CMB-S4 Status Update

Julian Borrill

Berkeley Lab & UC Berkeley

CMB-S4 Co-Spokesperson

Overview

- This is primarily a project update, not a review of the science case (which is spectacular!)

1. Project Status

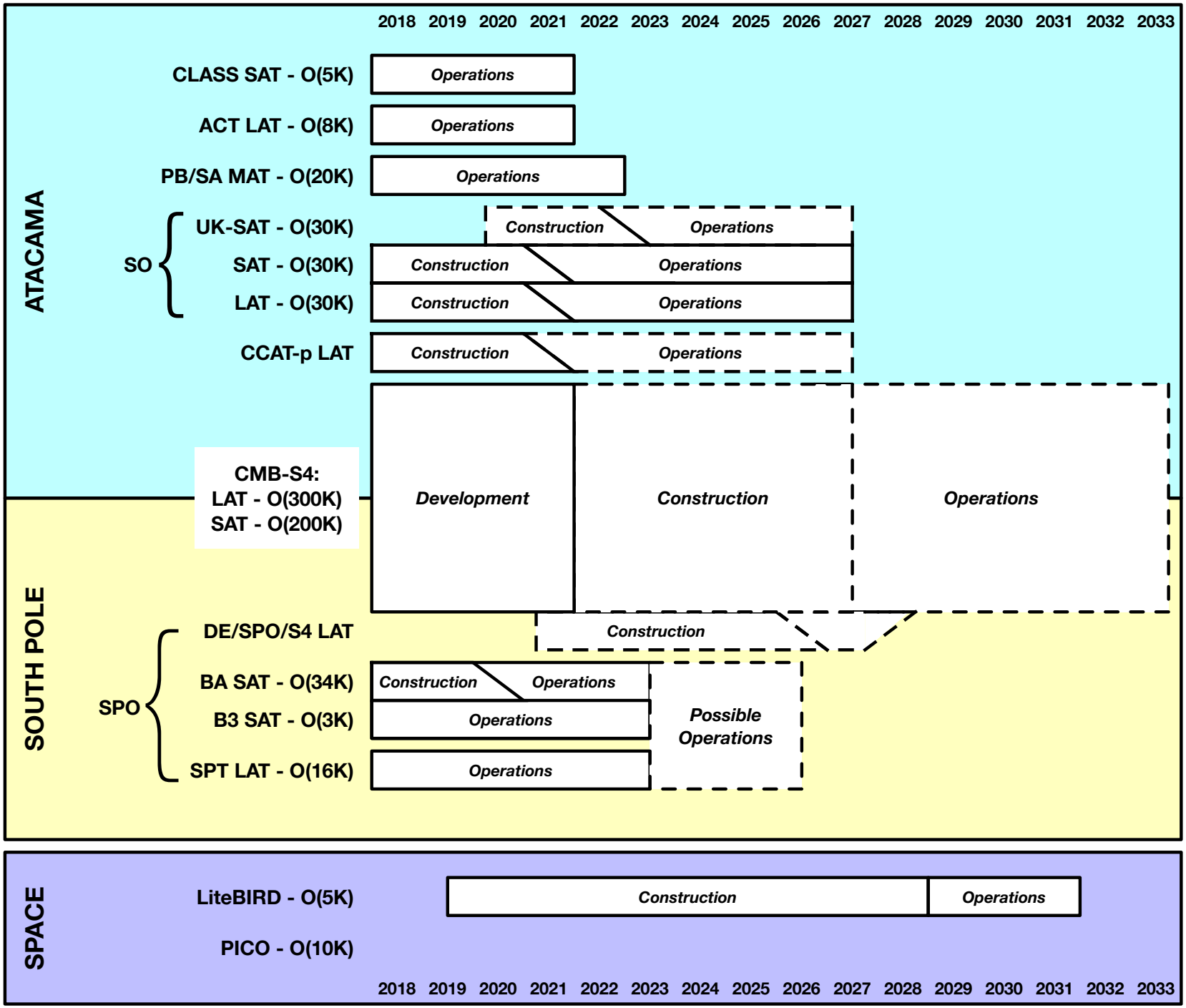
2. Reference Design

3. Baseline Design

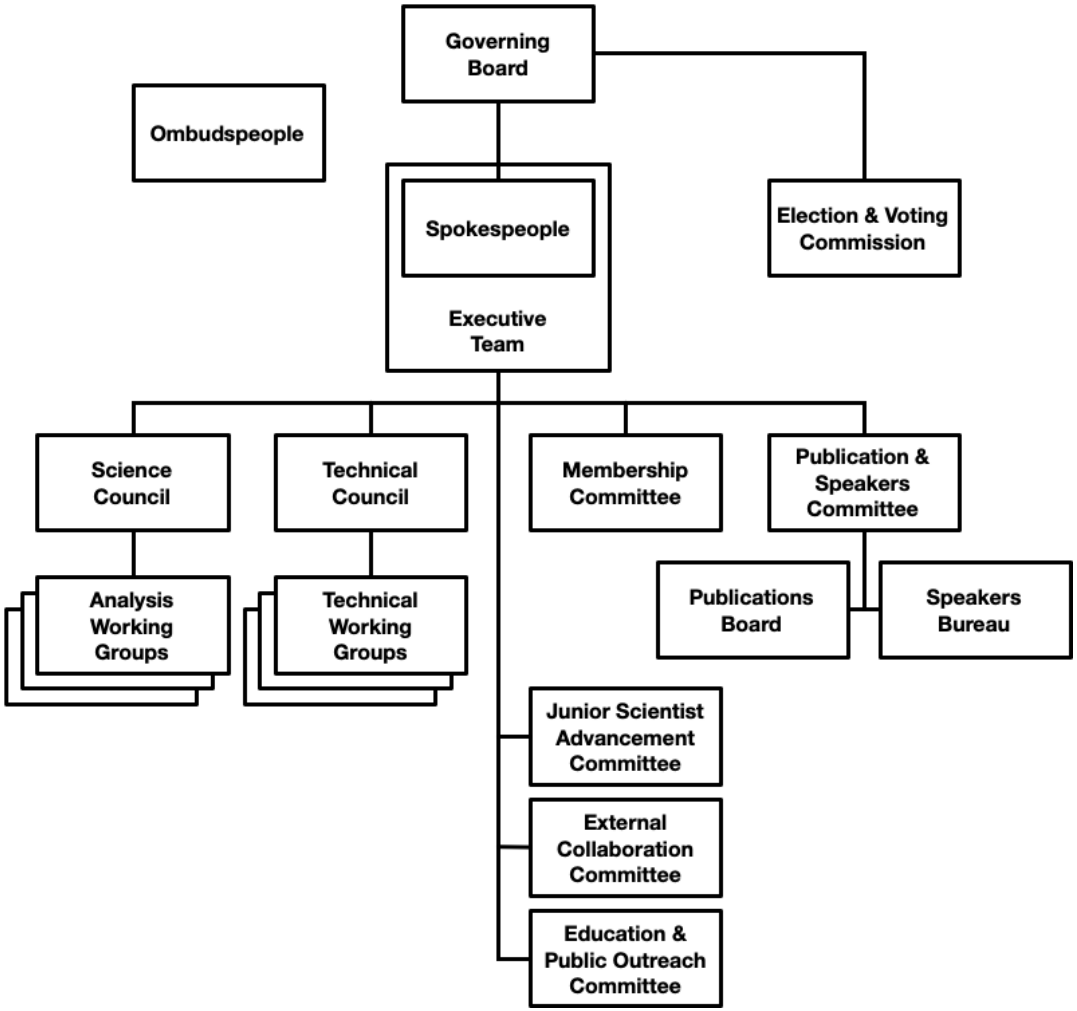
Pre-Project : 2013-19

- 2013 Snowmass: Community convergence on CMB-S4 concept
- 2014 HEPAP: Particle Physics Project Prioritization Panel
- 2015 National Academies: Strategic Vision for NSF Investments in Antarctic and Southern Ocean Research
- 2017 AAAC: CMB-S4 Concept Definition Task Force
- 2018 CMB-S4 Collaboration Formation
- 2019/20 National Academies: Decadal Survey on Astronomy & Astrophysics

It's been a long and complicated process but we've made it!


