Contents

1 Scientific, Technical, and Management Section

0.5 pg. executive summary goes here: the sky is sunny

1.1 Science Objectives

5 pages for all science goals including the (temporary) two sections below.

1.1.1 The Inflationary Gravitional Wave Background

The verbiage below is taken from another proposal. Here we need to explain what are the science objectives of the CMBProbe, how the science objectives relate to the current state of knowledge, and to NASA's goals

The paradigm of inflation [1, 2, 3, 4, 5] makes several predictions that are consistent with all current astrophysical measurements [6, 7, 8, 9]. A robust prediction of inflation is the existence of a stochastic background of gravitational radiation with an amplitude depending on the mechanism driving the accelerated expansion [10, 11, 12, 13, 14]. In most scenarios, this 'inflationary gravitional wave background' (IGB) is predicted to have a spatial power spectrum whose amplitude is proportional to the energy scale of inflation $V^{1/4}$ via $V^{1/4} = 3.7 \times 10^{16}\, r^{1/4}$ GeV, where V is the inflaton potential and r is the ratio of the temperature quadrupoles produced by gravitional waves and by density perturbations. There are theoretical reasons $V^{1/4}$ may be close to the Grand Unification scale of 10^{16} GeV, suggesting detectable r values between $\sim$0.001 and $\sim$0.1. In addition to determining the energy scale of inflation, measurements of the IGB probe the scalar field potential at or above the Planck scale, which is particularly relevant for inflation models motivated by string theory [15]. Measurements of the IGB thus probe fundamental physics at the highest possible energy scales.

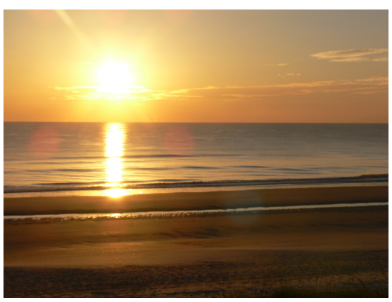

Figure 1: Sample Figure of Sunny Skies

The most promising way to search for the IGB is through its signature on the CMB polarization [16, 17]. Primordial energy density perturbations produce only a curl-free, or 'E-mode', pattern of polarization. Gravitional waves also produce a curl, or 'B-mode', pattern of polarization that density perturbations cannot produce [18, 19]. The amplitude of the B mode is related to the energy scale of inflation by $V^{1/4} = 2 \times 10^{16}\, (B_{peak}/0.1\, \mu\mathrm{K})^{1/2}$ GeV, where B_{peak} is the amplitude of the power spectrum of the B mode in μK at $\ell = 80$; see Fig. 1. In its recent report New Worlds New Horizons (NWNH), the decadal survey committee strongly endorsed sub-orbital searches for the B-mode signal from inflation saying that "The convincing detection of B-mode polarization in the CMB produced in the epoch of reionization would represent a watershed discovery." [20]

B-mode signatures near the expected IGB peak at $\ell = 80$ have recently been detected by BICEP2 [21]. However, the combination of Planck data with those from the BICEP2 and Keck Array collaborations have demonstrated that the B-mode signal measured is entirely consistent with contributions from polarized emission of Galactic dust and the signal from the gravitational lensing of CMB photons by the large scale structure of the Universe (see Section **??**) [22, 23**?**]. These data

