

Searching for the Heaviest Particle in the Universe

Miller Fellow Focus: Nicholas Rodd

On a Tuesday evening in late September 2010, an object crashed into the Earth's atmosphere somewhere above Millard County, Utah. The collision produced an enormous shower of energetic particles detected on the surface, which clocked the object as a proton carrying 30 Joules of energy. By everyday standards this may not seem impressive - the equivalent of a cricket ball travelling at 70 km/h. But recall the well known fact that a proton is about 26 orders-of-magnitude lighter than a cricket ball: this proton was one of the highest energy particles zipping through the cosmos. So who threw it? The truth is we don't know; the origin of the highest energy cosmic rays, which includes protons, neutrinos, and photons, is an open question.

As a Miller Fellow I've been exploring the possibility that these particles could originate from the decay of extremely heavy dark matter, as depicted in Fig. 1. Dark matter is the enigmatic substance that makes up 80% of the mass in the universe. Although we can't see dark matter, we can infer its existence and total mass from the gravitational pull it exerts on conventional matter. In fact near the



Earth there should be roughly one proton mass worth of dark matter per cm^3 . The leading hypothesis is that dark matter is itself made up of a new undiscovered particle. The question that drives my research is *what is that particle?*

There are no shortage of candidates. When describing particles, physicists usually measure their mass in units of energy, at least since Einstein. In these units a proton weighs in at 1 GeV or 10^9 electronvolts, and the dark matter density near the Earth is $1 \text{ GeV}/\text{cm}^3$. The leading candidate for many decades has been that dark matter should be a particle with a mass roughly 100 or 1000 times heavier than a proton, comparable to the mass of the recently discovered

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Call for Nominations:

Miller Research Fellowship Nominations

Deadline: September 10, 2020

Miller Research Professorship Applications

Deadline: September 14, 2020

Visiting Miller Professorship Departmental Nominations

Deadline: September 15, 2020

"I am so grateful for my time spent as a Visiting Miller Professor at UC Berkeley. Scientifically, it was exciting to have the freedom to step away from the narrow focus of my own research and think about how my area of expertise could be applied to problems in other disciplines. The Miller Institute has developed innovative and far-sighted strategies to provide fertile ground for seeding new ideas and advances that span disciplines, or even create new ones!"

Prof. Jennifer Schomaker,
Somorjai Visiting Miller Professor Fall 2019
University of Wisconsin, Dept. of Chemistry





Figure 1. A dark matter particle χ decaying somewhere out in the universe could be discovered when the energetic cosmic rays it releases eventually make their way to Earth.

Higgs boson. In this case there should be at least a thousand dark matter particles per m^3 , enough that an extremely sensitive device could detect one. But so far no signal has shown up. In recent years a different idea is in vogue: maybe dark matter is instead a *million-billion* times lighter than a proton, weighing $1 \mu\text{eV}$. In this scenario, there should be so many individual particles around that dark matter would behave like a wave. This would result in dramatically different signatures, including the possibility of dark matter interferometry, a detection technique I introduced while at Berkeley.

But neither of these dark matter candidates could explain where those cricket balls are coming from: as $1 \text{ GeV} \approx 10^{-10} \text{ J}$, they simply don't have enough energy to produce a 30 J cosmic ray. Instead we need a much heavier particle, we'd need to push dark matter to the limit. And in fact there is a limit, if dark matter is a fundamental particle it can't be heavier than the so-called Planck scale, $m_p \sim 10^{19} \text{ GeV}$. If the particle were any heavier, it would be lost within its own event horizon, and become a black hole!

Let's say dark matter, often denoted χ , has a mass at the Planck scale, i.e. 19 orders-of-magnitude heavier than a proton. This means there should be about 1 particle every 10,000 km^3 – the odds of one bumping into our detector is getting pretty small. We need another detection strategy. In most scenarios where dark matter is this heavy, the fundamental particle is often unstable. Like a neutron, if left on its own it will eventually decay to lighter particles. The lifetime for the decay has to be very long, otherwise all the dark matter in the universe would have long since vanished.

In fact in these models, the lifetime is more than 10 orders-of-magnitude longer than the age of the universe, meaning that only 1 in 10^{10} dark matter particles will have decayed in all of cosmic history. How could we ever hope to see such an event? By relying on the enormous amount of dark matter in the Universe. Our own Milky Way, which is mostly dark matter, has a mass 10^{12} times the mass of our sun, or about $10^{50} \times m_p$: a vast reservoir of particles, some of which will be decaying every second.

