The Adolph C. and Mary Sprague

Miller Institute

for Basic Research in Science

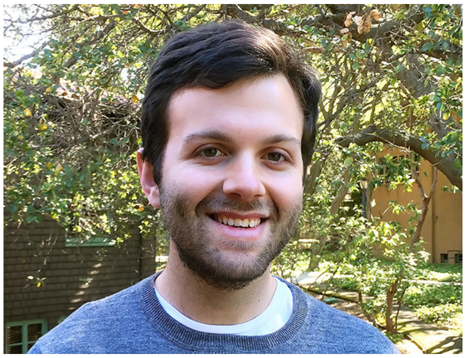
Newsletter
Spring 2015

CMB Lensing: Mapping our Dark Universe

Miller Fellow Focus: Blake Sherwin

One of the most striking facts about our universe is that most of its contents are invisible. A wealth of evidence implies that more than 80% of the matter in our universe is not made of atoms, but instead of invisible dark matter. Though this invisible substance has an unknown composition, it is of great importance. Every one of the hundreds of millions of known galaxies (including the one we inhabit) lies within a much larger halo of dark matter. Each of these halos is connected in an enormous filamentary dark matter network, whose shape and size encodes a wealth of information about the contents, history, and evolution of our universe. However, until recently, this cosmic network of dark matter remained unobserved.

How can we see invisible structures? Though dark matter does not emit or scatter light directly, it exerts a gravitational pull that allows us to observe its presence indirectly. A clump of dark matter gravitationally attracts rays of light that are passing by, which causes their paths to be slightly deflected. This process is known as gravitational lensing, because the effect is very similar to the deflection of light when it passes through a magnifying lens. As with a magnifying glass, gravitational lensing causes everything that lies behind to appear enlarged. This suggests a simple method for making maps of the large-scale matter distribution. To map out the mass, we must find subtle lensing features in the most distant source of light: the afterglow of the hot big bang, the cosmic microwave background radiation (CMB). Emitted nearly 14 billion years ago from more than 40 billion light years away, this CMB radiation has traversed the entire cosmic web of dark matter before reaching our telescopes, picking up signatures of gravitational lensing along the way. If we can find lensing features in this CMB light, we can therefore reconstruct maps of the mass distribution projected across the observable universe. However, the lensing features are more than a hundred thousand times smaller than the mean brightness of the CMB, so identifying them in real, noisy data can be challenging.



Early Measurements of CMB Lensing

Both as a graduate student and as a Miller Fellow in the Department of Physics, my focus has been on identifying the minute lensing effects in observations of the CMB, mapping out the cosmic distribution of mass on the largest scales, and extracting the information the mass distribution contains about the composition and history of the universe. When I began work on this field in graduate school,

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Miller Research Fellowship Nominations
Deadline: Thursday, September 10, 2015

Miller Research Professorship Applications
Deadline: Thursday, September 17, 2015

Visiting Miller Professorship Departmental Nominations
Deadline: Friday, September 18, 2015

For more information on all our programs:
MillerInstitute.berkeley.edu

In the News...

For updated news:
MillerInstitute.berkeley.edu

"The Miller Institute is one of those rare things in life that has literally no down side. It's all great. Great postdocs, great experiences for faculty and visiting scientists. A visionary gift to the university and its many beneficiaries!"

- Beth Burnside

Professor Emerita of Cell and Developmental Biology, Miller Professor 1991 and former UC Berkeley Vice Chancellor for Research

Call for Miller Professor Applications

Online Application Deadline: Thursday, September 17, 2015

Miller Research Professorship AY 2016-2017

The Miller Professorship program is looking with a view to the future in announcing the call for applications for terms in 2016-2017. The goal is to accommodate a greater range of campus faculty to participate in the vibrant Miller community. The objective of the Miller Professorship program is to provide opportunities for faculty to pursue new research directions on the Berkeley campus. For some, this may best be enabled by taking time off from teaching. This will continue to be an option. For others, the teaching obligations are critical to maintaining campus academic programs. There will thus be a new option for Miller Professors, allowing the continuation of campus service and teaching. Funds will be distributed differently depending upon the choice selected. Details of the terms and the application procedure are posted on the Miller Institute website. The primary purpose of the Miller Professorship program and the evaluation criteria will continue to be research excellence. Applicants will also be encouraged to describe their interest in participating in the Miller Institute community.

