The Adolph C. and Mary Sprague
MILLER INSTITUTE
for Basic Research in Science

Newsletter
Winter 2024

Tracing the cosmic fingerprints of galaxies through the oldest light in the Universe

Miller Fellow Focus: Boryana Hadzhiyska

Despite the large number of currently operating powerful telescopes, cosmic gas, which is predominantly made up of ionized atoms and electrons and comprises more than 15% of the Universe's total matter content (the rest of it is attributed to dark matter), continues to elude the precise mapping of its distribution. While telescopes allow us to readily observe the stars within galaxies, stars make up only a small fraction of all the gas in the Universe (about 2%). The majority of the gas is embedded in cosmic filaments and exists in the form of warm-hot intergalactic medium. Charting its distribution is not only crucial for understanding complex astrophysical processes, like the violent release of energy by Active Galactic Nuclei and supernovae, but also for unraveling the most profound mysteries of the Universe, including those related to gravity, dark matter, and cosmic inflation.

The key to uncovering the secret of the unmappable gas distribution, also known as the "missing baryon" problem, was recently discovered to lie in the interaction between free electrons in the gas surrounding massive galaxy clusters and photons. This interaction, called the kinematic Sunyaev-Zel'dovich (kSZ) effect, occurs as the free electrons encounter photons speeding through space. And the source of these photons

is none other than the cosmic microwave background (CMB), the oldest light in the Universe. When CMB photons cross paths with free electrons within galaxy clusters, the photons acquire energy from this interaction and leave distinct imprints, or "fingerprints," on the CMB map proportional to the cluster's relative velocity towards us and the amount of gas in and around it (see **Fig. 1**).

The CMB fingerprints left by the cosmic gas are incredibly faint. To detect them, we must stack hundreds of thousands of these fingerprints on top of each other. However, if we naively stack the CMB map around galaxies or galaxy clusters, the coveted kSZ signal disappears. This is because each of these massive cosmic structures has an equal chance of moving either towards or away

CONTINUED ON PAGE 2 >

INSIDE THIS EDITION

The Miller Institute is "dedicated to the encouragement of creative thought and the conduct of research and investigation in the field of pure science and investigation in the field of applied science in so far as such research and investigation are deemed by the Advisory Board to offer a promising approach to fundamental problems."

"The opportunity to meet and interact with Miller Institute faculty and postdoctoral scholars from a wide range of disciplines provided a rich intellectual experience that was one of the highlights of my stay at UC Berkeley as a Visiting Miller Professor."

- Joan Redwing
Distinguished Professor
MSE and Electrical Engineering
Penn State University
VMP Fall 2022

> CONTINUED FROM PAGE 1 [Miller Fellow Focus]

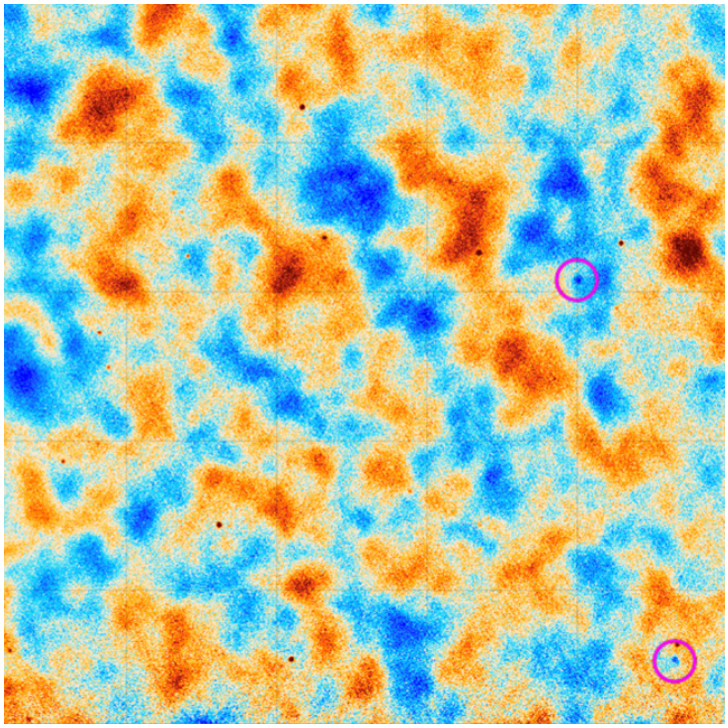


Figure 1. Cosmic fingerprints left from the thermal Sunyaev-Zel'dovich effect (indicated by purple circles) on the CMB map observed with the Atacama Cosmology Telescope (ACT).

from us, so on average the signal would cancel. However, if we somehow knew the velocity of the clusters, we could thwart this cancellation by weighting each galaxy by its radial velocity during the stacking, and that would yield a clearer fingerprint of the electron distribution within clusters. The good news is that we can estimate this velocity by solving the linearized continuity equation — a concept that you might remember from your favorite fluid dynamics class. But how come we can apply an equation that holds true for fluids to the Universe? Surprisingly, on ultra-large scales spanning thousands of galaxies, the structures in the Universe behave like a fluid, allowing for an independent estimation of the galaxy velocities based solely on their three-dimensional distribution.

