - Yearly schedule will be examined for each alternative **and optimized for population limits**
- Management/safety on-site will be similar in all scenarios
  - DM system install is also included in tallies on following slide (1-3 people depending on system)
- Personnel is combination of both major construction & I&C
  - If no lab building or high bay, infrastructure construction limited to possible MAPO interior renovations
  - Assumes use of 1 existing BART tower
  - SPLAT I&C personnel will increase if no high bay is available (working in colder temporary tent)
  - Need to continue to refine winter populations for different alternatives

On-site personnel: Putting it all together

It is important to remember, this is ***one possible schedule for each alternative***, particularly the one that minimizes years without optimizing for on-site personnel.

Includes extra I&C effort in no high bay option, but not extra setup/takedown crew

This is a feasible population in 2C, with CMB-S4 needing ~⅓ of station beds for 1-2 years. Again, more optimization is possible.

Configuration	Austral Season	Y1	Y2	Y3	Y4
2A) SPLAT only	S	14	34	27	-
	W	-	3	3	-
2A) SPLAT only, w/ high bay	S	14	14	31	18
	W	10	-	3	3
2B) SPLAT + S4 SAT	S	19	44	36	-
	W	5	3	5	-
2B) SPLAT + S4 SAT, w/ high bay	S	14	19	41	27
	W	10	5	3	5
2C) SPLAT + 3x S4 SAT,	S	24	53	54	-
	W	10	3	9	-
2XC) SPLAT + 3x S4 SAT, w/ high bay	S	14	24	50	45
	W	10	10	3	9

Frozen high bay

- Turn off heat when not in active use
  - Modify design such that critical subsystems/components can be removed and stored in heated area
  - Seal all cracks/cover any openings to prevent snow infiltration. Drain fuel lines/glycol loop.
  - Alternatively modify design to that minimal heat is supplied to critical parts/areas to prevent freezing, allow rest of high bay to go cold
- Prepping high bay for use & conversely for freezing will require extra personnel compared to baseline, and time at beginning and end of austral summer
- Significant aspects to be developed
  - How to ***safely*** access LATR in winter in case maintenance is required (i.e., could the winter crew conceivably bring high bay online, and then re-winterize?)
  - Where to store subsystem components that get removed?
  - How would we modify subsystem design (or scale back) to enable removal?
  - Could we group subsystems to keep only a small portion of high bay above freezing (reducing fuel costs, but not to zero)?
  - What systems have risk of failure after freeze/warm cycles?
  - How to protect building seals and chain/rail system for long freeze/ice accumulation?

Long duration balloon (LDB) high bays are winterized and allowed to freeze through McMurdo winter.

Other Considerations Compared to BASELINE

- Complexity
  - Fewer telescopes & buildings leads to less complex construction schedule
  - ‘No high bay’ options required increased complexity in I&C
  - Staying within existing CMB power consumption footprint removes need for independent power generation equipment, reduces complexity
- Development risks
  - ‘No high bay’ options remove development risks for large moving building in South Pole conditions (i.e., ice/snow accumulation on mechanisms). But also adds some risk in developing critical lift & install of LATR
- Flexibility
  - ‘No high bay/frozen high bay’ options reduce flexibility to access LATR in winter
- Performance (site infrastructure related only)
  - Limiting power usage to current CMB envelope likely beneficial to stability of south pole generators
- Reliability
  - ‘Frozen high bay’: subsystems will have some risk of failure due to freezing or extra handling from winterization
  - High bay impacts ability to service SPLAT (knock-on effect of SPLAT problems)
- Safety
  - ‘No high bay/frozen high bay’ options have significant implications for both human & equipment safety both during summer construction and winter operations

Comments / Questions?

Note that there is also a 30 minute AoA Q&A session tomorrow.