Applications from UC Berkeley faculty for Miller Research Professorship terms in the 2016-17 academic year will be accepted online beginning in May 2015. The purpose of the Professorship is to release members of the faculty from teaching and administrative duties and allow them to pursue research on the Berkeley campus. Appointees are encouraged to follow promising leads that may develop in the course of their research.

Applications are judged competitively and are due by Thursday, September 17, 2015. It is anticipated that between five to eight awards will be made.

Call for Visiting Miller Professor Nominations

Online Nomination Deadline: Friday, September 18, 2015

Visiting Miller Research Professorship AY 2016-2017

The Advisory Board of the Miller Institute for Basic Research in Science invites Berkeley faculty to submit online nominations for Visiting Miller Research Professorships and the Gabor A. and Judith K. Somorjai Visiting Miller Professorship Award for terms in Fall 2016 or Spring 2017. The purpose of these Visiting Miller Professorships is to bring promising or eminent scientists to the Berkeley campus on a short-term basis for collaborative research interactions. It is required that awardees are in residence at Berkeley during their appointment term. Faculty members or research scientists from any place in the world are eligible to be considered for sponsorship. Non-US citizens must be eligible for J-1 Scholar visa status. Faculty members at other UC campuses are eligible to be nominated for this program. The Miller Institute, as the sponsor and administrative department, will extend an invitation after advising the department of its selection.

Any questions regarding this program may be directed to the Institute's office by phone at (510) 642-4088 or by emailing the Miller Institute.

:: **Nomination & Application details**: MillerInstitute.berkeley.edu

:: **Questions?** Kathryn Day: 510-642-4088 | millerinstitute@berkeley.edu

The Adolph C. and Mary Sprague
Miller Institute for Basic Research in Science

Call for Nominations: Miller Research Fellowship

2016-2019 Term

Nomination Deadline: Thursday, September 10, 2015

The Miller Institute for Basic Research in Science invites department chairs, faculty advisors, professors and research scientists at institutions around the world to submit nominations for Miller Research Fellowships in the basic sciences. The Miller Institute seeks to discover and encourage individuals of outstanding talent, and to provide them with the opportunity to pursue their research on the Berkeley campus. Fellows are selected on the basis of their academic achievement and the promise of their scientific research. Miller Fellows also have a keen curiosity about all science and share an appreciation for an interdisciplinary experience. The Miller Institute is the administrative home department for each Miller Fellow who is hosted by an academic department on the Berkeley campus. All research is performed in the facilities provided by the UC Berkeley academic department. A list of current and former Miller Research Fellows can be found at: http://MillerInstitute.berkeley.edu/all.php?nav=46

Miller Research Fellowships are intended for exceptional young scientists of great promise who have recently been awarded, or who are about to be awarded, the doctoral degree. Normally, Miller Fellows are expected to begin their Fellowship shortly after being awarded their Ph.D. A short period as a post-doctoral fellow elsewhere does not exclude eligibility. However, applicants who have already completed substantial postdoctoral training are unlikely to be successful except in unusual circumstances. **A nominee cannot hold a paid or unpaid position on the Berkeley campus at the time of nomination or throughout the competition and award cycle**. Nominees who are non-US citizens must show eligibility for obtaining J-1 Scholar visa status for the duration of the Miller Fellowship. Non-US citizens will be required to prove English language proficiency prior to award. The Miller Institute does not support H1B visa status. The Fellowship term must commence between July 1 and September 1, 2016. Eligible nominees will be invited by the Institute to apply for the Fellowship. Direct applications and self-nominations are not accepted.

*All nominations must be submitted using the Online Nomination System at: http://**MillerInstitute.berkeley.edu**

Nominators will need the following required information to complete the online nomination process:

- Nominee's complete full and legal name (do not use nicknames)
- Nominee's current institution
- Nominee's complete, current, and active E-mail address, current mailing address with postal code and telephone number
- Nominee's Ph.D. Institution and (expected) Date of Ph.D. (month & year required)
- Letter of recommendation and judgment of nominee's promise by the nominator (saved in PDF format). Letter must be specific to the Miller Fellowship, have a current date, and be on institutional letterhead. The Executive Committee finds it helpful in the recommendation letter to have the candidate compared with others at a similar stage in their development.
- Nominator's current active E-mail address, title, and professional mailing address (include zip code/campus mail code)

The Institute provides a stipend of $65,000 with annual 2% increases and an annual research fund of $10,000, for total initial compensation of $75,000. There is provision for travel to Berkeley for Miller Fellows and their immediate families and a maximum allowance of $3,000 for moving personal belongings. Benefits, including medical, dental, vision and life insurance are provided with a modest contribution from the Miller Fellow. All University of California postdocs are represented by the UAW. Fellowships are awarded for three years, generally beginning August 1, 2016 and ending July 31, 2019. Approximately eight to ten Fellowships are awarded each year. Candidates will be notified of the results of the competition starting in mid-December, and a general announcement of the awards will be made in the spring.

