The Cosmic Foreground Explorer: A balloon borne microwave polarimeter to characterize large scale CMB polarization foregrounds

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1 COFE

The COsmic Foreground Explorer (COFE) is a balloon borne microwave polarimeter to measure the low frequency and low ℓ characteristics of some dominant polarized foregrounds.

2 COFE Primary goals

1. Measurement and understanding of the polarization characteristics of galactic foregrounds at low ℓ (2-100) and microwave frequencies below 50 GHz. These foregrounds include Synchrotron radiation, Bremstrahlung radiation, possible emission from spinning dust, and some potential contribution from point sources.

2. Exploration of the low-ℓ systematic limits to sub-orbital CMB polarization experiments for possible future large scale balloon borne missions.

3 COFE basic characteristics

Balloon borne: Balloon flights of nominal duration 12-24 hours, at a target altitude of 35 km, launched in the Northern and Southern Hemispheres.

Frequency coverage: Three bands centered at 10, 15 and 20 GHz, with separate cryostats for each frequency, and resolution of 80, 60 and 40 arcmin respectively. Each band occupies an independent telescope, while sharing data acquisition, computing, housekeeping electronics and liquid Helium (LHe) mass storage. Figure 1 shows atmosphere and model foreground emission for COFE bands and other frequencies interesting for CMB work.

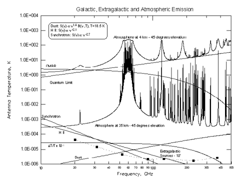

FIG. 1: Atmospheric and foreground emission from 10 to 500 GHz. COFE bands run from 10 to 20 GHz. For the target altitude of 35 Km, we expect well under 1 mK total emission from the atmosphere.

Telescope: Low cost copies of the previously flown BEAST optics [1, 2], a 2.2 m aperture, lightweight, off-axis telescope optimized for low cross-polar contamination and a wide focal plane. Figure 2 shows a sketch of the optical layout for the telescope modules. Figure 3 is a layout of the telescopes in the gondola.

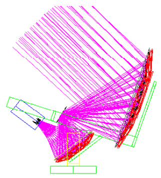

FIG. 2: Optical layout for the telescope modules. The rectangle on the left is the cryostat with the horn array. The beams from the horns are traced first through the secondary mirror then off the polarization modulator. The beams then reflect to the primary mirror and exit upper left.

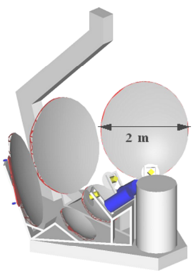

FIG. 3: One compact layout of the three telescopes in the gondola. The suspension structure rises from the back, leaving the front open for the beam exit and baffling. The large cylinder represents the LHe storage dewar.

Detector technology: InP MMIC amplifiers from NGST integrated into simple total power receivers (no phase matching, no waveguide outputs, and no OMT). Figure 4 is a schematic of the receiver module.

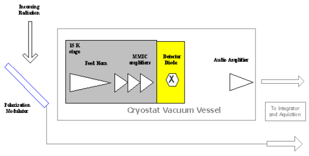

FIG. 4: Radiometer schematic. All RF gain, filtering and diodes are within the cryostat.

Feed horns: COFE has a conservative number of feeds required, and no ortho mode transducers or Hybrid tees, so the passive components are minimal. Figure 5 shows Q and Ka horns for reference.

FIG. 5: The BEAST Q and Ka array. The COFE horns and cryostat will be constructed with similar techniques, however the COFE radiometers will be simpler and more compact than BEAST, while the horns will be larger scaled versions of the ones shown.

Polarization modulation: COFE uses a reflection wave plate design, we have been developing, that allows simultaneous measurement of both Q and U, and intrinsically removes some of the most common sources of systematic error in polarization experiments. We have already demonstrated removal of receiver $1/f$ with this system. Figures 6, 7, 8, and 9 show a test configuration and data acquired by our design.

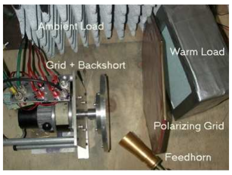

FIG. 6: Test setup of our spinning grid polarization chopper. The receiving horn at lower right couples to a 40 GHz radiometer sensitive to horizontally polarized incident radiation. The modulator at the center consists of a circular sheet of polypropylene with copper wires evaporated on the surface. The sheet is stretched on a frame and suspended in front of an aluminum backshort. The whole assembly rotates via the motor/encoder at left. In this configuration, the system is viewing a 350 K thermal absorber through a polarizing grid. This source grid views an 300 K target, giving a 50 K polarized signal.