2018 2019 2020 2021 2022 2023 2024 2025 2026 2027 2028 2029 2030 2031 2032 2033
ATACAMA
CLASS SAT - O(5K)
Operations
ACT LAT - O(8K)
Operations
PB/SA MAT - O(20K)
Operations
SO
UK-SAT - O(30K)
Construction
Operations
SAT - O(30K)
Construction
Operations
LAT - O(30K)
Construction
Operations
CCAT-p LAT
Construction
Operations
CMB-S4:
LAT - O(300K)
SAT - O(200K)
Development
Construction
Operations
SOUTH POLE
DE/SPO/S4 LAT
Construction
SPO
BA SAT - O(34K)
Construction
Operations
B3 SAT - O(3K)
Operations
SPT LAT - O(16K)
Operations
Possible
Operations
SPACE
LiteBIRD - O(5K)
Construction
Operations
PICO - O(10K)
2018 2019 2020 2021 2022 2023 2024 2025 2026 2027 2028 2029 2030 2031 2032 2033

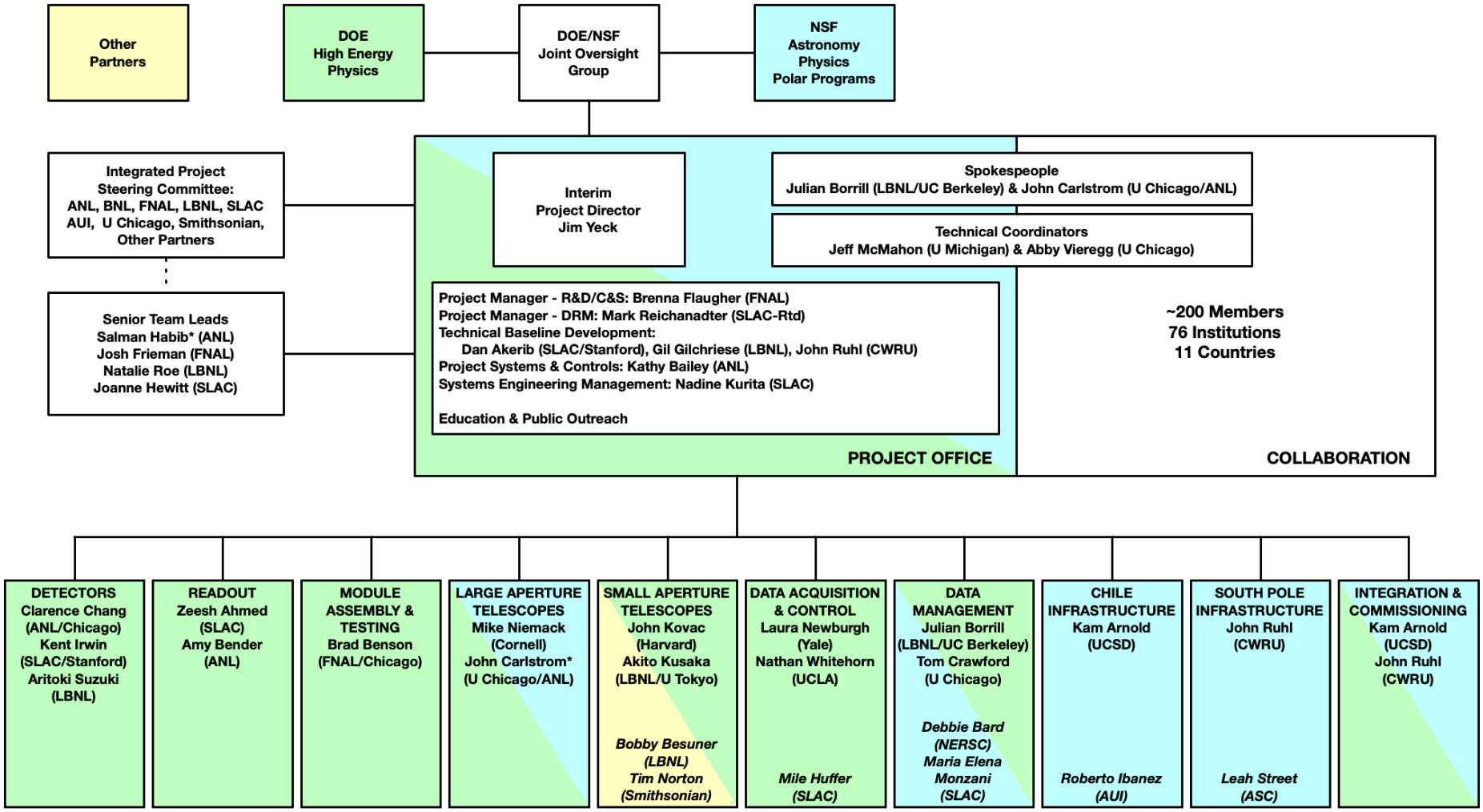
Collaboration



7 European Countries
- 22 senior members
- 10 postdoc members
- 1 student member
- 1 Governing Board rep

https://cmb-s4.org/wiki/index.php/Main_Page#Membership

Interim Project Office



* Acting

Current Status

- DOE CD-0 approved
  - CMB-S4 is a formal project; budget line-item from FY21
  - DOE reserve funding for FY19/20
    - FY19: $2.3M R&D (detector fabrication, cold optics, sidelobes, cryostats, simulations) + IPO
    - FY20: Targeting ~$10M
  - Lead lab(s) to be selected in early 2020
- NSF Mid-Scale Research Infrastructure proposal pending
  - $4M for 2 years for to get us to PDR (R&D, IPO)
  - Counts towards recommended 10% pre-MREFC funding
  - Led by University of Chicago

Project : 2019-35

- Joint DOE/NSF project
- International, foundation & project partners
- Construction:
  - FY19-27
  - $600M with inflation, including 35% contingency
    - In-kind contributions could reduce this by up to 25%
- Operations:
  - FY27-35
  - $32M in FY19 $
- Significant off-project scientist support in both construction & operations.

Construction Project : 2019-27

- DOE Major Item of Equipment (MIE)
  - Critical Decision process (CD-0, CD-1/3a, CD-2, CD-3b, CD-4)
- NSF Major Research Equipment and Facilities Construction (MREFC)
  - Design Review process (Conceptual, Preliminary, Final)
- Possible Partnerships
  - International
    - Likely via agreements with national agencies