We are grateful for your thoughtful participation in this process and hope that you regard the time you may devote to this effort justified by the contribution you will be making to the careers of distinguished young scientists.

MILLER INSTITUTE FOR BASIC RESEARCH IN SCIENCE
2536 Channing Way, Berkeley, CA 94720-5190
ph: 510-642-4088 | fax 510-643-7393
millerinstitute@berkeley.edu

Miller Research Fellowship Awardees 2015-2018

The Miller Institute is pleased to introduce the 2015-2018 Miller Research Fellows. Each year, the Miller Institute seeks to discover individuals of outstanding talent and to bring to Berkeley young scholars of great promise. Candidates are nominated for these awards and are selected on the basis of their academic achievement and the potential of their scientific research. The Fellows will be working with Berkeley faculty hosts for a three-year term beginning in the 2015 academic year. A full list of all past and present Miller Fellows is available on our website.

Ryan Dalton
Ph.D. - UCSF
Berkeley Dept. - Molecular & Cell Biology
Faculty Host: Diana Bautista

I am interested in how the extraordinary diversity in cell types found in animals arises. As a Miller Fellow I aim to apply molecular genetic techniques to uncover the gene regulatory logic behind diversification of somatosensory neurons.

Simone Ferraro
Ph.D. - Princeton University
Berkeley Dept. - Astronomy
Faculty Host: Uros Seljak

I study cosmology, that is the birth and evolution of the Universe as a whole. In my thesis I have focused on using the present-day distribution of galaxies to infer the physics of the very early Universe. Recently I have become excited about using galaxy velocities to study astrophysics and the elusive properties of dark energy, and I am developing new tools to do so.

Douglas Hemingway
Ph.D. - UC Santa Cruz
Berkeley Dept. - Earth & Planetary Science
Faculty Host: Michael Manga

My research in planetary geophysics combines theoretical modeling with observations to constrain the evolution of solid body surfaces and interiors. I use the shapes and gravity fields of planetary bodies, especially icy satellites, to learn about their internal structures, helping to place constraints on how they formed and evolved, and on what governs their behavior today. I am also interested in planetary magnetism and in how space weathering processes interact with magnetic fields on the surfaces of airless bodies like asteroids, Mercury, and the Moon.

Peter Hintz
Ph.D. - Stanford University
Berkeley Dept. - Mathematics
Faculty Host: Maciej Zworski

The evolution of many physical systems, like those arising in Einstein's theory of general relativity, quantum mechanics or electromagnetism, are described by partial differential equations. I study systems which exhibit wave-like properties, in particular aiming to understand how their long-time behavior depends on properties of the space on which the waves evolve. The correspondence principle, captured mathematically by microlocal analysis, is a powerful perspective for understanding the underlying equations, and it interacts in fascinating ways with other branches of mathematics such as Lorentzian and Riemannian geometry, dynamical systems and topology.

Cassandra Hunt
Ph.D. - University of Illinois at Urbana-Champaign
Berkeley Dept. - Physics
Faculty Host: Alessandra Lanzara

Ultrafast techniques can explore material properties on the fundamental timescale of the electron and phonon interactions, spin excitations, etc., which govern their macroscopic behavior. My research interests center on using targeted light excitation to perturb the lattice and electronic properties of correlated systems and materials with novel spin behavior. Selective perturbation can be used to identify important properties of the equilibrium system, but it can also be used to generate new phases that cannot be accessed in equilibrium.

Jeffrey Martell
Ph.D. - MIT
Berkeley Dept. - Chemistry
Faculty Host: Jeff Long

Many important chemical reactions in energy conversion, such as the oxidation of methane to methanol, are impractical to implement on an industrial scale, in large part because existing synthetic catalysts for these reactions operate slowly, display poor selectivity, and require high temperatures. By contrast, nature has produced metalloenzymes that catalyze many of these same reactions with high efficiency and selectivity under mild conditions, but most metalloenzymes deactivate quickly and are too expensive to be produced on a large scale. Metal-organic frameworks (MOFs) are porous synthetic materials with highly-ordered internal cavities whose sizes and shapes can be engineered. Drawing inspiration from nature, my research will focus on synthesizing MOFs with pores resembling the active sites of metalloenzymes and evaluating the catalytic properties of these materials.

