Contemporary Balloon-borne CMB Experiments

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With input from the Ballooning Community
(including S. Hanany, A. Kogut)
Long Duration Ballooning


• Wider frequency windows
  – Atmosphere makes > 150 GHz difficult
• Fidelity to large angular scales
• Space-like backgrounds
  – Sensitivity: one hour at 36km is like a day on the ground)
  – Analysis: data representative of a space mission
• Mission durations 5-100 days

At what price?

• Stringent limits on mass, power
• Complexity of automation
• Insane integration schedule
• Narrow, and scarce, flight windows
• Risky recovery
Long Duration Ballooning

Flight Options

• Antarctic Long Duration Balloon (LDB) : 10 – 30 days / 3 tons
• Wanaka Super Pressure Balloon (SPB) : 30 – 100 days / 1 ton
• Polar Night Flights : ~ 10 days
• Conventional Flight (Ft. Sumner, Palestine, Timmons) : 1 day

Flight Parameters

• 33-37 km altitude
• 1 km altitude stability (200 m for SPB)
• Annual flight windows
  – January (LDB, Svalbard), April (SPB, Wanaka), June (Palestine), September (Ft. Sumner)
Antarctic LDB

Chile, Argentina

McMurdo Station

Wanaka

New Zealand

Australia

Madagascar

South Africa

J. Gudmundsson
Super Pressure Ballooning

- 100 day flights
- 1 ton payload
- mid-latitudes (day/night cycle)

Second Flight Launched Yesterday!
Polar Night Flights
Sub-orbital radiative environment:

an overwhelming advantage above 200 GHz
Sub-orbital radiative environment:
radiative backgrounds comparable to that of Planck HFI

< 0.2 pW of optical background
(½ of our photons are from the CMB monopole!)
Balloon data representative of a space mission

Planck HFI

Spider 2015

William C. Jones  
CERN CMB Workshop, May 16, 2016

CERN
# Current/Pending Balloon Missions

<table>
<thead>
<tr>
<th>Missions Flown</th>
<th>survey area [sky fraction]</th>
<th>frequencies [GHz]</th>
<th>resolution [arcmin]</th>
</tr>
</thead>
<tbody>
<tr>
<td>EBEX (2012/13)</td>
<td>0.2</td>
<td>150/250/410</td>
<td>8/5/5</td>
</tr>
<tr>
<td>Nobody (2013/14)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Spider (2014/15)</td>
<td>0.1</td>
<td>94/150</td>
<td>42/28</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Missions Planned</th>
<th>survey area [sky fraction]</th>
<th>frequencies [GHz]</th>
<th>resolution [arcmin]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Piper (2016)</td>
<td>0.8</td>
<td>200</td>
<td>36</td>
</tr>
<tr>
<td>Spider (LDB 2017)</td>
<td>0.1</td>
<td>94-285 (3)</td>
<td>42-15</td>
</tr>
<tr>
<td>LSPE (Night 2017)</td>
<td>0.25</td>
<td>44-240 (4)</td>
<td>85-20</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Missions in Prep.</th>
<th>survey area [sky fraction]</th>
<th>frequencies [GHz]</th>
<th>resolution [arcmin]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Piper (2017-2020)</td>
<td>0.8</td>
<td>200-600 (4)</td>
<td>36-12</td>
</tr>
<tr>
<td>EBEX-IDS</td>
<td>0.035</td>
<td>150-360 (7)</td>
<td>8-3</td>
</tr>
<tr>
<td>BFORE</td>
<td>0.23</td>
<td>270-600 (3)</td>
<td>4</td>
</tr>
</tbody>
</table>
2013 Flight

