CMB-S4

Concept Definition Task Force Update

AAAC, NSF

2017 September 28

CDT Deliverables

Excerpt from the letter to Buell from three NSF Divisions and DOE HEP requesting the AAAC to establish "a Cosmic Microwave Background Stage 4 Concept Definition Task force (CMB-S4 CDT) as a subcommittee in order to develop a concept for a CMB-S4 experiment".

Specifically, the CDT is asked to deliver:

- The Science Requirements and their rationale
- Measurement and Technical Requirements derived from the Science Requirements
- Project Strawman Concept
- Options and Alternatives (prioritized to the extent possible) for:
  - Concept design (e.g. sites, telescopes, detectors)
  - Concept staging and schedule
  - Collaboration and Data models and interfaces
- R&D development needed, with priorities, to demonstrate technical readiness
- Cost ranges for the strawman concept, including explanations for how they were developed.

Science

- Primordial gravitational waves and inflation
  - r
- Light relics
  - N_{eff}

Design drivers

- Neutrino mass measurements
- Measurement of the evolution of cosmic structure

"Free" science

Simulations

Science req's $\longleftrightarrow$ Measurement req's $\longleftrightarrow$ Instrument & Mission req's
sims sims

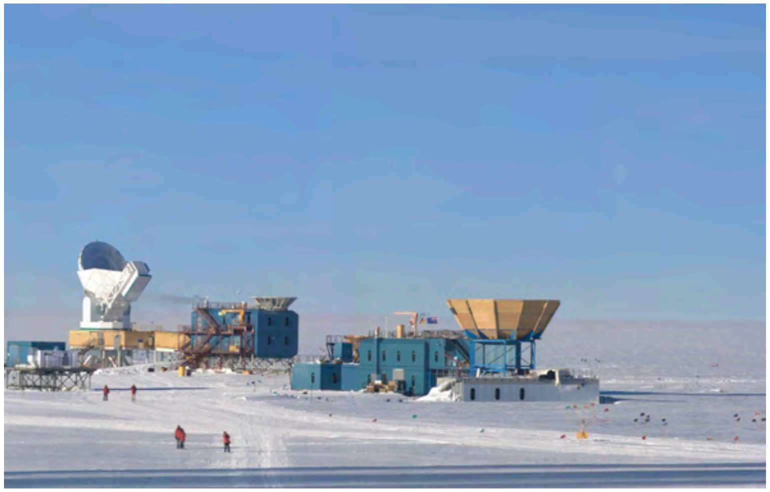
- Simulations incorporate:
  - Historical experience at Pole of observing efficiency, instrument performance, atmospheric effects, and other factors the affect "map noise".
  - Most realistic foreground representations to date, in terms of both physical characteristics and model uncertainties

    Physical models of dust (Hensley and Draine); 3-d MHD simulations of synchrotron emission; appropriate correlations between synchrotron and dust polarization directions based on magnetic field direction

    This is the first time low frequency foregrounds with structure on sub-degree scales have been used in `CMB simulations
  - The characteristics of residual systematic effects
- Compared to simpler simulations that have been run in the past, get roughly a factor of two additional degradation in maps
- For the first time, demonstrate that high angular resolution at low frequencies is required to capture synchrotron structure

Strawperson Concept

- CMB-S4 will be a single experiment and collaboration
- Two sites: South Pole and Atacama
  - South Pole has the best atmospheric conditions of any developed site
  - Atacama is also an excellent site and is needed to get to $f_{\rm sky} = 0.4$



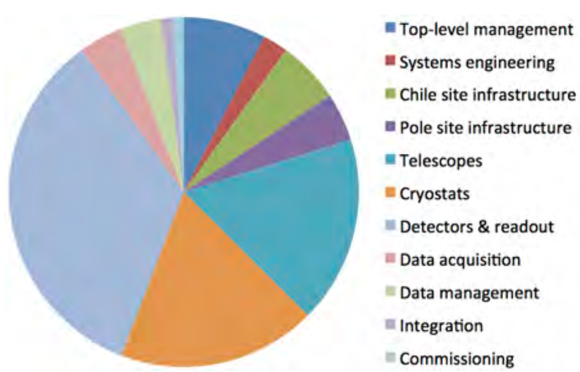
- Fourteen small (0.5 m) telescopes on two mounts, and three large (6 m) telescopes
  - Small for r
  - Large for r (lensing), and for light relics and other science
  - 14×16 k $= 224$ k (2 mm-equivalent) detectors on small telescopes
  - 3×96 k $= 288$ k (2 mm-equivalent) detectors on large telescopes
- Four years of observing with small telescopes
- Seven years of observing with large telescopes

Options and Alternatives

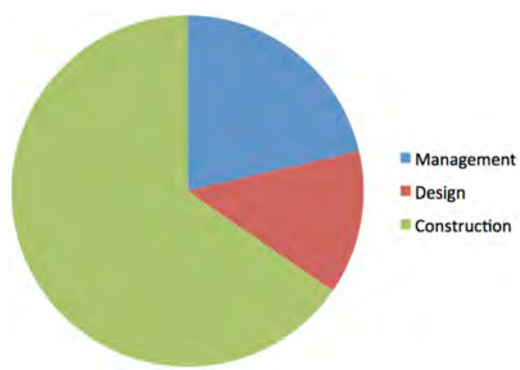
- We give options for
  - the use of existing telescopes that will be deployed prior to CMB-S4
  - alternative configurations with larger telescopes that would yield gains in the cluster science
- And discuss staging and schedule