Andrew Moeller
Ph.D. - Yale University
Berkeley Dept. - Integrative Biology
Faculty Host: Michael Nachman

Each human is an ecosystem containing over 100 trillion bacteria. Since the earliest animal ancestors, this 'microbiome' has evolved to house specific sets of bacterial taxa that guide development, aide in nutrition, and protect against disease. The vast majority of the evolutionary history of the microbiome is unkown: it is unclear how the environmentally derived microbes that first inhabited animal ancestors became the complex, highly integrated microbial communities that dwell within us today. My current research seeks 1) to delineate the evolutionary transitions in the composition of the microbiome across the tree of vertebrate life and 2) to evaluate how host-microbe associations evolve in natural populations of hosts.

Jessica Ray
Ph.D. - Washington University in St. Louis
Berkeley Dept. - Civil & Environ. Engineering
Faculty Host: David Sedlak

Stresses on global drinking water continue to rise due to population growth and consequential economic and energy demands resulting in the need to replenish drinking water sources via water and wastewater treatment. I will be investigating engineered geomedia and other technologies used to treat organic contaminants in stormwater to reduce negative effects on receiving waters. The transport and transformation of contaminants will be tested at Research Center for Reinventing the Nation's Urban Water Infrastructure (ReNUWIt) center sites in efforts to manage urban water systems.

Julian Shun
Ph.D. - Carnegie Mellon University
Berkeley Dept. - Statistics / EECS
Faculty Host: Michael Mahoney

The rapid growth in data sizes has raised many challenges in how to efficiently and accurately analyze large data. Using fast algorithms and parallel machines to perform analysis can provide significant speedups in computation time, and using statistical techniques can improve the accuracy and usefulness of the analysis. I am interested in studying fundamental theoretical and practical questions at the interface between computer science and statistics for large-scale data analysis.

Rachel Zucker
Ph.D. - MIT
Berkeley Dept. - Materials Science & Engin.
Faculty Host: Mark Asta

Surfaces are as fundamental as chemical composition in determining material properties. They also give nanomaterials their extraordinary characteristics. I will be working at the junction between materials science and applied mathematics, developing models that connect material interface structures to bulk properties. These models could help design micro- and nano-scale systems, including semiconductor devices and energy storage materials.

Call for Nominations

Miller Research Fellowship 2016-2019

Online Nomination Deadline: Thursday, Sept. 10, 2015

http://MillerInstitute.berkeley.edu

(More information online & on PAGE 3)

-Miller Memories-

Would you like to contribute your Miller memories to our 60th Anniversary collection? Send your brief comments and/or photos to: MillerInstitute@berkeley.edu

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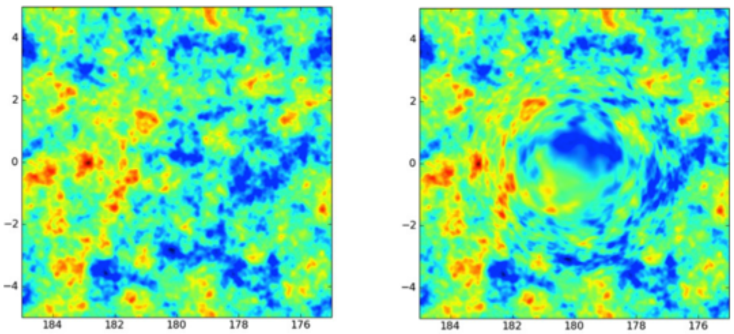

Figure 1. Illustration of the effect of gravitational lensing on the cosmic microwave background (CMB). At left, the original brightness pattern of the primordial CMB radiation is shown. At right, a massive structure of dark matter is placed in front, leading to gravitational lensing magnification of the CMB radiation that originates behind it (note: this is an exaggerated cartoon of a very small effect). By searching for these lensing features in measurements of the CMB, the projected cosmic mass distribution can be mapped out.

the lensing signal had not yet been detected in CMB data alone, as the minute signal was buried under noise and spurious streaks and other imperfections in real CMB data. In collaboration with Sudeep Das and my adviser David Spergel, I found new methods to overcome such challenges and developed a pipeline to statistically extract the lensing signal from noisy CMB data. After successfully testing our pipeline on simulations we applied it to CMB data from the Atacama Cosmology Telescope and detected the lensing effect in the CMB alone for the first time, probing the amplitude of dark matter structures at distances of billions of light years away. We used our novel measurements to independently confirm previous results from supernovae that had demonstrated that the cosmos is, surprisingly, accelerating apart.

