

SPIDER: A Balloon-Borne Polarimeter for Measuring Large Angular Scale CMB B-modes

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SPIDER is a balloon-borne polarimeter that is designed to measure CMB B-mode polarization. The experiment is scheduled to launch from Alice Springs, Australia in December of 2009 and will target large angular scales where the B-mode signal from primordial gravity waves dominates. In a mid-latitude, around the world, 25 day flight *SPIDER* will map out roughly 50% of the sky. The instrument will observe in five frequencies ranging from 80 GHz up to 275 GHz enabling accurate characterization of the interstellar dust foreground.

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1. Introduction

SPIDER is a balloon-borne millimeter-wave polarimeter that targets the large angular scale B-mode polarization of the CMB. Probing CMB B-modes effectively probes the energy scale of Inflation, addressing the most fundamental of questions. *SPIDER* will also measure the curl-free E-mode component of the CMB. Constraining the amplitude of the low- ℓ Reionization peak of the EE angular power spectrum will significantly improve the determination of the Compton depth, τ , and possibly the details of the Reionization epoch. As a multi-frequency experiment *SPIDER* will measure the polarized emission from interstellar dust with unprecedented precision. This represents a crucial step toward the accurate characterization of CMB foregrounds essential to any space mission that would target the tiny CMB polarization signal.

2. The Spider Instrument and Flight

The instrument, depicted in Figure 1, consists of 6 monochromatic telescope inserts enclosed in a single LN/LHe cryostat. *SPIDER* will spin in azimuth with telescopes fixed in elevation. The experiment builds on the legacy of several successful suborbital experiments. For example the payload attitude control system will use the same basic designs incorporated in the BLAST and BOOMERANG experiments. The *SPIDER* optical train, shown in Figure 2 is based on the well-characterized BICEP design. A rotating half-wave plate, placed at each telescope aperture, will provide ideal polarization modulation. For detectors *SPIDER* will use a new generation of antenna-coupled bolometer arrays. The *SPIDER* flight plan is to launch from Alice Springs, Australia in December 2009, maintaining constant latitude, traveling around the world in roughly 25 days.

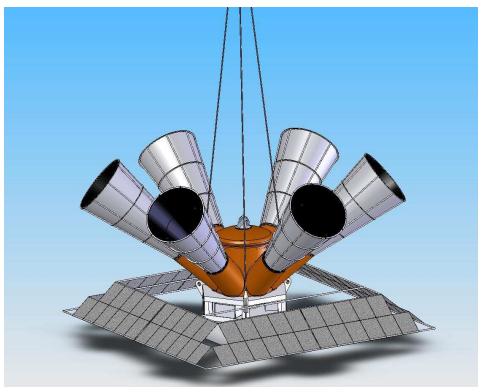


Figure 1: The *SPIDER* payload is designed to obtain maximum sky coverage from a twenty to thirty day mid-latitude balloon flight around the world. The experiment will map out roughly 50% of the sky observing only at night.

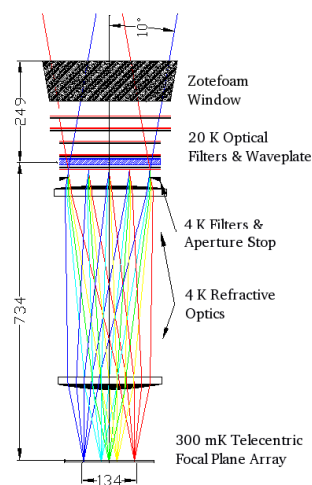


Figure 2: The *SPIDER* optics are based on the BICEP design. *SPIDER* will incorporate a rotating half-wave plate to modulate incoming polarization signal.

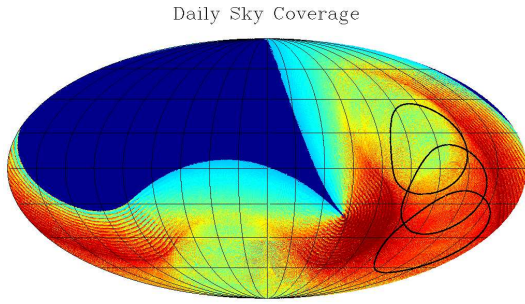


Figure 3: Simulated *SPIDER* sky coverage for a mid-latitude, 25 day flight, observing only at night.

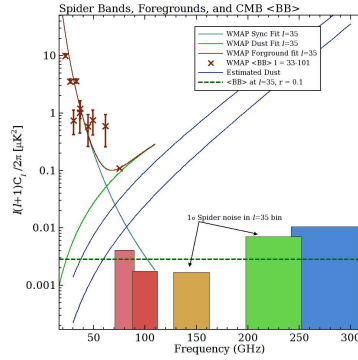


Figure 4: *SPIDER* 1σ sensitivities in each of the 5 observing frequencies at $\ell = 35$. Curves are estimates for foreground dust (rising with frequency) and synchrotron (falling with frequency). The data points are from the WMAP 3 year data [1].

SPIDER aims to map out approximately 50% of the sky. Figure 3 shows the simulated *SPIDER* sky coverage for 16 detectors spread over the bolometer array's range in elevation.

3. Astrophysical Foregrounds

Astrophysical foregrounds will be the biggest challenge to obtaining high precision measurements of CMB polarization. At high frequencies the polarized emission from dust dominates and at low frequencies polarized synchrotron emission dominates. *SPIDER* meets this challenge by observing, with high sensitivity, in 5 bands ranging in frequency from 80 GHz up to 275 GHz. Figure 3 summarizes the current knowledge of polarized foreground emission. The vertical bars show *SPIDER* 1σ sensitivities at $\ell = 35$ at each of the observing frequencies. A summary of *SPIDER* observing bands, including beam sizes, bandwidths, number of pixels/detectors in each band and detector/instrument sensitivities is given in Table 1.