So what happens when a Planck scale particle decays? There will be an enormous explosion of energy distributed amongst fundamental particles (the decay releases the equivalent of 500 kg of TNT), one of which could eventually find its way into Utah's upper atmosphere. The possibility that this could happen had been known for a long time. But there were mostly only rough estimates for what you should actually see. What we need is a quantitative prediction for the distribution of cosmic rays – including protons, electrons, photons, and neutrinos – produced in such a decay.

This is exactly what I've been working to compute as a Miller Fellow. Teaming up with experts on the theory of the strong nuclear force, we have built upon techniques traditionally used for calculating the details of when two particles collide, for example at the Large Hadron Collider. We have pushed these ideas to their extremes, as needed to describe energy injections at the Planck scale, incorporating a number of physical effects that only become relevant at the highest energies. Our results often differ significantly from the rough estimates that existed in the literature.

> CONTINUED FROM PAGE 2 [Miller Fellow Focus]

An example of our results is depicted in Fig. 2. There I show the distribution in energy of photons, denoted dN/dx , produced from a dark matter decay. The results are plotted in dimensionless variables $x = 2E/m_\chi$ (where E is the photon energy) so that I can compare the distribution for different dark matter masses: the plot shows a spectrum for every decade in mass from a TeV (10^3 GeV) all the way to the Planck scale. There is a lot of physics packed into this result; for instance, the fact the evolution slows down as we approach the Planck scale can be understood from an analogy between our calculation and the diffusion equation.

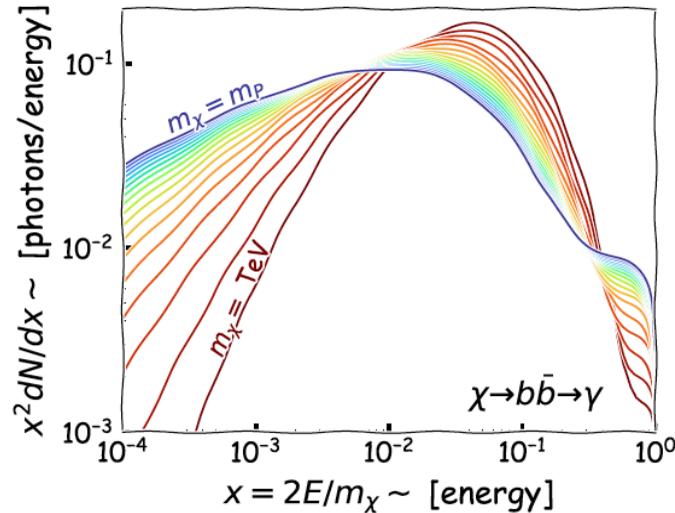


Figure 2. *The distribution of photons produced in the decay of heavy dark matter.* One curve is shown for each decade of dark matter mass between a TeV (10^3 GeV) and m_p (10^{19} GeV), where 1 GeV is the mass of a proton. We use dimensionless variables $x = 2E/m_\chi$, i.e. the ratio of the photon energy to the dark matter mass, so that the results at dramatically different energies can be compared.

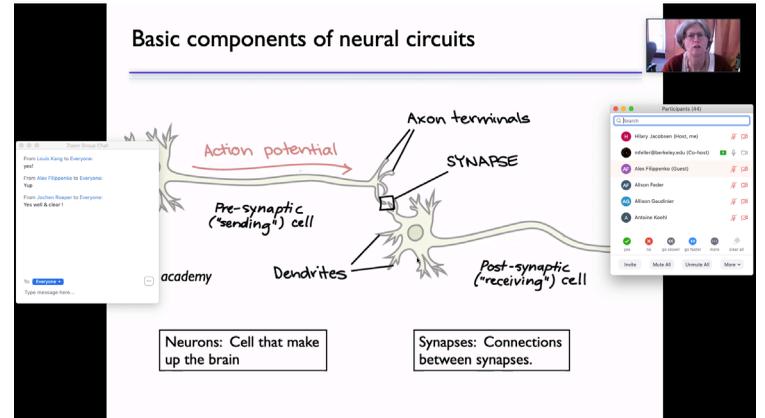
But in the end, we now have the tools to quantitatively examine whether there are hints for dark matter in cosmic-ray data. I'm currently working with a neutrino telescope known as the IceCube Observatory in the South Pole to find out, and I'm excited that we might soon find evidence that could unravel the mystery of dark matter.

Nick Rodd grew up in Melbourne, Australia, and completed his B.Sc. and LL.B. at Melbourne University. Afterwards, he finished his M.Sc. in Physics at the same institution. In 2013, Nick moved to the US and obtained his Ph.D. at MIT with Tracy Slatyer focusing on the indirect detection of dark matter, and the hint of a signal at the galactic center. Since 2018, Nick has been a Miller Fellow in the Berkeley Center for Theoretical Physics, working to extend the hunt for dark matter to both higher and lower masses. His favorite plotting color is orange, and whenever possible he likes to wear flip-flops.