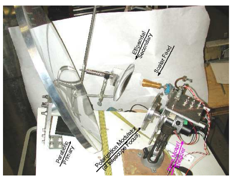

FIG. 7: A small telescope used to test the polarization modulator on the sky. We used a warm HEMT radiometer to view the sky in Santa Barbara. By calibrating with an external wiregrid, we were able to confirm our sensitivity to Q or U.

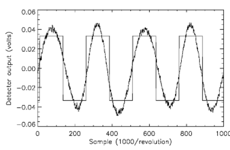

FIG. 8: Sample signal from a polarized thermal source. A single revolution of the modulator is shown, along with the reference signal to be used for demodulation. Commutating using this signal gives Q, for instance, while demodulating with a reference phase shifted by $\pi/4$ gives U.

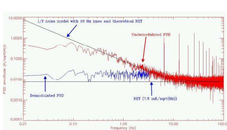

FIG. 9: Sample data from our room temperature radiometer viewing the sky. The undemodulated PSD displays the $1/f$ knee of the HEMT radiometer of 10 Hz and a white noise of 7.6 $\mathrm{mK}/\sqrt{\mathrm{Hz}}$. The demodulated data have no visible $1/f$ and a white noise level consistent with expectation.

Cryogenics: Large lightweight LHe storage tank with a very low parasitic continuous transfer line coupled to heat exchangers at the receivers. This highly efficient system was developed for BEAST and is robust, reliable, and simple to use.

T measurement: While foreground polarization is the primary goal, we will investigate ways of modifying COFE to allow total power or differential T measurements (internal Dicke switching, focal plane chopping etc).

4 Sky coverage

COFE will pointed 45° from the horizon to minimize ground and balloon pickup. The gondola will rotate at one rotation per minute. For a nominal 12 hour flight from Ft Sumner New Mexico, this gives about 25% of the sky for each detector. The following table and Figures 10, 11, and 12 show estimations obtained from COFE flight simulations.

Table 1 – Sensitivity estimates for COFE.

Frequency (GHz)	10	15	20
$T_{\mathrm{sys}}(K)$	8	10	12
Bandwidth (GHz)	4	4	5
Number of receivers	3	6	10
Aggregate sensitivity δT $(\mu\mathrm{K}\sqrt{\mathrm{s}})$	138	118	94
Aggregate sensitivity δP $(\mu\mathrm{K}\sqrt{\mathrm{s}})$	110	93	74

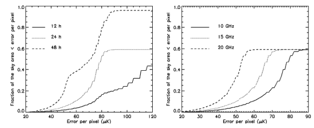

FIG. 10: Estimates of sensitivity per square degree pixel for the three COFE bands and for three subsets of the basic observation program (12 and 24 hour flights in New Mexico + 24 hours flight in the Southern Hemisphere). The relative benefits of integration time and sky coverage are visible.

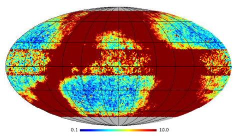

FIG. 11: Signal to noise per 1 degree pixel anticipated if the galactic foreground is 30% polarized. This map is for the 10 GHz band, 24 hours of data from the Northern Hemisphere and 24 hours from the Southern Hemisphere. Note the doubly sampled data on the celestial equator where the maps overlap. We expect to see significant structure well off the galactic plane.

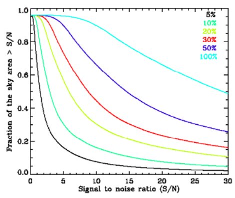

FIG. 12: Integrated histogram of anticipated signal to noise for several assumed fractional polarizations at 10 GHz. We plot the fraction of the entire sky measured with better than a given signal to noise for a full range of polarization fractions. Note that 100% is a rough guide to our T sensitivity.

5 Tentative year shedule

2006 – Finalize optical frame, gondola, and polarization modulator prototype.

2007 – Assemble first telescope system, and perform ground tests.

2008 – Two Ft Sumner flights.

2009 – Analysis of flight data and preparation for Southern Hemisphere flights.

References

[1] Childers, J. et al. 2005, ApJS, 158, 124
[2] Figueiredo, N. et al. 2005, ApJS, 158, 118

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