Instrument Overview

(and updates)

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Overall post-AoA configuration

Chile:

- **Two 6m CD (like SO) LATs** (aka "CHLATs"), with 85 tube cryostats (LATR)
  - Bands: LF, MF, HF

South Pole:

- **One 5m TMA LAT** (aka "SPLAT"), with an 85 tube cryostat (LATR)
  - Bands: ULF, LF, MF, HF

- Three SAT mounts, each with one cryostat with three 60cm optical tubes
  - **9 tubes total** (down from 18 in previous baseline)
  - Bands: LF, MF1, MF2, HF *(MF's are "split" into low and high)*

Of particular note:

- TMA LAT low ell sensitivity is now included in the baseline r forecasts.
- Observing time for r-science (South Pole) is now ~10 years (was 7). CHLAT obs are still at 7 years.

Design progress

Lots!

See upcoming L2 talks.

"Best Estimate" vs Requirements

- Current "Best estimate" design is captured in: **"CMB-S4 Instrument Description - 2023"** (google spreadsheet)
  https://docs.google.com/spreadsheets/d/1kdXD4dPnWmEMRDwG8Hl6jBj0cdDFoXc2lfT-A8z_jmM/edit?usp=sharing
  - Inputs from many people! Thanks you!
  - See also Sara Simon's "Experiment Models" talk on Wednesday, in the "Simulations and Data Challenges" session
  - This will all soon be archived as a dated "Design freeze" version, which will be used (mostly) for the DC0 simulations.
    - *Exception: CHLAT DC0 sims were already run.*

- Requirements are captured in Jama *(See Bobby Besuner's talk Wednesday)*

- For many things, we've been setting Requirements == Best Estimate, but this is evolving. (Needs more evolution).

- This talk is about design targets and the "best estimate" performance.

Bands : LF and HF

These bands are shared by all telescopes (CHLAT, SPLAT, SATs)

	LF		HF	
Letter name	**LF_1**	**LF_2**	**HF_1**	**HF_2**
(Nominal band "numerical" names)	**25**	**40**	**230**	**280**
Band Center (on-wafer filters, GHz)	24.75	36.5	227.0	285.5
Fractional bandwidth (nu_h - nu_l)/nu_center	0.263	0.466	0.256	0.207
Lower band edge	21.5	28.0	198.0	256.0
Upper band edge	28.0	45.0	256.0	315.0

LF band edges were reviewed and revised in order to make them fit in the OMT bandwidth, and for the OMTs to fit on the wafer given tradeoffs with horn size and pixel count, while looking at sensitivity to CMB and synchrotron.
Numbers in red have changed from previous designs, shifted lower.
Other bands (ULF, MF's, HF) have not been changed.

Bands : Band centers depend on where you measure them.

CHLAT		ULF	LF		MF		HF	
	Totals	20	25	40	90	150	230	280
Band Center (**on-wafer filters**)		20.0	24.75	36.5	91.5	148.5	227.0	285.5
Band center (**at telescope input;** includes effect of optics)		20.2	25.0	37.5	92.8	149.7	227.8	285.8
Band center (**at CMB**; includes effects of optics and atmosphere)		20.2	25.0	37.4	92.9	149.7	227.7	285.6

SPLAT								
Band Center (on-wafer filters)		20.0	24.75	36.5	91.5	148.5	227.0	285.5
Band center (at telescope input; includes effect of optics)		20.2	25.0	37.5	92.8	149.7	227.8	285.8
Band center (at CMB; includes effects of optics and atmosphere)		20.2	25.0	37.4	92.9	149.7	227.7	285.6

SATs		LF		MF1		MF2		HF	
(Nominal band "numerical" names)	Totals	25	40	85	145	95	155	230	280
Band center (on-wafer filters)		24.75	36.50	85.0	145.0	95.0	155.0	227.0	285.5
Band center (at telescope input; includes effect of optics)		25.7	38.7	85.0	144.9	95.0	154.9	226.8	285.3
Band center (at CMB; includes effects of optics and atmosphere)		25.7	38.6	85.1	145.0	95.0	154.9	226.6	285.0

"Band center" here is for a Rayleigh-Jeans source. Need to calculate for other sources.

Sensitivities

Some of the changes in design that have affected sensitivity calculations:

Common factors:

- Using readout NEI = 45pA/sqrt(Hz), R_operating = 6mOhms, rather than assuming a 5% fractional increase in NEP across the board. This improves sensitivity at high frequency bands, hurts it in low frequency bands.
- Using a uniform module efficiency = 65% for all bands, rather than small deviations from that. *(Using tophat bands everywhere; ran with "shaped" bands and found only very small changes)*

LATs:

- f/#'s have increased as the design has become more realistic, decreasing optical efficiency
  - SPLAT camera design is much more mature (see Gallardo etal paper).
  - CHLAT camera design is less mature, but expectation is similar, will run w/ f/2.0 soon.
- Small changes in filters (eg nylon thickness)

SATs:

- HDPE lenses (not silicon) now in HF tubes
- Windows are thinner, 3cm -> 2cm, reducing optical load.

