CMB-S4 Science Goals

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- more of these are better

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Instead they are the goals that drive the design and will be used to define the success of the experiment.

- fewer of these are better

CMB-S4 Science Goals

Currently driving the design

- Primordial gravitational waves
- Light relics

Free science

- Neutrino mass measurement
- Measurement of evolution of cosmic structure
- ...

Gravitational Waves

- With CMB-S4 we hope to detect cosmological gravitational waves present at recombination.
- Such gravitational waves would be 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.

Gravitational Waves

- 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.

Gravitational Waves

- In the absence of a detection, constraints from CMB-S4 would rule out the most widely studied classes of inflationary models.

Science goal:

- Robust detection of gravitational waves if $r \geq 3 \times 10^{-3}$
- Upper limit of $r < 10^{-3}$ at 95% CL otherwise

Science Requirement:

$\sigma(r) = 5 \times 10^{-4}$ for *r*=0 after 4 years of observation

Much ongoing work to turn these into measurement and instrument requirements.

Light Relics

- CMB-S4 explores and constrains a wide range of extensions of the standard model of interest to the particle physics community.
- Many extensions of the standard model to higher energies predict light, long-lived particles.
- CMB-S4 is 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.

Light Relics

Science goal:

- Exclude presence of single spin-1/2 or spin-1 degree of freedom that decoupled from standard model just after reheating at 95% CL.
- Exclude single scalar degree of freedom that decoupled around the QCD phase transition

Science Requirement:

$\sigma(N_{\rm eff}) = 0.027$ after 4 years of observation

Much ongoing work to turn these into measurement and instrument requirements.

Neutrinos

- A major effort is underway to study neutrino 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 complementary to lab-based experiments.
- It 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.
- It will independently measure the sum of neutrino masses through cluster counts with comparable sensitivity.

Evolution of Cosmic Structure

CMB-S4 will

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