EBEX 250 GHz

Planck processed as EBEX

Pol Signal to Noise on galaxy at 150 log

Pol Signal to Noise on galaxy at 250 log

Pol Signal to Noise on galaxy at 410 log

Observational Cosmology - University of Minnesota
Spider 2015: Overview

<table>
<thead>
<tr>
<th>Sky coverage</th>
<th>About 10 %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scan rate (az, sinusoid)</td>
<td>3.6 deg/s at peak</td>
</tr>
<tr>
<td>Polarization modulation</td>
<td>Stepped cryogenic HWP</td>
</tr>
<tr>
<td>Detector type</td>
<td>Antenna-coupled TES</td>
</tr>
<tr>
<td>Multipole range</td>
<td>10 &lt; ℓ &lt; 300</td>
</tr>
<tr>
<td>Observation time</td>
<td>16 days at 36 km</td>
</tr>
<tr>
<td>Limits on r†</td>
<td>0.03</td>
</tr>
</tbody>
</table>

† Ignoring all foregrounds, at 99% confidence

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<tr>
<th>Frequency [GHz]</th>
<th>94</th>
<th>150</th>
</tr>
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<tbody>
<tr>
<td>Telescopes</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Bandwidth [GHz]</td>
<td>22</td>
<td>36</td>
</tr>
<tr>
<td>Optical efficiency</td>
<td>30-45%</td>
<td>30-50%</td>
</tr>
<tr>
<td>Angular resolution* [arcmin]</td>
<td>42</td>
<td>28</td>
</tr>
<tr>
<td>Number of detectors†</td>
<td>652 (816)</td>
<td>1030 (1488)</td>
</tr>
<tr>
<td>Optical background‡ [pW]</td>
<td>≤ 0.25</td>
<td>≤ 0.35</td>
</tr>
<tr>
<td>Instrument NET† [µK-rts]</td>
<td>6.5</td>
<td>5.1</td>
</tr>
</tbody>
</table>

*FWHM. †Only counting those currently used in analysis
‡Including sleeve, window, and baffle
Spider 2015: survey coverage
Spider 90 GHz

\[ \mu K_{\text{CMB}} \]
Reobserved HFI 143 GHz
PIPER and LSPE

PIPER (Goddard)
2 short duration flights/year
Northern + Southern = ~80% sky/year
4 years = 8 flights (2016-2020)
200, 270, 350, 600 GHz

LSPE (Rome)
25% sky/flight (Svalbard, Norway)
1st Flight: 12/2017
44, 90, 150, 240 GHz
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S. Hanany
**EBEX-IDS**

- 7 bands: 150, 180, 220, 250, 280, 320, 360 GHz

- 1500 sq. deg. Co-observe with BICEP/Keck + Simmons Array

- Sinuous Antenna Trichroic Pixels (PB2, SPTRol, LiteBIRD)

**Total of 20562 detectors**
BFORE

Advanced ACTPol & Simons Array

SPIDER

SPTPol/SPT-3G

BICEP / Keck
The observational challenge:

A detection of primordial fluctuations must confirm:
• Spectral energy distribution
• Angular power spectrum
• Statistical isotropy

Experimental requirements:
• Extreme sensitivity \([\text{primordial signal} < 100 \text{ nK}_{\text{rms}}]\)
  (and control of systematic effects)
• Large survey area \([\text{signal is} \geq \text{degree-scale}]\)
• Multiple frequencies \([\text{as many as you can – we don’t know how many are needed…}]\)

Balloon experiments are able to address all these, with data representative of a space mission.
The observational challenge:

Planck 2015
The observational challenge:
**SPIDER: Probing the early Universe with a suborbital polarimeter**

Fraisse, et al. (2011)
arxiv: 1106.3087

Exhibit significantly less polarized dust emission. This study suggests that without component separation, degree-scale polarized dust emission will limit the constraints of any experiment at or above the level of $r \sim 0.03$, even in the portions of the southern sky most free of Galactic dust emission.
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Spider 2015: Foreground Estimates (thermal dust and synchrotron)
Spider 2015: flight performance
SPIDER: Probing the early Universe with a suborbital polarimeter

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