EBEX - E and B Experiment

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Introduction
Cosmic Microwave Background (CMB)

- **Afterglow Light Pattern 380,000 yrs.**
- **Dark Ages**
- **Development of Galaxies, Planets, etc.**
- **Inflation**
- **Quantum Fluctuations**
- **1st Stars about 400 million yrs.**
- **Big Bang Expansion 13.7 billion years**
- **Dark Energy Accelerated Expansion**

Image: WMAP science team
Polarization

- Scalar perturbations
  - Density perturbations
  - E-modes
- Tensor perturbations
  - Gravity waves
  - E-modes & B-modes
Gravitational Lensing
Power Spectra

\[ \frac{\langle (l+1)C_{ll}/2\pi \rangle^2}{\mu K} \]

\( l \)

- \( E \)
- \( B \)
- \( B \) lensing
- Gravity Waves
EBEX in a Nutshell

- A CMB Polarimeter
- Long duration balloon-borne
- Use >1000 bolometric TES
- 3 Frequency bands: 150, 250, 410 GHz
- 8’ resolution at all frequencies
- Polarimetry with continuously rotating half wave plate
- 11 days of data collected in 1/2013 and are being analyzed
Ballooning in Antarctica

- Instantaneous sensitivity
- Frequencies > 250 GHz
- Long duration flights
  - Favorable wind patterns
  - Sparsely populated
  - No sunset
- Challenges
  - Limited bandwidth
  - Observation time
Overview of Instrument
Instrument

7.6 m

Sun Shades

Ground Shield

Solar Panels

Sun Shades

8 Feet

Ground Shield

2725 kg Suspended Science Weight
2.6 kWatt max provided by panels
**Instrument**

- **Azimuth Motor**
- **Cable Suspension**
- **Inner Frame**
- **Elevation Axis**
- **Outer Frame**
- **Radiation Cooling Panels**
- **Star Camera**
- **Secondary Mirror**
- **Gyros**
- **Receiver**
- **Readout Electronics**
- **Primary Mirror**

Dimensions: **8 Feet**
Bolometer Theory

- Steady state power flow
  \[ P = G(T - T_{bath}) \]
- Time to relax
  \[ \tau = \frac{C}{G} \]
**Transition Edge Sensor Bolometers**

\[ P_{total} = G(T - T_{bath}) \]

\[ = P_{electrical} + P_{optical} \]

\[ = \frac{V^2}{R} + P_{optical} \]

\[
\frac{dP_{electrical}}{dT} = \frac{d}{dT}\left(\frac{V^2}{R}\right) = -\frac{dR}{dT}\frac{V^2}{R^2}
\]
Detector Development

- 213 TES bolometers (3 wafers) operated in NA flight (2009)
- For LD:
  - Optimize saturation power
  - $(4, 9, 12)$ pW for $(150, 250, 410)$ GHz

![Graph showing Measured Saturation Power for 347 250 GHz detectors, Target Saturation Power, Average Observed Load.](image)
Detector Development

- 213 TES bolometers (3 wafers) operated in NA flight (2009)
- For LD:
  - Optimize saturation power
  - Develop the tools to tune >1000 TES
    - with limited CPU and I/O
      - All tuning algorithms controlled by boards
      - Flight computer issues one command, receives returns, telemeters returns upon request
    - and *quickly* assess and retune
      - Automated assessment of TES IV
      - SQL-based database to facilitate efficient commands
Detector Development

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    - with limited CPU and I/O
      - and quickly assess and retune
        - Automated assessment of TES IV
          - SQL-based database to facilitate efficient commands
2012 Flight
2012 Flight

- 25.5 days at float (>33.5 km)
- 11 days of data
- 6000 deg$^2$ of constant dec
- Calibration scans on RCW38
Azimuth Motion – Free Rotation

- Full Rotations
  - $0.3 < v < 0.6$ deg/sec
  - Periodic Change of Direction

- 0.4 deg/sec
  - 40-50° p-p

- 0.6 deg/sec
  - 100° p-p
In-Flight Readout Noise

\[ \dot{i}_n (pA/\sqrt{Hz}) \]

Frequency (Hz)

Expected Squid Noise

in-flight squid noise (@ 915 kHz)

Total count = 16

SQUID B206

Measured noise / Predicted noise

Statistical frequency
Ground Calibration + 2012 Flight

- Optics, bands as designed
- We are seeing astrophysical signals

![Graph showing counts over time](image1.png)

![Graph showing band relative binned signal to noise](image2.png)
The Future + Summary
The Future - EBEX6K

- 1048 3-band multichroic pixels
- Each pixel is dual polarization
- Sinuous-antenna design (PB2, SPTPol)
- Total of 6048 detectors
- x64 multiplexing
EBEX6K

- 1048 3-band multichroic pixels
- Each pixel is dual polarization
- Sinuous-antenna design (PB2, SPTPol)
- Total of 6048 detectors
- x64 muxing
- 5 µK*arcmin
- 2σ upper limit on r=0.007
  (excludes lensing cleaning, foregrounds, or systematic uncertainties)

Fly in 12/2016 (?)
Summary

• First use of TES bolometers on a balloon platform

• We have >10 days data from 6000 deg$^2$ – Stay tuned

• Planning to probe $r<0.01$ with EBEX6K
Acknowledgements

- NASA
- Canada Space Agency
- National Science Foundation
- Canada Research Chairs Program
- Natural Sciences and Engineering Research Council of Canada
- Canadian Institute for Advanced Research
- Science and Technology Facilities Council (UK)
- Minnesota Supercomputing Institute
- National Energy Research Scientific Computing Center
- Minnesota and Rhode Island Space Grant Consortia
- Funding from Collaborating Institutions
- Sigma Xi
- Private Donations