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# Colin Bischoff

## Education and Employment

- 2013–present      Research associate, Harvard-Smithsonian Center for Astrophysics, Supervisor: John Kovac
- 2010–2013        Postdoctoral fellow, Harvard-Smithsonian Center for Astrophysics, Supervisor: John Kovac
- 2002–2010        University of Chicago, Ph.D. in physics. Thesis title: *Observing the Cosmic Microwave Background Polarization Anisotropy at 40 GHz with QUIET*, Advisor: Bruce Winstein
- 1998–2002        Stanford University, B.S. in physics with honors. Thesis title: *Synchrotron X-Ray Scattering Study of Structural Distortions in the Double-Layer Manganite  $La_{1.2}Sr_{1.8}Mn_2O_7$* , Thesis advisor: Martin Greven

## Fellowships and Awards

- 2008–2009        Grainger Foundation Fellowship, University of Chicago.
- 2003                Sachs Fellowship, University of Chicago.
- 2002–2003        McCormick Fellowship, University of Chicago.
- 2002                Jeff Willick Memorial Award, Stanford University.

## Publications

24. Keck Array and BICEP2 Collaborations 2016, *BICEP2/Keck Array VII: Matrix Based E/B Separation Applied to BICEP2 and the Keck Array*, submitted to ApJ (arXiv:1603.05976)
23. Keck Array and BICEP2 Collaborations 2016, *BICEP2/Keck Array VI: Improved Constraints On Cosmology and Foregrounds When Adding 95 GHz Data From Keck Array*, Phys. Rev. Lett. 116, 031302
22. BICEP2 Collaboration 2015, *BICEP2 III: Instrumental Systematics*, ApJ 814, 2, 110
21. BICEP2/Keck and Planck Collaborations 2015, *A Joint Analysis of BICEP2/Keck Array and Planck Data*, Phys. Rev. Lett. 114, 101301
20. BICEP2, Keck Array, and SPIDER Collaborations 2015, *Antenna-coupled TES bolometers used in BICEP2, Keck Array, and SPIDER*, ApJ 812, 2, 176
19. BICEP2 and Keck Array Collaborations 2015, *BICEP2/Keck Array V: Measurements of B-mode Polarization at Degree Angular Scales and 150 GHz by the Keck Array*, ApJ 811, 2, 126
18. T. Ruud et al. 2015, *The Q/U Imaging Experiment: Polarization Measurements of the Galactic Plane at 43 and 95 GHz*, ApJ 811, 2, 89

## Publications (continued)

17. BICEP2 and Keck Array Collaborations 2015, *BICEP2/Keck Array. IV. Optical Characterization and Performance of the BICEP2 and Keck Array Experiments*, ApJ 806, 2, 206
16. Abazajian et al. 2015, *Inflation physics from the cosmic microwave background and large scale structure*, Astropart. Phys. 63, 55, Snowmass white paper
15. Abazajian et al. 2015, *Neutrino physics from the cosmic microwave background and large scale structure*, Astropart. Phys. 63, 66, Snowmass white paper
14. Huffenberger et al. 2014, *The Q/U Imaging Experiment: Polarization Measurements of Radio Sources at 43 and 95 GHz*, ApJ 806, 1, 112
13. BICEP2 Collaboration 2014, *BICEP2 II: Experiment and Three-Year Data Set*, ApJ, 792, 1, 62
12. BICEP2 Collaboration 2014, *BICEP2 I: Detection of B-Mode Polarization at Degree Angular Scales*, Phys. Rev. Lett., 112, 241101
11. J. Kaufman et al. 2014, *Self-Calibration of BICEP1 Three-Year Data and Constraints on Astrophysical Polarization Rotation*, Phys. Rev. D, 89, 062006
10. D. Barkats et al. 2014, *Degree-Scale CMB Polarization Measurements from Three Years of BICEP1 Data*, ApJ, 783, 2, 67
9. QUIET Collaboration 2013, *The Q/U Imaging Experiment Instrument*, ApJ, 768, 1, 9
8. S. Moyerman et al. 2013, *Scientific Verification of Faraday Rotation Modulators: Detection of Diffuse Polarized Galactic Emission*, ApJ, 765, 1, 64
7. QUIET Collaboration 2012, *Second Season QUIET Observations: Measurements of the CMB Polarization Power Spectrum at 95 GHz*, ApJ, 760, 2, 145
6. O. Tajima, H. Nguyen, C. Bischoff, A. Brizius, I. Buder, and A. Kusaka 2012, *Novel calibration system with sparse wires for CMB polarization receivers*, J Low Temp Phys, 167, 936
5. Z. Staniszewski et al. 2012, *The Keck Array: A Multi Camera CMB Polarimeter at the South Pole*, J Low Temp Phys, 167, 827
4. QUIET Collaboration 2011, *First Season QUIET Observations: Measurements of Cosmic Microwave Background Polarization Power Spectra at 43 GHz in the Multipole Range  $25 \leq \ell \leq 475$* , ApJ, 741, 2, 111
3. C. Bischoff et al. 2008, *New Measurements of Fine-Scale CMB Polarization Power Spectra from CAPMAP at Both 40 and 90 GHz*, ApJ, 684, 2, 771
2. D. Barkats et al. 2005, *CMB Polarimetry using Correlation Receivers with the PIQUE and CAPMAP Experiments*, ApJS, 159, 1, 1
1. D. Barkats et al. 2005, *First Measurements of the Polarization of the Cosmic Microwave Background Radiation at Small Angular Scales from CAPMAP*, ApJ, 619, 2, L127