  - Private Foundations
    - Smithsonian, Simons/Heising-Simons, …
  - Other Projects
    - Equipment re-use (SO/SPO including European SATs/LAT)
    - Complementary data (ELFS, LiteBIRD, …)

Construction Project Timeline

Fiscal Year Quarter	CMB-S4 Planning Timeline
Q4 FY2018	**R&D Proposal to DOE & CDR Proposal to NSF**
Q2 FY2019	**Critical Decision 0 (CD0)**
Q2 FY2019	**Initial Input to the Decadal Survey**
Q4 FY2019	**NSF CDR, Start Preparing for DOE CD1**
Q2 FY2021	**Decadal Survey Results**
Q2 FY2021	**NSF PDR and DOE CD1 & CD3A (Long Lead Construction) Approved**
Q2 FY2022	**NSF FDR and DOE CD2 Approved**
Q4 FY2023	**DOE CD3B Approved**
Q4 FY2026	**DOE CD 4 Approved, Start of Operations in Q1 FY2027**

- Each review requires a correspondingly mature design
  - DOE & NSF use different adjectives for the same design stages!

Detector Fabrication

- December 2018 project review identified detector fabrication capacity as a major risk.
- Project office convened the Detector & Readout Taskforce to survey current & projected capacity.
  - Sufficient capacity exists over 5 current fab sites (ANL, GSFC, JPL, NIST, UCB) but significant cost & schedule risks remain
    - too many agencies, not enough redundancy.
  - Identified 3 possible new/expanded high-capacity DOE sites (ANL++, LBNL/SeeQC, SLAC)
- August 2019 detector fabrication review evaluated the plans at these 3 sites & recommended pursuing all of them.
  - Off-project DOE funds for development

Reference Design

- Developed for Astro2020, CD-0, NSF CDR
  - Must be ready for rigorous Technical, Risk & Cost Evaluation (TRACE)
  - Typically adopted most mature & well-costed technology:
    - SO/CCATp-style 6m LATs
    - BA-style 3-shooter SATs
    - Horn-coupled dichroic TES detectors
    - Time-domain multiplexed readout
    - Compromise between BA & SO SAT pixel illumination
  - Justified by preliminary science/measurement/technical requirements flowdown

Science Goals

1. Primordial Gravitational Waves

   If $r = 0$, achieve a 95% confidence upper limit of $r \leq 0.001$

   If $r \geq 0.003$, achieve a 5σ detection.