A question you might have then is what can we do with these cosmic fingerprints? This is where my current research comes into play. An immediate and important application is the comparison between the gas distribution we infer and our best models predicted by the most powerful and accurate numerical simulations of the Universe to date. Our preliminary findings from measuring the fingerprints of galaxy clusters with the latest datasets, which we hope to share soon, suggest that even the most advanced simulations underestimate the true strength of violent processes expelling gas from the centers of galaxy clusters (see **Fig. 2**). Understanding these feedback effects is central to deciphering the complex processes that mold galaxies and give them their distinctive characteristics.

While previous analyses used precise three-dimensional information about the positions of galaxies, for the first time, we are stacking these fingerprints around galaxies from an imaging survey, which have less precisely known radial positions, but contain a much larger number of galaxies, outweighing the precision loss from using fuzzy positions. But how can we infer the radial velocity of galaxies from an imaging survey? It turns out that the colors of galaxies provide the necessary information to map their 3D distribution albeit with some margin of error. Although the galaxy distribution appears somewhat blurry in this scenario, we previously showed using simulated galaxy data sets that our measurement is still possible and could be successfully applied to imaging data. We hope that our work will transform our ability to locate cosmic gas within the largest galaxy datasets.

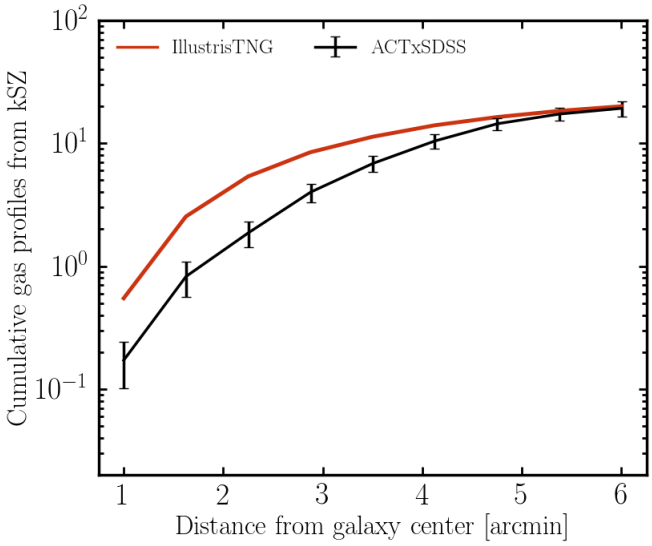


Figure 2. Comparison between the cumulative gas profiles measured from the stacking of galaxies from the SDSS survey on the ACT CMB map and state-of-the-art cosmological simulation IllustrisTNG. The profiles are shown as a function of angular distance (measured in arcmins) from the centers of the stacked galaxies. The simulation curve approaches a plateau at smaller angular distances, indicating that the expulsion of gas from the cores of clusters is weaker than in the real Universe.

The expulsion of gas from the cores of these massive structures challenges the assumption that gas follows dark matter. Since our most powerful methods for "weighing the Universe," including gravitational lensing, are sensitive to the combined effects of both components, underestimating this gas expulsion can introduce inconsistencies into our cosmological model. Various discrepancies in cosmology related to the clumpiness of the Universe are currently under investigation. Intriguingly, stronger gas feedback could potentially help reconcile these tensions, making the miscalibrated gas distribution a pivotal piece of this cosmological puzzle.

CONTINUED ON PAGE 3 >

> CONTINUED FROM PAGE 2 [Miller Fellow Focus]

As we calibrate the impact of gas on the Universe's structures, we also open the door to probing the physics of the primordial Universe. In particular, on the largest physical scales of our Universe, the kSZ effect provides a cleaner way to infer the matter distribution. This has significant implications for understanding the origin of the Universe and the initial quantum fluctuations, a topic that remains a subject of intense debate. By connecting the kSZ effect to cluster velocities, we gain a unique window into the large-scale structure of the cosmos, allowing us to investigate primordial physics. On smaller physical scales, the kSZ effect holds even more surprises. With a thorough understanding of gas processes, it serves as a direct probe of gravity and general relativity, tracking the growth of cosmic structure across time.

