New Cosmological Data and the Values of the Fundamental Parameters
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The *TopHat* Cosmic Microwave Background Anisotropy Experiment

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Abstract. We have developed a balloon-borne experiment to measure the Cosmic Microwave Background Radiation anisotropy on angular scales from ~50° down to ~20′. The instrument observes at frequencies between 150 and 690 GHz and will be flown on an Antarctic circumpolar long duration flight. To greatly improve the experiment performance, the front-end of the experiment is mounted on the *top* of the balloon. With high sensitivity, broad sky coverage, and well-characterized systematic errors, the results of this experiment can be used to strongly constrain cosmological models and probe the early stages of large-scale structure formation in the Universe.

1. Introduction

After the detection of spatial anisotropy in the Cosmic Microwave Background Radiation (CMBR) on large angular scales by the Cosmic Background Explorer (*COBE*), the detection phase for CMBR anisotropy studies was completed. We are now in a detailed measurement phase motivated by the promise that precise measurements of the CMBR anisotropy will strongly constrain cosmological models and may provide quantitative information on some of the fundamental questions of structure evolution in the early Universe (e.g. Jungman et al. 1996). From an observational viewpoint, the required measurements are very challenging because of the high sensitivity required and potential systematic errors from both the observing environment and the local astrophysical foregrounds, both of which may limit the ultimate quality of results obtainable and hence the information content that can be reliably derived from the observations. NASA is planning to launch the Microwave Anisotropy Probe (MAP) satellite in 2001 to observe the entire microwave sky at higher angular resolution than *COBE* and ESA is planning the Planck Surveyor later in the decade with extended wavelength coverage and even higher angular resolution. While these satellite efforts will provide definitive measurements of the sky, a great deal can be learned from sensitive instruments with partial sky coverage at higher angular resolution than the COBE instruments (de Bernardis, P. et al. 2000, Hanany et al. 2000). To meet these challenges, we have developed a balloon-borne experiment which focuses attention on not only improved sensitivity, but greater sky coverage and reduced systematic errors. Here we review the experiment, the observing program and the results that may be expected.

2. Instrumentation

The development of long-duration Antarctic circumpolar ballooning and progress in detector technology have provided opportunities for significantly improving the sensitivity and sky coverage of balloon-borne instrumentation for studies of the CMBR. To take advantage of these new opportunities and reduce systematic errors, we have developed a novel instrument concept: *TopHat.* Designed to provide reliable, high quality measurements of the CMBR anisotropy, *TopHat* is designed to minimize both systematic and foreground spurious signals. We achieve these advantages by placing the a portion of the instrument on *top* of the balloon (see Figure 1), creating an observing environment unequaled in any sub-orbital CMBR experiment performed to date. By mounting the front-end of the instrument on top of the balloon, the entire sky above the instrument is clear and is free of supporting structures which could scatter radiation from the earth into the far sidelobes of the optics. Thus, this potential source of systematic uncertainty is dramatically reduced. The *TopHat* experiment (see Figure 2) will use a multi-channel radiometer to map a large (~48° diameter) region of sky near the South Celestial Pole (SCP) at ~20′ resolution. To accomplish this simply, the ~1 meter on-axis Cassegrain telescope is tipped 12° off the zenith

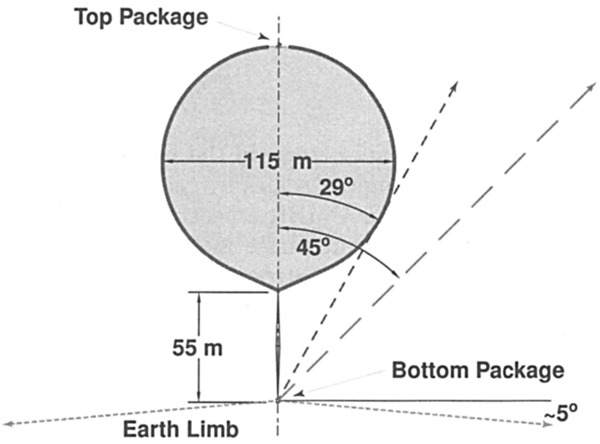

Figure 1. Scale drawing of a $2.8\text{x}10^7$ ft^3 balloon and payload at float altitude. For *TopHat* the scientific payload has components suspended both below and on the top of the balloon. The top and bottom packages are connected by communications and power cables running on the surface of the balloon. View angles to the edge of the balloon and the earth's limb are shown as seen by a traditional package suspended below the balloon.