2. The Dark Universe

   Achieve $\Delta N_{eff} < 0.06$ at 95% confidence.

3. Mass-Mapping

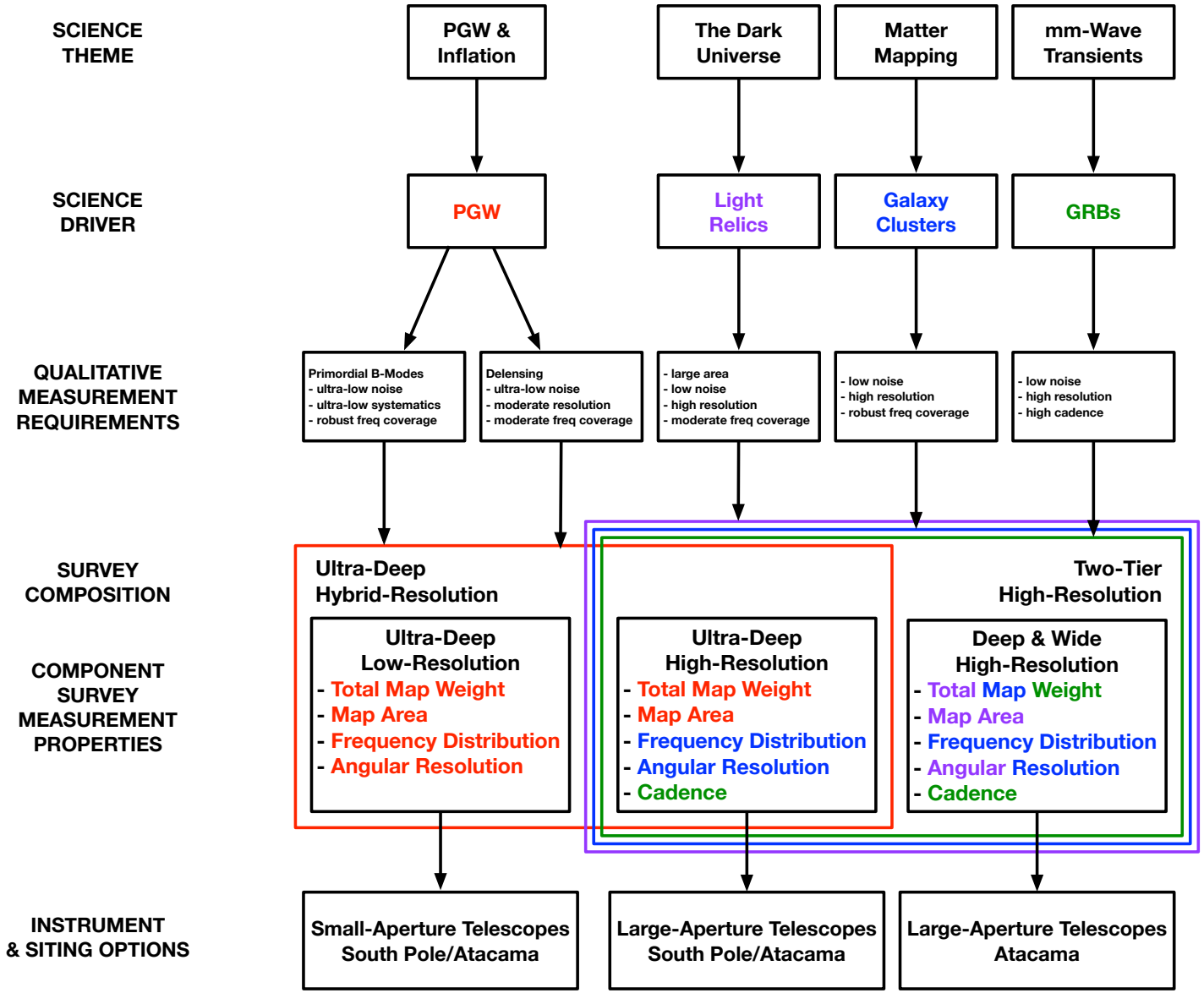
   Achieve a lower mass limit for galaxy clusters that is below $10^{14}\ M_{\odot}$ at $z \geq 2$.

4. Millimeter-Wave Transients

   Measure many gamma-ray burst afterglow light curves.

All kinds of other science will be enabled by the measurements made to meet these goals, but these are the primary design drivers.