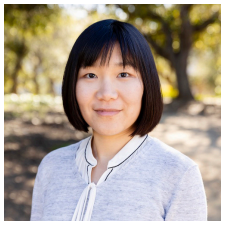
The study of the kSZ is still in its infancy, but it presents a promising and potent new probe that bridges the gap between galaxy formation and cosmology. It provides a path forward that was previously obstructed by the elusive fingerprints of cosmic gas. As we continue our exploration, we hope to unlock more cosmic mysteries and contribute to a deeper understanding of the Universe.

Boryana Hadzhiyska originally comes from Sofia, Bulgaria, and is currently a joint postdoctoral fellow at University of California, Berkeley, and Lawrence Berkeley National Lab, where she works on various concepts in (mostly) theoretical cosmology. Dr. Hadzhiyska did her undergrad at Princeton in astrophysics, then she did a Master's at the University of Cambridge in Applied Mathematics, where she worked on the gravitational lensing of the Cosmic Microwave Background, and she returned to the US to do her PhD at Harvard on cosmological simulations. In her free time, she is an avid cyclist, and she likes learning new languages and reading classic novels.

Contact: boryanah@berkeley.edu

Next Steps

Veronika Sunko
Postdoc @ Orenstein lab
Physics
UC Berkeley



Yi Zhang
Assistant Professor
Mathematics and Atmosphere
Ocean Science
Courant Institute of
Mathematical Sciences
NYU

In the News

(see more current & past Miller Institute news: **miller.berkeley.edu/news**)

Yang Yang (Miller Fellow 2016-2018) was awarded a **2023 Fellowship for Science and Engineering from the David and Lucile Packard Foundation.** The Yang Research Group combines expertise in synthetic biology and synthetic chemistry to develop new strategies to discover and evolve novel modes of biocatalysis that are not only new-to-nature but also new-to-chemistry.

Umesh Vazirani (Miller Professor 1999-2000 and 2018-2019) was awarded a $2.4M grant from the Department of Energy to advance production-ready quantum computing.

Feng Wang (Miller Fellow 2005-2008 and Miller Professor 2021-2022) received the **Frank Isakson Prize for Optical Effects in Solids** *"for pioneering and trail-blazing works on the exploration of new physics and exotic phenomena in 1D and 2D quantum materials that have guided advances in the field."* This award recognizes outstanding optical research that lead to breakthroughs in the condensed matter sciences.

John Cardy (Visiting Miller Professor Fall 2015) was named a co-recipient of the **2024 Breakthrough Prize in Fundamental Physics** for *"profound contributions to statistical physics and quantum field theory, with diverse and far-reaching applications in different branches of physics and mathematics."*

R. David Britt (Visiting Miller Professor Fall 2023) was inducted into the **American Academy of Arts & Sciences.**

Alanna Schepartz (Miller Professor 2022-2023) is among the first cohort of **ARC Innovation Investigators.** This award provides funding to researchers to pursue visionary ideas in curiosity-driven ambitious science research.

David Drubin (Miller Professor 2021-2022) received the **2023 Keith R. Porter Lecture Award** from the American Society for Cell Biology (ASCB). This award is named in memory of Keith R. Porter and presented to an outstanding and innovative leader at the forefront of cell biology, actively contributing fundamental new knowledge to our understanding of cell biology.

Emeritus Miller Institute Members!

Do you wish to receive the Miller Institute newsletter at your home address? Please email millerinstitute@berkeley.edu with your updated address information so as not to miss a single issue.

Miller Research Competitions: Awards

On November 28, 2023, the Advisory Board of the Miller Institute met to select next year's Professorship awards. The Board is comprised of four advisors external to UCB: Scott Edwards (Evolutionary Biology, Harvard), Anna Gilbert (Math, Statistics & Data Science, Yale), Linda Hsieh-Wilson (Chemistry, Caltech) and Eliot Quataert (Astrophysical Sciences & Astronomy, Princeton); and four internal Executive Committee members: Executive Director Chung-Pei Ma (Astronomy & Physics), Jeffrey Long (Chemistry and Chemical & Biomolecular Engineering), Nicole King (Molecular & Cell Biology) and Alistair Sinclair (Computer Science). The Board is chaired by Chancellor Carol Christ.

The Miller Institute is proud to announce the awards for Professorship terms during the 2024-2025 Academic Year. These outstanding scientists pursue their research, following promising leads as they develop. The Visiting Miller Professors join faculty hosts on the Berkeley campus for collaborative research interactions.

