Balloon Borne Observations of the Cosmic Microwave Background Radiation

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A BRIEF HISTORY OF TIME

Big Bang

\[ t = 10^{-32}\text{ sec} \]

Inflation

\[ t = 400,000\text{ years} \]

\[ T = 3,000\text{ K} \]

14 billion

\[ t \text{ (years)} \]

2.7 K

\[ T \text{ (K)} \]
T = 2.73 K
Mather et al. 1990

Color Scale = ±150 micro K
Smoot et al. 1992
Early Development of the Universe

Big Bang

Big Bang plus tiniest fraction of a second \(10^{-43}\)

Inflation

COBE Sky Map

Big Bang plus 300,000 Years

Light from first galaxies

Big Bang plus 15 billion years

Observational Cosmology - University of Minnesota
• COBE had ~10 degree angular resolution

• Higher angular resolution encodes
  • geometry of space
  • total matter and energy content
  • constituents of matter and energy
  • evolution of the universe
  • …more

• Balloons
  • Atmosphere = source of emission
  • Higher resolution = larger aperture
  • Faster turnaround
- North American balloon-borne
- Resolution: 10’
- Bolometers cooled to 0.1 K
- Funding from NASA/NSF (1993 - ~2001)
**MAXIMA Results**

- 3 hour flight from Palestine in 1998.

- Highest angular resolution image of the CMB

- Statistical properties of the CMB over broadest range of angular scales

- **To this date:** Highest Instantaneous Sensitivity CMB Instrument

- Best determination of the total energy density of the universe (contemporaneous with boomerang)

- Together with data from supernovae: conclusive evidence for both dark matter and dark energy

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*Science*: “One of the ten most important scientific breakthroughs for the year 2000”
The Next Frontier - Polarization

• CMB is polarized

• Convert ‘degree of polarization’ and ‘angle of polarization’ to: ‘E mode’ and ‘B mode’

• E mode originates at the epoch of decoupling

• B mode is signature of the inflationary epoch (t=10^{-35} \text{ sec})

• Detection of B mode would give un-ambiguous evidence for inflation

• Detection of B mode would fix the energy scale of inflation

• B mode polarization is the only known way to probe inflation directly

WMAP 2006
B-mode Polarization Challenges

• Signal is less than 100 nanoK

• Energy scale of inflation is unknown to ~10 orders of magnitude

• Signal could be substantially less than 100 nanoK

• Signal is expected to be dominated by foregrounds
EBEX – E and B EXperiment

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EBEX Science Goals

• Detect or improve current upper bound on B-mode by x10

• Characterize polarized foregrounds

• Detect B-mode lensing signal

• Provide high s/n measurement of E–mode polarization

• Test new technologies that are candidates for a future CMB polarization satellite
EBEX in a Nutshell

Sensitivity
• Long duration balloon borne
• Up to 1476 bolometric TES

Foregrounds
• Frequency range with only one foreground
• 3 Frequency bands: 150, 250, 420 GHz

Systematic Error Rejection
• Polarimetry with half wave plate

Schedule
• Funded by NASA since March 05
• NA test flight 2008
• Cable Suspension gondola (modelled after BLAST)

• 1.5 x 1.8 m primary

• 1 m secondary

• 1500 Lb cryostat

• Detectors maintained at 0.3 K
EBEX Focal Plane

- Total of 1476 detectors
- Maintained at 0.27 K
- 3 frequency bands/focal plane

- \( G = 15 \text{ pWatt/K} \)
- \( \text{NEP} = 1.4 \times 10^{-17} \text{ (150 GHz)} \)
- \( \text{NEQ} = 156 \mu\text{K*rt(sec)} \text{ (150 GHz)} \)
- \( \tau = 3 \text{ msec} \)
Payload Specs

- Weight: 5000 Lb
- Moment of Inertia: 1920 Kg m²
- Power: 1100 Watt
- Cryogen hold time: 24 days
- Data rate: 10 MBits/sec
- Data storage: 3 TBytes
Closing Words

• Balloon payloads have provided an extremely cost effective way to probe the cosmic microwave background radiation

• They have a critical role in being pathfinders for future NASA missions

• They have a critical role in training the next generation of our technology leaders

• They have already produced cutting edge science (MAXIMA, Boomerang, MAXIPOL, Archeops) and they will continue to do so into the future
**EBEX Flight Specifications**

- 14 days
- 350 deg$^2$
- ~20,000 8’ pixels
- Low dust contrast (4μK rms)
- 796, 398, 282 TES detectors at 150, 250, 420 GHz
- 0.7 μK/8’ pixel - Q/U;
  0.5 μK/8’ pixel - T
EBEX Optics

6 degree diameter, diffraction limited FOV; Strehl > 0.9