Measurement Requirements



Technical Specification (RD)

- 6 x 3-Shooter SATs

Frequency (GHz)	30	40	85	145	95	155	220	270
Tubes/Wafers	2/24		6/72		6/72		4/36	
#Detectors	576		21144		21144		33752	
NET/detector (μK √s)	177	224	270	238	309	331	747	1281
FWHM (arcmin)	72.8		25.5		22.7		13.0	

- 3 x 19-Tube LATs (2 wide-area + 1 delensing)

Frequency (GHz)	20	27	39	93	145	225	278
Tubes/Wafers	0+1/4	2+2/24		12+12/144		5+4/56	
#Detectors	160	1920		124560		52416	
NET/detector (μK √s)	438	383	250	302	356	737	1840
FWHM (arcmin)	10	7.4	5.1	2.2	1.4	1.0	0.9

Baseline Design

- Requirement for DOE CD-1 & NSF PDR
  - Very close to what we will actually build
- Includes much more detailed/robust flow-down
  - Alternatives evaluated & down-selects justified.
- Focus of coming year's activity in time for CD-1/PDR in Q2 2021.

- We also plan to have CD-3a on this timescale
  - Need to identify long lead-time procurements in all areas.

Science to Measurement Flowdown

- Focus of Analysis Working Groups
- Key measurement requirement questions:
  - Frequency coverage, sensitivity & resolution
    - Ultra-deep - split bands on SATs? 20GHz on a LAT?
    - Delensing - sensitivity to match SATs; resolution
    - Wide/deep - galaxy removal for survey area, CIB for SZ, …
  - Survey strategies
    - Elevation vs atmosphere for all
    - Coverage vs cadence for wide/deep
    - Dedicated or incidental for delensing
- All in the presence of systematics
  - Foregrounds, atmosphere, ground-pickup, …
  - Beams, bandpass mismatch, x-correlated noise, calibration …

Measurement to Technical Flowdown

- Focus of Technical Working Groups
- Key technical requirement questions:
  - Optical coupling (horn vs lenslet)
  - Readout (tmux vs μmux vs fmux)
  - SATs (3-shooter vs 1-shooter; pixel illumination)
  - LAT ground shielding (yes vs no)
  - Wide-area LATs (2 x 19-tube vs 3 x 13-tube)
  - Delensing Telescope (location, aperture, sensitivity)
    - LAT questions include dependencies on possible partners

Technical WGs

- Each WBS Level 2 element has a technical working group associated with it, coordinated by the L2 lead(s).
- Each TWG is preparing the plan for its downselects
  - Schedule, metrics, R&D, dependencies, …
- These plans will then be
  1. presented and refined at the collaboration meeting: San Diego, October 17th - 19th
  2. subject to external expert scrutiny at the annual project review: Chicago, November 4th - 5th
  3. executed in time to be written up for CD-1: fall 2020 for spring 2021

Analysis WGs

- Baseline design decisions will need to be informed by analysis of simulations that can distinguish between the options.
- Move from science working groups generating partial simulations specific to their science area to the project generating common complete mission simulations for all analyses.
- Move from science working groups to analysis working groups focused on pipelines & processing:
  - Low-ell BB
  - Maps to Power Spectra
  - Maps to Other Statistics
  - Sources (including transients)
- Also sky modeling as part of a community-wide activity.

Summary

- CMB-S4 is an official project!
- The reference design represents a huge increase in sensitivity:
  - Statistics: 3.5 million detector-years (10x)
  - Systematics: lessons learned + project systems engineering
- Work is ramping up fast for CD-1/PDR in 2021; the time for engagement & key partnership decisions is *now*.
- Further details:
  - Science Case, Reference Design, Project Plan: *arXiv:1907.04473*
  - Astro2020 White Paper (summary): *arXiv:1908.01062*
  - CMB-S4 website: https://cmb-s4.org/publications.php
- Fall meeting: http://cmbs4meeting2019.ucsd.edu/index.html

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TOAST workshops:

- San Diego, October 14th – 16th (before CMB-S4 meeting)
  - https://github.com/hpc4cmb/toast-workshop-ucsd-2019
- Trieste, November 20th – 22nd
  - https://github.com/hpc4cmb/toast-workshop-trieste-2019
- Japan, early 2020