Sensitivities - Changes for LATs

		ULF	LF		MF		HF	
SPLAT	**(new f/# = 2.18)**							
2023	Detector NET_CMB (uKrtsec)	427	412	262	326	299	581	1328
2021	Detector NET_CMB (uKrtsec)	333	287	269	287	269	549	1296
2023	Poptical (pW)	0.11	0.14	0.90	1.17	2.97	8.20	11.85
2021	Poptical (pW)	0.134	0.23	1.41	1.51	3.61	8.61	11.3

CHLAT	**(old f/# = 1.9) (to be re-run with f/# =2.0)**							
2023	Detector NET_CMB (uKrtsec)	395	373	232	290	323	716	1767
2021	Detector NET_CMB (uKrtsec)		314	256	292	327	740	1850
2023	Poptical (pW)	0.17	0.205	1.094	1.495	4.421	12.326	17.641
2021	Poptical (pW)		0.27	1.37	1.56	4.73	12.5	17.0

Dominated by changes in f/#, and LF band edges.
Some impact from readout noise change (esp at low freqs), and window/filter changes (at high freqs)

Sensitivities - Changes for SATs

			LF		MF1		MF2		HF	
SATs			**25**	**40**	**85**	**145**	**95**	**155**	**230**	**280**
2023	Detector NET_CMB (uKrtsec)		164	202	284	285	246	305	623	1509
2021	Detector NET_CMB (uKrtsec)		171	216	314	335	275	360	727	1747
2023	P_optical (pW)		0.58	2.32	2.99	4.36	2.92	4.63	9.96	12.42
2021	P_optical (pW)		0.57	2.57	3.06	5.5	3.2	5.9	13.2	16.2

Dominated by window thickness reduction from 3cm to 2cm, LF band edge changes.

Beams - "to date"

So far we have been using estimates scaled from other experiments (eg BK, SO) rather than bespoke calculations for CMB-S4 that take our design details into account.

CHLAT:

- Have been using circa ~2018 calculations from SO. *(https://cmb-s4.uchicago.edu/wiki/images/Lat-noise-190311.pdf)*
- A 2020 SO paper (https://arxiv.org/pdf/2009.10138.pdf) has updated estimates for MF, HF that we've adopted. *(Need to check whether bands were the same)*

SPLAT

- Have been using CHLAT values scaled by ratio of illuminated primary diameters, (5/5.7).

SAT

- Have been using values from Kovac's BA-scaled "option 5" here (55cm at LF/MF, 44cm at HF): https://docs.google.com/spreadsheets/d/1B9A5-lYr1wAbOUgFDcnYv7q0_WXgXNU7EhlfBRqavm4/edit?usp=sharing

Beams - changes from 2021

Table of 2021 beam sizes vs current best estimate from scalings

Beams - plan

Short term (later this week)**:** Update scalings.

Longer term (fall?): Use real horn illuminations [Modules], real optics [LATs and SATs], to make better estimates. *[Need to organize/plan who is doing what.]*

Short term:

CHLAT: Use 2020 SO paper values at MF to scale to LF.

SPLAT: Update primary illumination diameters to better value, re-do scaling.

SAT: Use "Truncated Gaussian" values derived here (https://github.com/JohnRuhl/CMB_expt/blob/main/cmbs4/BeamEstimates.ipynb), with 56cm diameter aperture and edge tapers given by SAT parameters spreadsheet: https://docs.google.com/spreadsheets/d/1xTZEtBvrsAFqms-Ymj5rgwYUUCGBMwlwPexrQfZEYgI/edit?usp=sharing

Sensitivities - future work

- HF band optimization (including "can all HF wafers have the same Psat?")
- ULF band optimization (including "should it be dichroic"?)
- Real horn+optics frequency-dependent spillover calculations
- Real on-sky beam calculations given horn and telescope designs

Systematics

Things actively being worked on:

LATs

- "Map Multi-Tool" (Alex Hryciuk + Jeff McMahon) *[general paper in progress]*
  - for time constants (AH)
  - for crosstalk (Cesiley King + Johanna Nagy)
- Beam-calibration and N_eff (Maps2Cell project: Dan Grin + Francis-Yan Cyr-Racine)

SATs

- Near beam sidelobes (Kirit Karkare, Clara Vergés)
- Band center knowledge and variations (Colin Bischoff)
- *(Generalized additive & multiplicative framework: KK, CV, CB)*

Need to accelerate this work to have a reasonable story for fall 2023 reviews.

Opportunities to help

Lots of instrument-modeling work is going on in the L2 groups, which all have regular telecons:
(See the "CMB-S4" google calendar, open for anyone to view)

- **Optics, beams, etc:**
  - LAT+LATR Working Groups (Mondays 1:30pm eastern),
  - SAT Working Group (Mondays 5pm eastern)

- **General catch-all:**
  - Systematics+Sensitivity Working Group (alternate Mondays 12:30pm eastern)

- **Other groups and efforts?** (Speak up!)