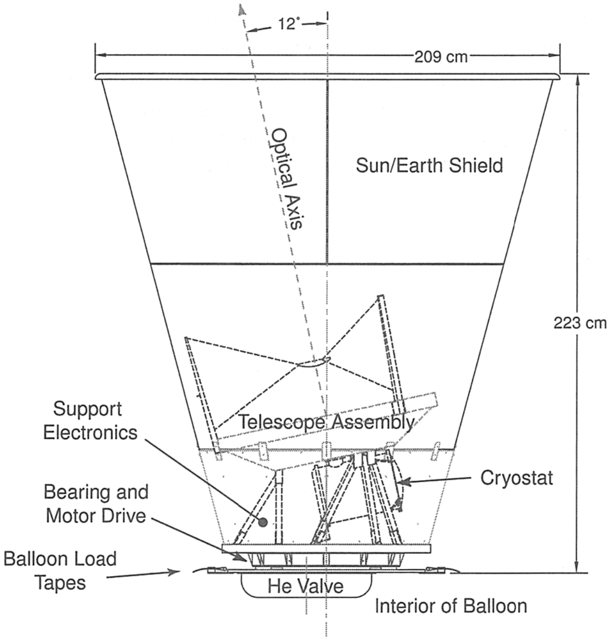

Figure 2. Configuration of the *TopHat* experiment. The *TopHat* experiment will be launched from McMurdo Station, Antarctica during the Austral summer. Since the Sun is above the horizon during the entire flight, a substantial Sun/Earth shield is required to make sure that sunlight never strikes the secondary mirror of the short focal length telescope. The ~1 meter telescope is an on-axis Cassegrain with the secondary suspended on thin dielectric fibers. The radiometer operates in a total power mode with the only modulation being the rapid rotation (4 RPM) of the entire package.

and spins at 4 RPM about the vertical axis. From its latitude of $\sim -78°$ each rotation sweeps out a circle of 24° diameter with a part of the circle passing over or very near the SCP. As the earth rotates, the center of the circle itself moves in a circle around the SCP so the entire polar cap region of ~48° diameter is observed each day in a highly redundant manner. Because of the many repeated observations of the same beams on the sky, this scanning pattern allows for many checks on the data quality and reliability. Since *TopHat* will be launched from Antarctica as a Long Duration Balloon (LDB) flight and will have ~2 weeks of observing, a significant fraction of the flight data will be used to study and characterize systematic errors in flight while still using most of the observing time to provide high sensitivity measurements of the CMBR anisotropy. The L^3He cooled radiometer uses bolometric detectors to observe in five spectral bands between 150 and 690 GHz. These bands allow us to characterize both the CMBR and insterstellar dust emission. A single *TopHat* LDB flight is expected to measure over 1800 deg^2 of sky in these bands. independent samples. While the SCP region of the sky we plan to observe is not free of interstellar dust emission, a potential contaminant to the CMBR observations, a large portion of the region has low dust emission. These low emission regions are similar to regions in which we have successfully separated the dust component from the CMBR in an earlier experiment four channel radiometer on the Medium Scale Anisotropy Measurement (MSAM) experiment (Cheng et al. 1994). We therefore estimate that ~70% of the observed region will be provide high quality data and thus will be useful for cosmological analysis using techniques similar to those we have already employed (Cheng et al. 1997, Inman et al. 1997).

3. Expected Results

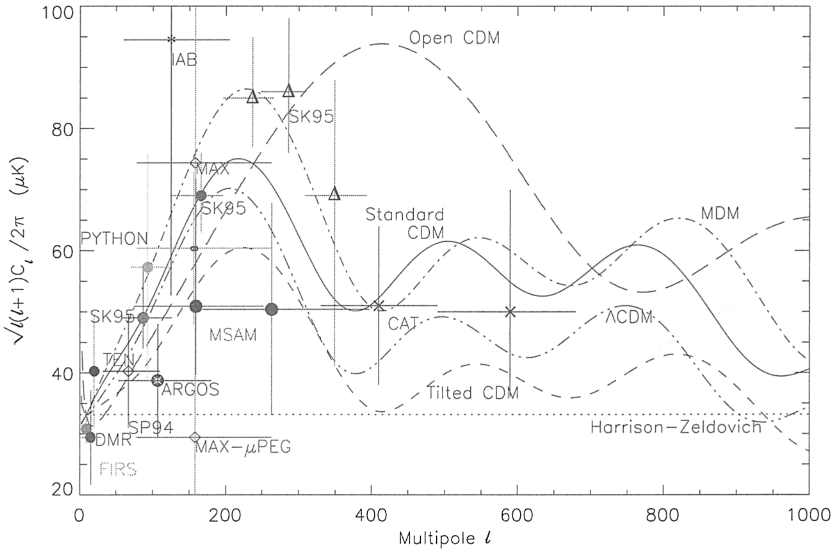

Figure 3. The figure shows some selected measurements along with the CMBR anisotropy power spectra predicted by some popular cosmological models. We have plotted the spectrum of the multipole moments, C_l, with linear scales on both axes to highlight the range of C_l sampled by recent and planned experiments and to better show the range of error bars on these earlier measurements.