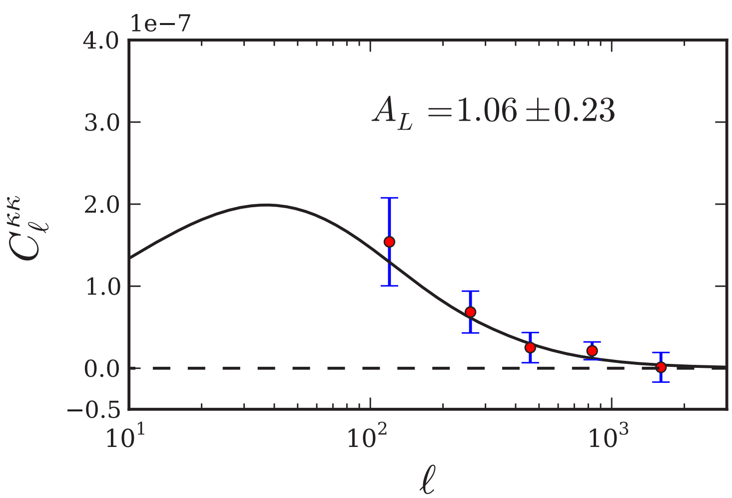

Figure 2. A detection of the lensing effect in CMB data alone (first made as part of my thesis work). The red points show the power spectrum of the lenses, i.e., the typical strength of the gravitational lenses as a function of (the inverse of) their angular extent. The points are in excellent agreement with the theoretical prediction of our standard cosmological model, shown as a black line.

CMB Polarization Lensing and the New High-Precision Regime

Building on our first measurements of the lensing power, CMB lensing science has rapidly progressed from moderate signal-to-noise first detections to precise measurements. While measurements of lensing features in the brightness pattern of the CMB have become increasingly powerful, they are intrinsically limited, because non-lensing CMB brightness fluctuations can mimic the appearance of lensing. However, measurements of lensing effects in the polarization of the CMB radiation do not suffer the same problem, as the non-lensing polarization fluctuations are much smaller; measuring signatures of lensing in the CMB polarization will therefore allow us to achieve much higher precision. With collaborators in Berkeley on the POLARBEAR telescope, I worked to demonstrate this new, powerful polarization lensing technique. On a small area of the sky, we made first CMB polarization lensing measurements from CMB data alone and constructed cosmic mass maps with unprecedented detail.

Working with both ACTPol and POLARBEAR telescopes, I am currently analyzing new CMB brightness and polarization data to make some of the most precise measurements of the lensing effect. These maps will probe features in the cosmic mass distribution to two-percent-level precision. Planned successor experiments AdvancedACT and Simons Array will provide maps of nearly all the mass in the universe with still higher (sub-percent) precision. Such high-fidelity maps of the mass distribution will allow new insights into cosmology and fundamental physics.

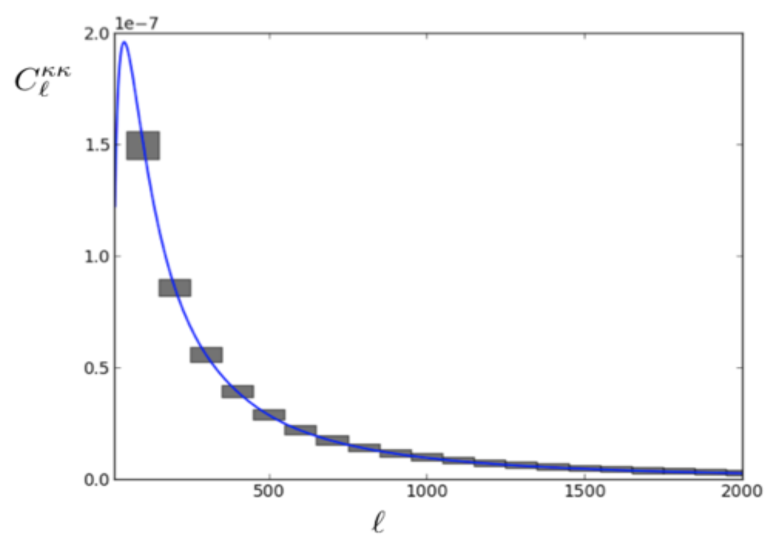

Figure 3. Near-future lensing measurements will achieve much higher precision, as illustrated above. This plot shows the measurement errors on the lensing power (as in Figure 2) expected within the next two years from the ACTPol experiment I am currently working on. Such high-precision lensing measurements will allow improved constraints on the properties of neutrinos, cosmic acceleration, and the inflationary big bang.