## Conference Proceedings

8. I. Buder et al. 2014, *BICEP2 and Keck Array: upgrades and improved beam characterization*, in: Proc. SPIE 9153, 915312
7. K. Karkare et al. 2014, *Keck Array and BICEP3: spectral characterization of 5000+ detectors*, in: Proc. SPIE 9153, 91533B

## Publications (continued)

6. C. Bischoff for the BICEP Collaboration 2013, *A CMB B-mode Search with Three Years of BICEP Observations*, in: Proc. IAU Symposium No. 288, Astrophysics from Antarctica, M. G. Burton, X. Cui, & N. F. H. Tothill (eds.), 61
5. R. W. Ogburn IV et al. 2012, *BICEP2 and Keck Array operational overview and status of observations*, in: Proc. SPIE 8452, 84521A
4. S. Kernasovskiy et al. 2012, *Optimization and sensitivity of the Keck Array*, in: Proc. SPIE 8452, 84521B
3. R. O'Brient et al. 2012, *Antenna-coupled TES bolometers for the Keck Array, Spider, and Polar-1*, in: Proc. SPIE 8452, 84521G
2. A. Vieregg et al. 2012, *Optical Characterization of the Keck Array Polarimeter at the South Pole*, in: Proc. SPIE 8452, 845226
1. C. Sheehy et al. 2010, *The Keck Array: a pulse tube cooled CMB polarimeter*, in: Proc. SPIE 7741, 77411R

## Talks

- *Measurements of Degree-Scale B-mode Polarization with BICEP2, Keck Array, and BICEP3*; Rencontres de Moriond Cosmology (invited talk), March 20 2016.
- *Constraining Cosmological Inflation with BICEP2, Keck Array, and BICEP3*; University of Cincinnati Physics Colloquium, February 25 2016.
- *Measurements of Degree-Scale B-mode Polarization with BICEP2, Keck Array, and BICEP3*; Marcel Grossmann 14, July 14 2015.
- *Joint Analysis of BICEP2, Keck Array, and Planck*; Boston University Astronomy Colloquium, March 2 2015.
- *Joint Analysis of BICEP2, Keck Array, and Planck*; Kavli Institute for Cosmological Physics Friday Seminar, February 13 2015.
- *Beam Mapping for BICEP2 and Keck Array*; UC San Diego CMB group meeting, May 20 2014.
- *Detection of B-Mode Polarization at Degree Scales Using BICEP2*; UC Davis Physics Colloquium, April 21 2014.
- *Detection of B-Mode Polarization at Degree Scales Using BICEP2*; Boston University High Energy Experimental Physics Seminar, April 17 2014.
- *Detection of B-Mode Polarization at Degree Scales Using BICEP2*; NRC Herzberg Institute for Astrophysics and University of Victoria Physics Colloquium, April 8 2014.
- *Detection of B-Mode Polarization at Degree Scales Using BICEP2*; Harvard-Smithsonian Institute for Theory and Computation, April 3 2014.
- *Final Results from Three Years of Observations with the BICEP Telescope*; Kavli Institute for Cosmological Physics Friday Seminar, May 17 2013.
- *Final Results from Three Years of Observations with the BICEP Telescope*; American Physical Society April Meeting, April 13 2013.

## Talks (continued)

- *Final Results from Three Years of Observations with the BICEP Telescope (almost)*; International Astronomical Union XXVIII General Assembly, August 21 2012.
- *Final Results from Three Years of Observations with the BICEP Telescope (almost)*; Scientific Committee for Antarctic Research XXXII Open Science Conference, July 18 2012.
- *Current Status of QUIET*; American Physical Society April Meeting, February 13 2010.
- *Measuring CMB Polarization with QUIET*; Lawrence Berkeley National Lab Research Progress Meeting, November 24 2009.
- *Current Status of QUIET*; Santa Fe '09 Cosmology Summer Workshop, July 9 2009.
- *Measuring CMB Polarization from the Garden State with CAPMAP*; The Path to CMBPol – Upcoming Measurements of CMB Polarization, July 1 2009.
- *The QUIET Polarimeter Array*; URSI National Radio Science Meeting, January 4 2007.