It is common to characterize the angular power spectrum of the CMBR by estimation of its two point correlation function, or more conveniently its Legendre transform, C_l. We plot some selected measurements of the angular power spectrum of the CMBR anisotropy using the multipole moments, C_l, in Figure 3. On the same graph we also show the power spectra for some popular models. For many models (with Gaussian fluctuations), the information content in the power spectrum is complete. For topological defect models, additional information would be found in the higher order correlations and the phases. The multiple peaks in the spectra of many of the models are the result of acoustic oscillations in the baryon-photon fluid. These characteristic peaks and valleys are a generic consequence of structure formation by gravitational instability and hence are a sensitive probe of the geometry of the Universe. The height of the first few peaks depends on the matter-radiation ratio, while odd-to-even peak heights depend on the baryon-photon ratio.

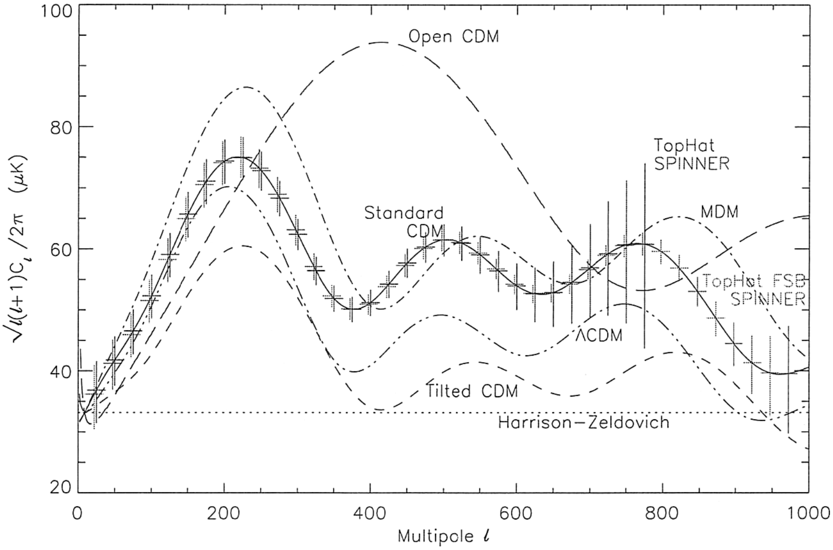

Figure 4. In this figure we show the same set of models as in Figure 3. The errors are calculated from our estimated sensitivity (including the loss of sensitivity due to astrophysical foreground separation) and assuming a uniform weight per solid angle bars plotted are for bands of width, δl=25. The gray symbols (most easily seen beyond l ~800) are labelled *TopHat* FSB and show what might be expected if a small array of a new type of compact high optical efficiency detector, frequency selective bolometers (Kowitt et al. 1996), were used in the *TopHat* with a slightly smaller beam.

The longer duration, broad l-space coverage, and high sensitivity of the *TopHat* experiment should dramatically improve our ability to distinguish among models. Figure 4 shows an estimate of the data quality obtainable with a successful *TopHat* Antarctic LDB flight. Estimated errors are plotted assuming an underlying standard Cold Dark Matter (CDM) model.

Although we expect to obtain a map with ~1800 deg^2 only 900 deg^2 were used in estimating the errors because modelling of the interstellar dust may reduce the sensitivity of our measurements in part of the sky. With data of this quality, we estimate that many interesting cosmological parameters could be well determined. Table 1 shows estimates of the error bars of some of these parameters or combinations of them that could be determined from a successful *TopHat* flight. Here n_S is the spectral index of the scalar modes, $\Omega_{tot} = \Omega_0 + \Omega_\Lambda$ is the total density of the universe in units of the critical density, Ω_0 is the matter contribution to the critical density, Ω_Λ is the cosmological constant contribution to the critical density, and Ω_b is the baryon contribution to the critical density. h is the Hubble constant in units of 100 km sec^{-1} Mpc^{-1} and τ is the optical depth to the surface of last-scattering. Even tighter constraints could be obtained if additional external information from galaxy surveys and Type Ia Supernova observations were included.

Table 1. How Well Can Cosmological Parameters Be Determined?

Measurement	Δn_S	$\Delta\Omega_{\rm tot}$	$\Delta\Omega_0 h^2$	$\Delta\Omega_b h^2$	$\Delta\Omega_\Lambda$	$\Delta\tau$
TopHat	0.11	0.04	0.025	0.003	0.20	0.25

4. Discussion

Sensitive multi-band instruments operating from the observationally clean environment on top of a balloon offer the opportunity to make very high quality measurements of the CMBR anisotropy. If the adiabatic curvature fluctuations are the correct model for structure formation (see Figures 3 and 4), then analysis of partial sky coverage maps can produce reliable estimates of fundamental cosmological parameters that will only be much more accurately determined when the next generation of cosmology satellites are launched in coming years.

Acknowledgements

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