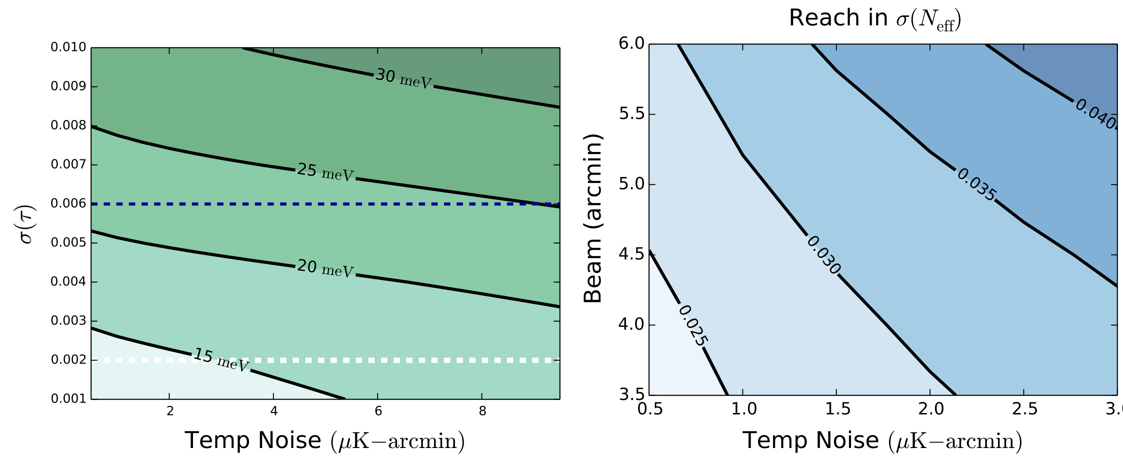

Figure 2: [Placeholders] *Left:* Neutrino mass constraints as a function of the prior on τ. *Right* $N_{\rm eff}$ Forecasts as a function of resolution in arc-min and temperature noise in μK-arcmin assuming $f_{\rm sky} = 0.7$.

give an upper limit of $r < 0.09$ at 95% confidence level. Most importantly, the constraint is largely limited by Planck's noisy measurement of the dust properties in the 353 GHz band; a noiseless dust map could shrink the constraint by a factor of two [22]. Further progress — detections or improved limits — requires instruments with higher sensitivity at *both* the dust and CMB frequency bands so that this Galactic foreground can be properly identified and removed.

1.1.2 Neutrinos and Light Relics

Much of the information about our thermal history and the particle content of the universe is encoded in the T and E power spectra. A high-precision measurement of these spectra over the full sky is expected to significantly improve our understanding of the post-inflationary universe. This is particularly true in E-mode polarization where far fewer modes have be measured at the level of cosmic variance.

1.1.3 CMB spectral distortion science

In addition to the CMB temperature and polarization anisotropies targeted by CMB imagers, *unique* new information about early-universe physics can be gained by studying the energy spectrum of the CMB [24, 25, 26, 27]. The measurements of COBE/FIRAS have shown that the average CMB spectrum is extremely close to that of a blackbody at a temperature $T_0 = (2.726 \pm 0.001)\,\mathrm{K}$ [28, 29]. However, several standard processes are expected to distort the CMB spectrum [e.g., 30] at a level that is within reach of present-day technology [31, 32]. The classical distortion shapes are known as Compton-y and chemical potential (μ-type) distortions [33, 34] and are caused by energy exchange of CMB photons with free electrons. A μ-distortion can only be produced in a hot and dense environment present at redshifts $z \gtrsim 5 \times 10^4$, while y-type distortions appear at lower redshifts. This makes μ-distortions a unique messenger from the early Universe.

Future studies of the CMB spectrum will open a new unexplored window to early phases before the recombination era ($z > 10^3$), which cannot be probed in any other way. This will not only allow us to test the standard cosmological paradigm (e.g., inflation and reionization) but also opens up a huge discovery space to non-standard physics (e.g., decaying/annihilating particles) and new tests of the nature of dark matter. This immense potential and complementarity with CMB anisotropy studies has made CMB spectral distortions an important future target and identifying experimental routes towards measuring these tiny signals from the early Universe will be one objective of the proposed mission study.

The largest guaranteed distortion is caused by the late-time energy release of forming structures and from reionization [35, 36, 37, 38, 39], creating a y-type distortion with $y \simeq 2 \times 10^{-6}$ [e.g., 39, 40]. This signal is only one order of magnitude below the current limit from COBE/FIRAS and, even with most pessimistic assumptions about foregrounds, should be clearly seen with next-generation spectrometers, telling us about the total energy output of first stars, AGN and galaxy clusters. In particular, group-size clusters ($M \simeq 10^{13}\,M_{\odot}$) contribute to this distortion. These are still sufficiently hot (temperature $kT_{\rm e} \simeq 1\,{\rm keV}$) to create a visible relativistic temperature correction to this large y-distortion, which could be used to constrain cluster feedback models [40]. These two inevitable signals probe the low-redshift Universe and provide clear targets for future spectral distortions measurements and their requirements in the presence of foregrounds.

Next generation CMB spectrometers are also expected to improve the μ-distortion limits. This will allow us to place stringent bounds on the presence of long-lived decaying particles [41, 42, 43, 44] and other new physics [e.g., 45, 46, 47, 48, 49], but a clear target is predicted from the dissipation of small-scale perturbation....

1.2 The Challenges: Foregrounds, systematics

3 pages. Discuss the challenge of Foregrounds and Systematics.

1.3 Current and Forthcoming Efforts and the CMB Probe

2.5 pages. S3 experiments, forthcoming S4, Baselines CMB Probe options and their complementarity with S4.

1.4 State of Technologies

2 pages. Discuss the technologies, their TRL, and what will be studied

1.5 Mission Study, and Management Plan

1.5 pages; Describe what we want to do, who is doing what, what we are funding

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