## Teaching and Mentoring

2012–present	Founded a cosmology journal club to keep up to date on current research and encourage graduate students to read more papers.
2010–present	Assisted with supervising graduate students Chin Lin Wong (Harvard Physics, graduated September 2014), Kirit Karkare (Harvard Astronomy), Jake Connors (Harvard Physics), Kate Alexander (Harvard Astronomy), and Victor Buza (Harvard Physics).
Fall 2013	Teaching fellow for Harvard University Computer Science 109/Statistics 121/Applied Computation 209: Data Science including development of lab assignments, Profs. Hanspeter Pfister (Computer Science) and Joe Blitzstein (Statistics).
Summer 2013	Advised summer undergraduate John Roberts on a project to characterize broad-spectrum microwave sources used for instrument characterization.
Summer 2012	Assisted Ashland High School student Ankit Kumar on a summer project to create a guided tour of BICEP CMB research in World Wide Telescope.
Fall 2006	Teaching assistant for University of Chicago Physics 121: Introductory Mechanics for non-majors including lab section, Prof. Yau Wah.
2000–2002	Undergraduate peer tutor for physics and math, Stanford University.

## Professional Service

- Member of International Astronomical Union.
- Reviewer for *Astrophysical Journal*, *Journal of Astronomical Instrumentation*.

## Public Outreach

- *Observing the Origin of the Universe from Antarctica*; Keene Public Library Astronomy Lecture Series, February 29 2016.

## Public Outreach (continued)

- *Observing the Origin of the Universe from the South Pole*; Smithsonian's Stars Lecture, Smithsonian National Air and Space Museum, January 24 2015.
- *Observing the Origin of the Universe from the South Pole*; Presentation to the Cape Cod Astronomical Society in Yarmouth, MA, September 9 2014.
- *South Pole Astronomy*; exhibit for DiscoverSTEM 2013 at Acton-Boxborough Regional High School, November 4 2013.
- *Observing the Origin of the Universe from the South Pole*; Presentation to the Cape Cod Astronomical Society in Yarmouth, MA, August 1 2013.
- *Observing the Universe from Antarctica*; Teen program at the Malden Public Library in Malden, MA, July 29 2011.
- *Cosmology at the South Pole*; Lecture at the Gleason Public Library in Carlisle, MA, March 16 2011.
- *Bang! The Origin of the Universe*; Teen program at the Homewood Public Library in Homewood, IL, 2007.

## Research Experience

My research career has focused on measuring the polarization of the Cosmic Microwave Background (CMB), particularly the search for *B*-mode polarization at large angular scales. I have been involved in development, deployment, operation, and data analysis for many of the leading experiments in the field, which are detailed below.

### BICEP2 and Keck Array

North American assembly and integration of two of the five Keck receivers before they were shipped to South Pole. Continuing operation of Harvard test facility and beam mapping range, including a spare Keck receiver and a copy of the BICEP three-axis telescope mount. Pre-deployment testing of 95 GHz, 220 GHz, and 250 GHz focal planes for Keck Array upgrades. Five austral summer deployments to Antarctica for BICEP2 and Keck Array maintenance, repairs, upgrades, and calibration. Past deployment seasons are 2010–2011 (initial Keck deployment), 2011–2012 (Keck expansion to five receiver configuration), 2012–2013 (BICEP2 undeployment), 2013–2014 (95 GHz upgrade for Keck), 2015–2016 (220 GHz upgrade for Keck). Responsible for writing Keck Array CMB observing schedules, providing advice and support for Keck winter-over. Responsible for integration and control of stepped half-wave plates in two Keck receivers for the 2011 observing season.

Extensive work on optical calibration for both BICEP2 and Keck Array at Harvard and on site at the South Pole. Optical calibrations include unpolarized (thermal source) beam mapping, far sidelobes mapping, and a particular focus on polarization angle calibration with a rotating polarized source. Design and development of novel optical calibration sources.

Key member of BICEP/Keck data analysis team, with a focus on bandpower statistics and likelihood methods for component separation and parameter constraints. Developed multi-component, multi-spectrum likelihood analysis used for the primary result in BICEP2/Keck Array/Planck joint analysis, as well as ongoing and future analyses with multi-frequency data from Keck Array. Integration of BICEP2/Keck/Planck likelihood in CosmoMC Monte Carlo Markov Chain software package, to facilitate use of our data by the wider cosmology community.

## **Research Experience (continued)**

### **BICEP1**

Data analysis for final three-year results paper, Barkats et al. 2014, which included first demonstration of beam systematics deprojection technique. Developed quadratic estimator for  $r$  that was used for the primary science result. Evaluation of systematic uncertainty in polarization angle calibration for cosmic polarization rotation analysis in Kaufman et al. 2014.

### **QUIET**

Designed electronics for detector module bias and readout. Integration and testing for the 90 GHz receiver, starting from R&D on single detector modules and culminating in tuning and optimization of a 90 element array. Deployment of 40 GHz and 90 GHz receivers to the Chajnantor Observatory at 5000 meters elevation in the Atacama Desert. On-site troubleshooting of problems with cryogenics and telescope drive system.

Key member of one of the two parallel data analysis pipelines. Wrote low-level software libraries used across the QUIET Collaboration. Data selection and blind analysis verification for 40 GHz polarization results using a suite of null tests. Studies of noise correlation between channels in a detector module. Polarization angle calibration using observations of the moon.

### **CAPMAP**

Deployment activities and observing shifts for three seasons of CAPMAP. Built, optimized, and characterized the four 40 GHz polarimeters. Assembly and integration of two (out of four) CAPMAP cryostats. Detector noise characterization. Polarization angle calibration.