Contact: nrodd@berkeley.edu
Website: nickrodd.com

Miller Members Adapt

As shelter-in-place orders continue in Berkeley because of the spread of SARS-CoV-2, the Miller Institute members still find ways to connect and share their research.



Tuesday Lunches continue online! Executive Director Marla Feller gives a lunch talk over Zoom called "How do you wire up a neural circuit to compute the direction of motion?"



Miller members enjoy a socially distanced hang out in the park in Berkeley!

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From the Executive Director



Marla Feller, Miller Institute Executive Director & Paul Licht Distinguished Professor in Biological Sciences

How many years can some people exist before they're allowed to be free?

How many times can a man turn his head and pretend that he just doesn't see?

-Bob Dylan,
Blowin in the wind, 1963

I continue my tradition of including Bob Dylan lyrics in my annual letter. In what is perhaps his most famous song, Dylan poses questions that continue to be asked today. The recent events surrounding the murder of innocent Black

people has not only woken up the country, it has woken up the Miller Community. I have been blown away by the response of the Miller Fellows who are putting together a strategic plan for the Miller Institute to be a more welcoming environment for scientists coming from diverse communities and to help increase the pool of applicants to apply to the Fellowship program. Though many of us feel like we have been doing what we can, we recognize there is more to do – and I speak for the entire Executive Committee in saying we look forward to working with the Fellows to implement changes that will meet these goals.



Of course, the Miller community has also been disrupted by the appearance of SARS-CoV-2 and the resulting pandemic. The abrupt shut down of the University and the surrounding communities continues to affect all of our research and also has introduced an air of uncertainty that has

impacted people on personal and professional levels. It has become quite clear that science is so critical for our understanding of the many aspects of this pandemic and hopefully seeing our way out of it. In this realm, it has been wonderful to learn more about the virus and its impact on society from our Miller community. I offer a few examples here. Former Miller Professor Britt Glaesinger (2015) gave a heavily watched seminar in the molecular virology of SARS-CoV-2. Former Miller Professor Bin Yu (2004, 2016-2017) has been working on forecasting *"the severity of the epidemic for individual counties and hospitals in the US."* And current Miller Fellow Cara Brook (2017-2020) - who studies zoonotic infections with a focus on viral infections in Madagascar fruit bats - has given several presentations on her work both to the Miller community and on campus, and was also interviewed on CNN!



Prior to the March shutdown the Miller community was firing on all cylinders. New Chief Administrator for the Miller Institute, Hilary Jacobsen, has spent the year learning the ropes and is bringing strong leadership and a wonderful energy to the Institute during these challenging times. Unfortunately, the departure of staff member Erin Douglass left a lot more work for everyone but with the help of the long-time Miller Staff Emily Birman and Donata Hubert, the Miller Institute continues to run smoothly. I do want to acknowledge the tremendous effort Hilary has put in keeping the community going via Slack and Zoom lunch meetings and for facilitating the efforts of the Miller Fellows for implementing change that will enhance diversity.

*Note: Photos on this page showing Miller members in close proximity were taken before shelter-in-place orders.

Despite these challenging times, there have been highlights to the year. We had a Fall Dinner presentation by UC Berkeley Professor Eva Nogales, which included an overview of the principles and use of cryo-electron microscopy (cryo-EM), a structural biology technique that is revolutionizing how we understand the workings of macromolecular complexes. She gave several examples of how cryo-EM has been used in her lab to study large, flexible and challenging complexes involved in processes as diverse as chromosome segregation during cell division, and the regulation of gene expression at the transcriptional level. Some of the images she has generated will replace some of the cartoons we biologists use in thinking about these basic cellular processes. In addition, the year was filled with fascinating weekly lunch talks by Fellows, Miller Visiting Professors and Miller Professors. We have continued these talks, now via Zoom. I am so glad so many of our current Fellows and Professors continue to participate in these weekly events. Also, our Senior Miller Fellows – Professors Susan Marqusee (Chemistry/Molecular and Cell Biology), Michael Jordan (Electrical Engineering and Computer Sciences/Statistics), and Alex Filippenko (Astronomy) - contributed to the community last year by hosting small group lunches with Fellows and of course, through their participation in Miller Institute events.

Once again, the Spring Symposium Committee, under the guidance of faculty leader Michael Manga (Earth and Planetary Science), put together a spectacular program. We held out for as long as we could but in early March, we decided to cancel the event, which in the end was the right thing to do. Luckily all of the speakers have agreed to participate next year, so expect a full report in the Fall 2021 newsletter!