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Roger Bilham
Visiting Miller Professor Fall 2004

Kenneth Eisenthal
Visiting Miller Professor Fall 1989

Alice Guionnet
Visiting Miller Professor Fall 2006

L. "Maha" Mahadevan
Visiting Miller Professor Spring 2006

Geoff Marcy
Miller Professor 2011 - 2012
2015 Miller Senior Fellow

Ryosuke Motani
Miller Fellow 1997 - 1999

Sarah Otto
Miller Fellow 1992 - 1994

Vijay Pande
Miller Fellow 1996 - 1998

More Info: MillerInstitute.berkeley.edu

Join us to *Celebrate* *60 years* of Science

Friday, January 15 - Sunday, January 17, 2016

Friday evening: Reception - Alumni House

Saturday - Stanley Hall

8:30 – 8:45	Registration
8:45 – 9:00	Welcome
9:00 – 11:45	Talks
12:00 – 1:00	Lunch
1:00 – 3:15	Talks
3:15 – 3:45	Break
3:45 – 6:00	Talks
6:30	Hors D'oeuvres Dinner

Sunday - Optional Tours

8:00 – 5:00	Geology Tour of Marin County
10:00	Advanced Light Source Astronomy Department – Telescope UC Botanical Garden
11:00	UC Botanical Garden UC Museum of Vertebrate Zoology
12:00	UC Museum of Vertebrate Zoology

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Miller Institute for Basic Research in Science
2536 Channing Way, #5190
Berkeley, CA 94720-5190
510.642.4088
MillerInstitute.berkeley.edu

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miller_adm@berkeley.edu

Miller Fellow Focus

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Applications of Precise Lensing Maps: The Properties of Neutrinos and Inflation

Highly precise CMB lensing mass maps will be powerful probes of new physics, because the form of the cosmic dark matter distribution is sensitive to the properties of elementary particles. In particular, the matter distribution is affected by the presence of neutrinos, a type of particle with poorly understood properties. Though neutrinos make up a quarter of the known species of elementary particles, their masses are completely unknown, and the mechanism that determines their mass is not understood. The shape of the cosmic web of dark matter depends on the masses of these particles, because the more massive neutrinos are, the more their motions smooth out fine features in the cosmic dark matter distribution. With lensing data from ACTPol, POLARBEAR and their successors, we will measure the detailed form of the matter distribution and hence determine how massive neutrinos are. This will elucidate the properties of this mysterious type of particle and may give insight into the physical origin of their masses.

Precise knowledge of the CMB lensing signal will also allow us to learn more about the beginning of the universe. Our primary theory for the cosmic origin is inflation -- a mechanism that causes the universe to initially expand exponentially fast, faster than the speed of light. However, despite strong evidence, this hypothesized mechanism has not been definitively established, and little is known about the energy scale at which it took place. While a certain characteristic pattern (B-modes) in the polarization of the CMB would be definitive evidence for inflation and would determine its energy scale, measurements of this inflationary pattern are currently limited because inflationary effects can be confused with similar effects from lensing. However, if we can directly measure the CMB lensing signal (as described previously), we can disentangle the two effects and determine which part of the CMB polarization arises from lensing and which from inflation. Precise lensing maps therefore will be crucial in obtaining the most powerful constraints on inflation and the very early universe.

The science of CMB lensing is still young, but it has already begun to reveal the immense dark structures that surround us. By probing the nature of cosmic acceleration, determining the masses of neutrinos, and allowing deeper insights into the inflationary big bang, upcoming high-precision CMB lensing measurements will contribute in many ways to our understanding of the universe.

Born in Berkeley but raised in Europe, Blake Sherwin (Miller Fellow 2013-2016) studied Physics and Mathematics at Cambridge University in England before moving to Princeton for graduate school. His general scientific knowledge peaked at age 8 when he read his science encyclopedia every night. When not thinking about cosmology, Blake enjoys snowboarding and teaching math at San Quentin.

Contact Blake: blakesherwin@gmail.com