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Prospects for ACT: Simulations, power spectrum, and non-Gaussian analysis

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Abstract

A new generation of instruments will reveal the microwave sky at high resolution. We focus on one of these, the Atacama Cosmology Telescope, which probes scales $1000 < l < 10{,}000$, where both primary and secondary anisotropies are important. Including gravitational lensing, thermal and kinetic Sunyaev–Zeldovich (SZ) effects, and extragalactic point sources, we simulate the telescope's observations of the CMB in three channels, then extract the power spectra of these components in a multifrequency analysis. We present results for various cases, differing in assumed knowledge of the contaminating point sources. We find that both radio and infrared point sources are important, but can be effectively eliminated from the power spectrum given three (or more) channels and a good understanding of their frequency dependence. However, improper treatment of the scatter in the point source frequency dependence relation may introduce a large systematic bias. Even if all thermal SZ and point source effects are eliminated, the kinetic SZ effect remains and corrupts measurements of the primordial slope and amplitude on small scales. We discuss the non-Gaussianity of the one-point probability distribution function as a way to constrain the kinetic SZ effect, and we develop a method for distinguishing this effect from the CMB in a window where they overlap. This method provides an independent constraint on the variance of the CMB in that window and is complementary to the power spectrum analysis.

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1. Introduction

Several survey telescopes (SPT,[1] APEX,[2] ACT[3]) will open a poorly probed regime of the microwave background: arcminute scales at frequencies up to a few hundred GHz. The sensitivities of these instruments will be a few micro-Kelvin. These efforts will provide a large amount of high-quality data, but face a different set of challenges than lower resolution surveys, such as WMAP.[4] For lower resolution experiments, the primary anisotropies of the CMB are the principal signal. The major contaminant is the galaxy, whose emission is diffuse and drops off rapidly away from the galactic center. By contrast, for higher resolution experiments, secondary anisotropies dominate at small scales. Assuming the observations are away from the galaxy at high frequencies, the major contaminant is extragalactic point source emission. For a wide range of interesting scales, point sources contribute substantially more power than the instrument noise.

The statistical properties of the primary CMB differ from those of these signals. Primary anisotropies, from the surface of last scattering, dominate the CMB on degree scales. The fluctuations are Gaussian, so the power spectrum sufficiently describes the anisotropy. Secondary anisotropies, such as lensing and the Sunyaev–Zeldovich (SZ) effect, depend on the late-time, non-linear evolution of the universe. Their imprints need not be Gaussian.

In this work, we investigate the prospects of these experiments to extract the power spectrum and other statistical information for the components that contribute at these angular scales and frequencies. We are particularly interested in determining the primordial power spectrum from the primary CMB. Such a determination would enable one to determine the amplitude and slope of the fluctuations on small scales and, in combination with large scale observations, would allow one to place powerful constraints on models of structure formation. We model our investigations on the Atacama Cosmology Telescope (ACT), a 6 m off-axis telescope to be placed in the Atacama desert in the mountains of northern Chile (Kosowsky, 2003). ACT's bolometer array is anticipated to measure in three bands from 145 to 265 GHz, with planned beams of 1–2′ (see Table 1). ACT plans to survey about 100 square degrees of the sky with high signal to noise. In Section 2, we simulate observations based on the specifications of ACT.

The first problem in extracting the primary CMB information from observations is separating the components on the sky with distinct frequency dependences. Although many signals at these scales are not Gaussian, the power spectrum is still the most important of the statistics, and in Section 3 we extract the power spectrum with a multifrequency analysis. The power spectrum analysis requires knowledge of the frequency dependence of the signals and of the scatter in that relation. Our knowledge is presently incomplete, and any error biases the estimated power spectra. Our discussion explores the impact of estimating some of this frequency information from the data itself.

The second problem in extracting the primary CMB information is that one of the secondary anisotropies, the kinetic Sunyaev–Zeldovich (kSZ) effect (and its analogs like the Ostriker–Vishniac effect and patchy reionization effect), has the same frequency dependence as the primary CMB. This complicates their separation, requiring an explicit template for the kSZ power spectrum. Again our knowledge is incomplete, and any error biases the primary CMB power spectrum. We address in detail the impact of secondary anisotropies on the estimation of the amplitude and slope of primordial fluctuations.

Table 1
Frequency channels, beam full-width at half-maximum, and detector noise (thermodynamic temperature) of the mock survey, based on ACT design goals

Band (GHz)	Beam FWHM (arcmin)	Sensitivity per pixel (μK)
145	1.7	2
210	1.1	3.3
265	0.93	4.7

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[1] http://astro.uchicago.edu/spt/.

[2] http://bolo.berkeley.edu/apexsz/.

[3] http://www.hep.upenn.edu/act/act.html.

[4] http://map.gsfc.nasa.gov/.