Miller Professorship Awards

Mina Aganagic
Physics/Math

Raphael Bousso
Physics

Robert Dudley
IB

David Eisenbud
Math

Allen Goldstein
ESPM

Markita Landry
CBE

Michael Manga
EPS

Russell Vance
MCB

Noah Whiteman
IB/MCB

Fei Xu
Psychology

Visiting Miller Professorship Awards

Dana Louis (Louigi) Addario-Berry
Statistics
Host: Steven Evans
Home Institution: McGill University

Giulio Cerullo
Chemistry
Host: Michael Zuerch
Home Institution: Politecnico di Milano

Marina Filip
Somorjai Visiting Miller Professor
Physics
Host: Jeffrey Neaton
Home Institution: University of Oxford

Sabre Kais
Chemistry
Host: Ashok Ajoy
Home Institution: Purdue University

Vidya Madhavan
Physics
Host: James Analytis
Home Institution: University of Illinois Urbana-Champaign

Lene Rasmussen
NST
Host: Danica Chen
Home Institution: University of Copenhagen

Nicola Spaldin
Physics
Host: Jeffrey Neaton
Home Institution: ETH Zürich

Harald Stenmark
MCB
Host: James Hurley
Home Institution: University of Oslo

Daniel Suess
Chemistry
Host: Jeffrey Long
Home Institution: MIT

Recent Publications

Cara Brook (Miller Fellow 2017-2020) is a first author of the research article "Reservoir host immunology and life history shape virulence evolution in zoonotic viruses," published in *PLOS BIOLOGY.*

Chadi Saad-Roy (Miller Fellow 2022-2025) is a first author of the recent article, "Dynamics in a behavioral–epidemiological model for individual adherence to a nonpharmaceutical intervention," published in *PNAS*.

Vayu Hill-Maini (Miller Fellow 2020-2023) is a co-author of the paper, "Microbial foods for improving human and planetary health," about sustainable food production, published in *Cell*.

Melissa Wilson (Miller Fellow 2011-2014) was a principal investigator for the new study, "The complete sequence of a human Y chromosome." She also led the analysis of so-called pseudoautosomal regions of the Y chromosome. The result is the first truly complete sequence of a human Y chromosome which appeared in the journal *Nature*.

A research paper by **Aavishkar Patel** (Miller Fellow 2019-2022), "Solvable theory of a strange metal at the breakdown of a heavy Fermi liquid," published in *PHYSICAL REVIEW B (2022)*, was recognized with a **"Frontiers of Science Award" by the International Congress of Basic Science.** The goal of this award is to encourage young scholars to look to the frontiers of basic science, set goals to obtain breakthrough results as early as possible, and contribute wisdom and energy to humankind's study of the mysteries of the natural world. Aavishkar is also the first author of the paper, "Universal theory of strange metals from spatially random interactions," published in *Science*.

Kerstin Tackmann (Visiting Miller Professor 2023, Physics) is the author of the paper, **"10 Years of Higgs Boson Measurements at ATLAS and CMS,"** published in the journal *Letters in High Energy Physics.*

Make a Gift

Private donations are becoming an increasingly significant resource for the Miller Institute. Your personal investment in support of the future of the Miller Institute will be greatly appreciated.

Join Miller friends and alumni in contributing to this important endeavor by logging on to **miller.berkeley.edu/gift** to help support the independent research of the Miller Institute members.

2023 Annual Fall Dinner

Guest speaker Dr. Tony DeRose, Chief Technical Officer, X in a Box LLC., presents his talk, "Math in the Movies — A Story of Technology Transfer."

(L - R): Former Miller Senior Fellow Raymond Jeanloz, Visiting Miller Professor Jose Fuentes, Miller Fellow Olatubosun Fasipe and Miller Professor Hillel Adesnik

(L - R): Miller Fellow Rohil Prasad, UC Berkeley Professor Daniel Tataru and Visiting Miller Professor Mihaela Ifrim

(L - R): Guest Heriberto Sanchez, Kathryn A. Day Miller Postdoctoral Fellow Raul Ramos, Miller Fellows Anna Barth and Veronika Sunko, guest Petar Petrov

Gifts to the Miller Institute

The Miller Institute gratefully acknowledges the following contributors to our programs in 2023 (received between December 6, 2022 and December 31, 2023.) With your generosity, the Miller Institute is able to continue to support basic research in science at UC Berkeley.