4. *SPIDER* Science

SPIDER's primary scientific goal is to measure, with high fidelity, the CMB polarization on

Observing Band (GHz)	Bandwidth (GHz)	Beam FWHM (arcmin)	Number of Spatial Pixels	Number of Detectors	Single-Detector Sensitivity ($\mu\text{K}_{\text{CMB}}\sqrt{\text{s}}$)	Instrument Sensitivity ($\mu\text{K}_{\text{CMB}}\sqrt{\text{s}}$)
80	19	72	100	200	110	7.8
100	24	58	(2 \times)144	(2 \times)288	100	4.2
145	35	40	256	512	100	4.4
225	54	26	256	512	204	9.0
275	66	21	256	512	351	15.5

Table 1: Summary of *SPIDER* observing bands. Instrument sensitivities are derived by dividing the single detector sensitivity by the square root of the number of detectors. *SPIDER* will have a total of 2312 detectors observing at 5 different frequencies.

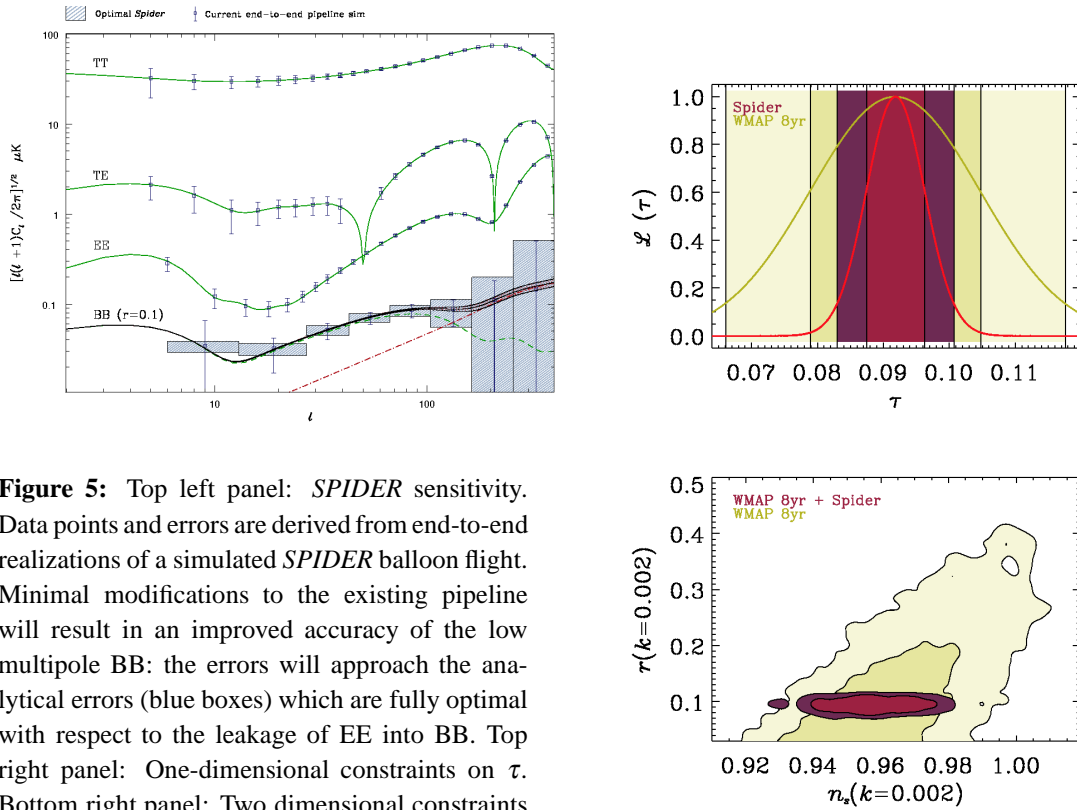


Figure 5: Top left panel: *SPIDER* sensitivity. Data points and errors are derived from end-to-end realizations of a simulated *SPIDER* balloon flight. Minimal modifications to the existing pipeline will result in an improved accuracy of the low multipole BB: the errors will approach the analytical errors (blue boxes) which are fully optimal with respect to the leakage of EE into BB. Top right panel: One-dimensional constraints on τ . Bottom right panel: Two dimensional constraints in the $n_s - r$ plane.

large angular scales. By aiming for large scale B-modes *SPIDER* minimizes the contamination to the BB angular power spectrum from B-mode induced by gravitational lensing. Figure 5 (left panel) illustrates the accuracy with which *SPIDER* will measure the TT, TE, EE and BB angular power spectra. We consider the effects on cosmic parameters in a minimal inflation model, with a uniform power law primordial index (n_s) and a single tensor-to-scalar ratio, r (it may well be that the inflation model is more complex in which case the high precision determination from *SPIDER* will be even more essential for unraveling the gravity wave induced contribution). From the EE spectrum alone *SPIDER* will improve the WMAP 8 year constraint on τ by more than a factor of three (figure 5 top right panel). The *SPIDER* constraints on r will break one of the more severe degeneracies (figure 5 bottom right panel) remaining in CMB data in the $n_s - r$ plane. *SPIDER* constraints on τ and r represent a reduction in the allowed volume in the $n_s - \tau - r$ parameter space by a factor greater than 50.

References

- [1] Page, L. et al., “Three Year Wilkinson Microwave Anisotropy Probe (WMAP) Observations: Polarization Analysis”, submitted to *Astroph. J.*, astro-ph/0603450