Design and performance of the BICEP Array receivers

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Polarized power spectra

E-Mode count as 10% of CMB anisotropies signal and have been detected.

B-Mode power depends from the energy scale of the primordial Gravitational Waves and they have not been detected yet.

$r$ is defined as the ratio of tensor to scalar amplitude and it requires very clean and sensitive measurements.
South Pole Station

- Located at the NSF Amundsen-Scott South Pole Station
- Dry, stable atmosphere, high altitude
- 24 hours coverage of the Southern Sky with no elevation drift
- ~1.5% of the sky, focus on ~600 deg² patch

Keck Array (2011-2018)
BICEP Array (2019-)

BICEP (2006-2009)
BICEP 2 (2010-2012)
BICEP 3 (2015-)
BICEP Array

- BICEP2 (2010-2012)
- Keck Array (2012-2017)
- BICEP3 (2015-)
- BICEP Array (2018-)

Telescope and Mount

Focal Plane

Beams on Sky
Antenna-Coupled TES Bolometers for CMB Polarimetry

Wafers on the sky to date: 40 (95 GHz); 32 (150 GHz); 16 (220 GHz); 8 (270 GHz)
BICEP Array facts

Cryostat based on Keck Array, Sub-K & Focal Plane based on BICEP3

Replace Keck Array in 2018, new mount.

4 Receivers:
- 30, 40 GHz
- 95 GHz
- 150 GHz
- 220, 270 GHz

Reference:
Eric Chauvin
### BICEP Array expected sensitivities

<table>
<thead>
<tr>
<th></th>
<th>30/40 GHz</th>
<th>95 GHz</th>
<th>150 GHz</th>
<th>220/270 GHz</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Tiles</strong></td>
<td>12</td>
<td>12</td>
<td>12</td>
<td>12</td>
</tr>
<tr>
<td><strong># Detectors</strong></td>
<td>192/300</td>
<td>3456</td>
<td>7776</td>
<td>13824/16224</td>
</tr>
<tr>
<td><strong># Det/ Tile</strong></td>
<td>32/50</td>
<td>288</td>
<td>648</td>
<td>1152/1352</td>
</tr>
<tr>
<td><strong>Beam FWHM (arcmin)</strong></td>
<td>76/57</td>
<td>24</td>
<td>15</td>
<td>10/8.5</td>
</tr>
<tr>
<td><strong>NET per det (uK-rts)</strong></td>
<td>268/334</td>
<td>267</td>
<td>315</td>
<td>900/1800</td>
</tr>
<tr>
<td><strong>Instr. NET (uK-rts)</strong></td>
<td>21/21</td>
<td>4.93</td>
<td>3.87</td>
<td>8.3/15</td>
</tr>
<tr>
<td><strong>3-yr map depth (uK-arcmin)</strong></td>
<td>7.5/7.5</td>
<td>1.9</td>
<td>1.4</td>
<td>3.0/5.5</td>
</tr>
</tbody>
</table>
BICEP Array: cryostat

- HDPE window
- Zotefoam IR load filter
- Alumina Lenses (HDPE for 30/40GHz receiver)
- Alumina 50K filter
- Nylon 4K IR filter
- 300K shell
- 50K shield
- 4K shield
- Niobium Flared Magnetic Shield 300mK
- Edge Filter
- Focal Plane
- He4/He3/He3 sorption Fridge
- Pulse Tube Cryocooler

Reference:
Mike Crumrine @ University of Minnesota
LTD18 - Alessandro Schillaci - Milan 2019
BICEP Array: BA1 receiver integration and test
BICEP Array: Focal Plane and Modules

30/40GHz Checker Board FPU

30GHz

40GHz

150GHz Mux/Nyq PCB (44 rows/ 16 cols)
BICEP Array: BA1 40GHz Module Spectral Response and Noise

See C. Zhang poster
BICEP Array: BA1 40GHz Antenna Beams

Wide band corrugated frame

See A. Soliman poster
BICEP Array: Mount integration and test

- The new mount is fully operative at UMN.
- BA-2 cold on mount with a 40GHz module.
**BICEP Array: projected sensitivities**

BK and SPT-3G communities working together for delensing
30/40GHz Diplexer

Work by Corwin Shiu, assisted by Bryan Steinbach, Roger O’Brien, and Krikor Megerian

Comparison of design to measured spectra

- Lowband
- Measured low band
- Highband
- Measured high band

Antenna bandwidth ~100%

Black dashed lines are model, white is f/1.5 stop

30GHz Band OE=35%

40GHz Band=28%
Microwave multiplexing (umux)

Frequency-domain multiplexing for DC-biased TESs

- Shunted resonances on single transmission line
  - TES current alters resonance frequency through rf SQUID
  - Signal is frequency modulation (FM)
- ~2000x over 4-8 GHz
- On-sky CMB demonstration with Keck 2019 @ 150GHz

See Ari Cukierman Talk on Wed 8:45
Thermal Kinetic Inductance Detectors (TKIDs)

- Bolometers with kinetic inductance thermometers
- KID-like readout, more design parameters
- Background limited for South Pole at 90GHz and higher
- $1/f \sim 1\text{Hz}$
- 20aW/rtHz at 10Hz
- $\sim 1\text{ms}$ time constants

See Albert Wandui’s Talk on Fri 2:45pm

See Lorenzo Minutolo’s Poster
Detector packing  

- Analysis by Lorenzo Moncelsi, Roger O’Brient, Corwin Shiu

- Will have circular footprint, hex-pack more pixels in focal planes.

- With the same target beam, uniform illumination allows pixels to be ~90% smaller than gaussian illuminated, so could nearly double the pixels count (bolometers and bias lines reduce this advantage some)

- Left: Dashed line shows uniform size over gaussian illumination at the feed

- Right: Similar gain and edge taper in resultant beams
Conclusions

● BICEP/Keck is producing the deepest maps in polarization at low-l CMB and with BK15 we have the lowest constrain on r ever published.

● 3 years (2016-2018) of 95GHz data from Bicep3 and 2 years of 270GHz from Keck to be added to analysis (BK18 data analysis - See Howard Hui Poster).

● BICEP Array 30/40GHz first receiver is performing well and it is getting ready for deployment in the incoming 2019/2020 austral summer.

● Expect to detect synchrotron in BK patch with only 1 year of observations!

● Next 150GHz receiver is almost fully designed and partially built for 2020/2021 deployment season