Costing

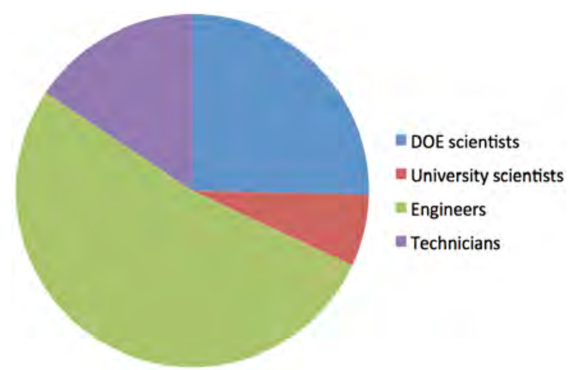
- Approach
  - Capture all aspects of the experiment with fidelity appropriate for a concept design, taking care not to miss any scope that might drive cost
  - Three parts: pre-project R&D; the construction project; and post-project operations
  - Construction costs based on a WBS, which includes design, pre-production prototypes, management, reviews, fabrication, integration, and commissioning
    - Costs estimated at WBS level 3 or lower, with contingency for each item based on maturity of design
    - Cost estimates based on costs for deployed instruments, estimated costs for instruments being designed now, or bottom-up estimates by experts, scaled to CMB-S4 using simple parametric models



Cost by WBS element



Cost by type of work



Effort by type of personnel

- Reviewed by a panel of DOE experts 12 September. Recommendations included in estimate.

Report

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The End

- We will have the final report in October, as promised!

BACKUP SLIDES

CDT Members

CDT

Julian Borrill	LBNL
John Carlstrom	Chicago
Tom Crawford	Chicago
Mark Devlin	Penn
Jo Dunkley	Princeton
Raphael Flauger	UCSD
Brenna Flaugher	FNAL
Shaul Hanany	U Minnesota
Kent Irwin	Stanford/SLAC
Bill Jones	Princeton
Brian Keating	UCSD
John Kovac	Harvard
Akito Kusaka	LBNL
Charles Lawrence (Chair)	JPL
Adrian Lee	Berkeley/LBNL
Jeff McMahon	Michigan
Mike Niemack	Cornell
Steve Padin	Chicago
Clem Pryke	Minnesota
Suzanne Staggs	Princeton
Ed Wollack	GSFC

Contacts:

Kathy Turner	DOE
Rich Barvainis	NSF
Brian Keating	AAAC

Advisory Board:

Lloyd Knox	UCD
Sarah Church	Stanford
Amber Miller	USC
Lyman Page	Princeton
John Ruhl	CWR
Martin White	Berkeley

Science — I

- Since the first detection of the CMB over 50 years ago, CMB measurements have continuously transformed our understanding of the early universe.
- Measurements of the CMB by ground-based, balloon, and satellite experiments have determined the age and composition of our universe, and provide strong evidence that the seeds of structure are quantum-mechanical.
- Observations have nearly exhausted the information accessible in primary temperature anisotropies, but with "Stage 3" experiments, precision measurements of polarization, lensing, and secondary effects have just begun.
- The "Stage 4" experiment CMB-S4 is the natural next step for ground-based CMB measurements, and will transform our understanding of the early universe and of particle physics yet again.

Science — II: Gravitational Waves

- CMB-S4 will be exquisitely sensitive to gravitational waves at recombination.
- If observed, these gravitational waves are a pristine relic of the primordial universe.
- In the foreseeable future, their imprint on the polarization of the CMB is our only way to detect them.
- These gravitational waves are independent from density perturbations, and a detection would provide a new window onto the early universe.

Science — III: Inflation 1

- Many models of inflation predict a gravitational wave signal large enough to be detected with CMB-S4.
- According to inflation, primordial gravitational waves arose as quantum fluctuations in the metric of spacetime.
- As a consequence, a detection of gravitational waves with CMB-S4 would provide insight into quantum gravity.
- In addition, a detection would measure the expansion rate and energy density during inflation.

Science — III: Inflation 2

- In the absence of a detection, constraints from CMB-S4 would rule out widely-studied classes of inflationary models.
- CMB-S4 will measure the polarization of the CMB on small scales with unprecedented precision.
- This will reduce uncertainties on many other primordial observables (e.g., primordial power spectrum, non-Gaussianity, isocurvature modes) by a factor of 2–3.

Science — IV: Light Relics

- CMB-S4 will explore and constrain a wide range of extensions of the standard model currently explored in the particle physics community.
- Many well-motivated extensions of the standard model to higher energies predict light, long-lived particles.
- CMB-S4 will be sensitive to light relics even if they interact too weakly to be detected in lab-based experiments.
- CMB-S4 will provide the most robust and precise cosmological constraints on light relics.

Science — V: Neutrinos

- Neutrinos are the least explored corner of the Standard Model of particle physics.
- A major effort is underway to study their properties in short- and long-baseline as well as neutrino-less double beta decay experiments.
- CMB-S4 will probe the properties of neutrinos in a way that is important and complementary to lab-based experiments.
- CMB-S4 will provide a measurement of the sum of neutrino masses through weak gravitational lensing of the CMB even for the minimum mass in the normal mass hierarchy.
- CMB-S4 will independently measure the sum of neutrino masses through cluster counts, with comparable sensitivity.

Science — VI: Evolution of Cosmic Structure

- CMB-S4 will determine the impact of feedback processes on the distributions of dark and baryonic matter in the Universe, by measuring the thermodynamic profiles of the ionized gas in galaxies, groups, and clusters.
- CMB-S4 will measure the growth of cosmic structure with galaxy clusters, enabling tests of modified gravity and dark energy in a complementary way to LSST.
- CMB-S4 will provide a legacy-class high-z ($z > 2$) cluster sample that will be the definitive target list for astrophysics studies with other experiments (e.g., JWST, LSST, Euclid, WFIRST, Athena).
- CMB-S4 will determine the duration of reionization using the kSZ effect.