CMB-S4 CDT Report

Key Points

AAAC Telecon

2017 October 23

Introduction

- Observations of the CMB have taught us an enormous amount about the early Universe
- CMB-S4 is the natural next step in CMB experiments
- At the request of the NSF and DOE, the Concept Definition Task Force (CDT) was set up to represent the CMB community and recommend a concept design for CMB-S4
- We have identified three science goals

Science I

- Two goals become design-driving science requirements, crossing clear critical science thresholds that cannot be reached with the upgrades planned for current (Stage 3) experiments
  - To test many of the simplest models of inflation, including those based on symmetry principles, that occur at high energy and large inflaton field range, CMB-S4 will detect or constrain the imprint of gravitational waves on the CMB polarization anisotropy, quantified by the tensor-to-scalar ratio r.

If $r = 0: \ \sigma(r) \leq 0.0005; \quad r < 0.001, 95\%$ confidence in four years

If $r = 0.003:$ measure at equivalent 4σ in four years

  - To probe the thermal history of our universe and detect or constrain the imprint of a wide range of possible low mass relic particles on the small scale CMB temperature and polarization anisotropy.

$\Delta N_{\rm eff} \leq 0.06, \ 95\%$ confidence in seven years

Science II

- A third science goal is achievable with the hardware implemented for the first two

  - Provide a legacy survey of nearly half the sky at centimeter to millimeter wavelengths.

    Gravitational interactions with all matter and EM interactions with baryonic matter leave signatures in the CMB as it traverses the Universe.

    Neutrino masses: In combination with large-scale-structure surveys. Independently through cluster counts.

    Evolution of cosmic structure: Trace the distribution of normal, baryonic matter in its ionized phase through the thermal SZ effect. Feedback. Map the total mass distribution through lensing of the CMB. Cross-correlations with other astrophysical tracers.

    Evolution of massive galaxy clusters from $z \approx 3$ to the present.

    Map the momentum field of LSS through kinetic SZ measurements.

    Catalogs of clusters and high-z galaxies.

  - Will have broad benefit to both the cosmological and astronomical communities

Simulations

- Simulations are the basis for the flowdown from science requirements to measurement requirements to instrument and experiment requirements
  - Worked hard on improving realism of foreground and instrumental systematic effects
  - Drew on a variety of sources to incorporate multiple effects
  - Projections are based on achieved, end-to-end performance over years of observing at two sites

Strawperson Concept I

The design of CMB-S4 is conservative, using an evolutionary approach grounded in things we know how to build

- A four-year r survey covering 3% (up to 8%) of the sky using
  - Fourteen 0.5-m-aperture cameras, each one measuring two of eight frequency bands from 30 to 270 GHz, and
  - A 6-m-class telescope covering seven frequency bands from 20 to 270 GHz
  - Broad frequency coverage is needed to deal with foregrounds
  - Low resolution for primordial B modes; high resolution needed for delensing
  - Total detector count is about 170,000 for the 0.5-m cameras, and 70,000 for the 6-m telescope.
- A seven-year $N_{\rm eff}$ survey covering 40% of the sky using
  - Two 6-m-class telescopes covering seven frequency bands from 20 to 270 GHz
  - Total detector count is about 140,000

Strawperson Concept II

- Two sites: South Pole and Atacama
  - South Pole has superior atmospheric stability, and offers continuous observations of a small, low-foreground patch of the sky. But it more restricted in the available sky coverage.
  - Atacama is also exceptional for mm-wave observations, and provides access to the 40% sky coverage needed for $N_{\rm eff}$ and the legacy survey.
- The optimum distribution of the 6-m and small-aperture cameras between the two sites has not been determined, and has little effect on cost.
- No new inventions are required. All technologies are based on existing capabilities
  - Pre-Project development investments would reduce risk and possibly cost

Cost

- We developed a comprehensive cost model to capture all aspects of the experiment
  - Pre-Project development; the construction Project; and post-Project operations
  - Incorporated all of the experience of the Stage-2 and Stage-3 experiments, plus help from project-costing experts at four DOE labs (Argonne, Fermi, Lawrence Berkeley, SLAC), plus a review of cost methodology with senior DOE/NSF project managers.
  - Much greater fidelity than simply "scaling up"

Estimate	Cost including contingency [$M in 2017]	Contingency [%]
Pre-Project development	9	
Construction Project.............	412	45
Annual operations		
Sites............................	18	100
Science analysis..............	14	150

Collaboration

- CMB-S4 will be a single experiment and collaboration

- The CDT report is built on a foundation of work by the CMB-S4 Collaboration, which was fully engaged and contributed throughout the process.

- The Collaboration is in the process of setting up a more formal and operational structure. It is eager, willing, and definitely will be ready for its role in building, operating, and extracting secrets of the Universe from CMB-S4!