Kathryn A. Day Miller Postdoctoral Fellowship Fund

The Kathryn A. Day Miller Postdoctoral Fellowship was established with a generous gift by Nobel Laureate Professor Randy Schekman and Professor Sabeeha Merchant to honor Kathy Day, who served as the Chief Administrative Officer at the Miller Institute for Basic Research in Science from 1989 - 2019. The purpose of the Fund is to provide an annual stipend, benefits and a research fund to a postdoctoral researcher at the Miller Institute who has demonstrated efforts towards community building and outreach in support of science.

Rachel Akeson
Anonymous (2)
Justin M. Brown
John Clarke
Kathryn A. Day (2)
Phyllis Day (2)
Dmitry Dolgopyat
Alex Filippenko
Eric & Christina Ford
Yu He
John E. Hunter III
Rita Huybrechts

Kathy Day with Kathryn A. Day Miller Postdoctoral Fellow Molly McFadden (2023-2026)

Ronald S. Johnson
Russell L. Jones
Vyacheslav Krushkal
Michael Manga
Frederick A. Matsen
Suzanne & Christopher McKee
Jonas Peters
Ken Ribet & Lisa Goldberg (2)
Kate & Dustin Rubenstein
Jesse Thaler (13)
Rebecca Bishop White (2)
Peter & Gloria Yu

Miller Institute for Basic Research in Science General Fund

The Miller Institute for Basic Research in Science is dedicated to the encouragement of creative thought and the conduct of research and investigation in the field of pure science. Contributions to this fund will support the four programs of the Miller Institute: the Miller Research Fellowship, the Miller Professorship, the Visiting Miller Professorship, and the Miller Senior Fellowship.

Anonymous (3)
Steven & Diana Brenner
Justin M. Brown
William Carter Craig (2)
Alex Filippenko
Iswar Hariharan
Gilbert A. Hawkins (2)
John E. Hunter III

Judith P. Klinman
Andrew Ogg
Eve Ostriker
Michael Turner
Salil Vadhan
Kenneth W. Wachter
David Weinberg (2)
Norman Yao

Miller Fellowship Program Development Fund

The Miller Fellowship Program Development Fund provides an annual stipend, benefits, and research support to young researchers at Berkeley. The program gives researchers the chance to explore ideas in a stimulating and supportive environment.

Dan-Virgil & Ioana Voiculescu (2)

3rd Annual New Miller Fellows Retreat

Members of our new Fellowship cohort (2023-2026) joined our Executive Committee and Institute staff in September for a New Fellows Retreat at the UC Botanical Gardens.
Top Row (L to R)**:** Clara Duman, Alistair Sinclair, Nicole King, Yanni Kipouros, James Santangelo, Augusto Ghiotto, Xueyue (Sherry) Zhang, Jeff Long
Bottom Row (L to R): Molly McFadden, Rohil Prasad, Olatubosun Fasipe, Ewin Tang, Ethan Lake, Yuhan Yao

Miller Fellows Rohil Prasad and Ewin Tang exploring plants at the UC Botanical Graden

Executive Committee Members L-R: Nicole King, Jeffrey Long, Alistair Sinclair and Executive Director Chung-Pei Ma

Miller Fellows and Executive Committee members in the Julia Morgan room at UC Berkeley's Botanical Gardens

Miller Fall Reception

Miller Fellow Yuhan Yao, Professor Michael Hutchings, former Miller Professor Suncica Canic

Former Miller Fellows Thibault de Poyferre and Rebecca Tarvin, Miller Senior Fellow Ken Ribet, former Miller Professor Dan Stamper-Kurn, Visiting Miller Professor Vilhelm Bohr and guest Diane Bohr

Former Miller Fellow Alfred Zong and former Miller Professor Andrew Ogg

University of California, Berkeley
Miller Institute for Basic Research in Science
468 Donner Lab
Berkeley, CA 94720-5190
miller.berkeley.edu

Miller Institute News : Winter 2024
Please send address corrections to:
miller_adm@berkeley.edu

2023 Miller Institute Mementos

Miller Senior Fellow Ken Ribet (center) hosted Miller members at the Faculty Club: Miller Professor Joshua Bloom, Miller Fellows Xueyue (Sherry) Zhang, Yi Zhang, Rohil Prasad, Molly McFadden, Augusto Ghiotto, Ewin Tang, Olatubosun Fasipe and Shashank Gandhi

SUBSCRIBE
TO OUR NEWSLETTER

Subscribe to our digital newsletter by visiting miller.berkeley.edu/news/newsletters and clicking on the SUBSCRIBE button!

2023 Miller End of Summer Picnic

For More Information:
Staff: Emily Birman, Clara Duman, Donata Hubert, Hilary Jacobsen & Vrinda Khanna
+ millerinstitute@berkeley.edu | miller.berkeley.edu