One of the most exciting events of the year was the start of the Kathryn A. Day Miller Postdoctoral Fellowship, initiated through an inspiring gift from Randy Schekman and Sabeeha Merchant. The fund received quite a boost with generous donations from Jennifer Doudna and Jamie Cate, as well as Jasper Rine and Cynthia Kenyon. In addition, the broader community has also responded with dozens of donations from current and former members of the Miller Community. See page 8 for more details about this fund and ways to give.



Summer represents a big change for the membership of the Miller Community. Several Miller Fellows are off to new adventures while we welcome 10 new Fellows this Fall; you can read more about the Fellows' next steps on page eight. Members of the Miller community continue to receive recognition for their professional accomplishments - to keep up with the great successes of the members of the Miller Community, check out the announcements on the Miller website (miller.berkeley.edu).

The leadership at the Miller remained constant this year. The Executive Committee - Stephen Leone from Chemistry/Physics, Yun Song from Statistics and Computer Science, and Roland Bürgmann from Earth and Planetary Science - continue to be active participants in Miller events in addition to working hard each Fall to select the next year's Fellows, Professors and Visiting Professors. Also remaining constant is the membership of the Advisory Board, which is composed of Professors Steve Block (Stanford), Feryal Ozel (University of Arizona), Luis Caffarelli (University of Texas – Austin) and Tim Stearns (Stanford). I will also continue for a second term of the Miller Executive Director, which is really one of the most wonderful honors of my career. I look forward to working with them and the rest of the Miller community to guide the Miller Institute into an era of increased diversity. And I hope to be seeing more of you in person very soon!



Call For Nominations: Miller Research Competitions

Miller Research Fellowship 2021-2024

Online Nomination Deadline: September 10, 2020

The Miller Institute for Basic Research in Science invites department chairs, faculty advisors, professors and research scientists at institutions around the world to submit online 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 sponsor and the administrative home department for each Miller Fellow who is hosted by an academic department. All research is performed in the facilities provided by the host UC Berkeley academic department(s), however remote work may be allowable in accordance with campus policies. A list of current and former Miller Research Fellows is available on our website.

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. 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 cycleward cycle, which can extend into February.** Nominees who are non-US citizens must be eligible for obtaining J-1 Scholar visa status for the duration of the Miller Fellowship. The Miller Institute does not support H1B visa status. The Fellowship term must commence between July 1 and September 1, 2021. 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: miller.berkeley.edu/fellowship.

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. 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 \$68,000 with annual increases on subsequent anniversary dates and an annual research fund of \$10,000, for total initial compensation of \$78,000. 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, 2021 and ending July 31, 2024. 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.

Miller Research Professorship AY 2021 - 2022

Online Application Deadline: September 14, 2020

The Miller Professorship program is pleased to announce the call for applications for terms in AY 2021-2022. The objective of the Miller Professorship program is to provide opportunities for faculty to pursue new research directions on the Berkeley campus and to participate in the vibrant interdisciplinary Miller community. For some, this may best be enabled by taking time off from teaching. For others, the teaching obligations are critical to maintaining campus academic programs. Thus the option for Miller Professors to continue 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 continues to be research excellence. Applicants are encouraged to describe their interest in participating in the Miller Institute community.

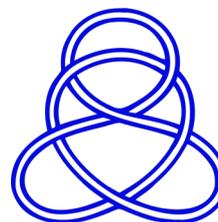
Applications from UC Berkeley faculty for Miller Research Professorship terms in the 2021-22 academic year are being accepted online now. Appointees are encouraged to follow promising leads that may develop in the course of their research.

Applications are judged competitively and are due by Thursday, September 14, 2020. It is anticipated that between five to eight awards will be made. Applications are available at our website: miller.berkeley.edu/professorship.

Visiting Miller Research Professorship AY 2021 - 2022

Online Nomination Deadline: September 15, 2020

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 2021 or Spring 2022. 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 be 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 the invitation to the nominee after advising the nominator of its selection. All nominations must be submitted using the Online Nomination System at miller.berkeley.edu/visiting-professorship.



In the News

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

Paul Alivisatos (Miller Professor 2001-2002) was named **2021 Priestley Medalist** for pioneering work in nanomaterials and service to the science community.

Omar Yaghi (Visiting Miller Professor 2009) received the **2020 Sustainable Water Award** from the Royal Society of Chemistry for his *"impactful development of water harvesting from desert air using metal-organic frameworks."*

Jeffrey Long (Miller Professor 2011) received the **2020 Ludwig Mond Award** from the Royal Society of Chemistry for *"pioneering work in the synthesis and characterization of inorganic molecules and materials exhibiting new physical phenomena."*

Michelle Antoine (Miller Fellow 2014-2017) won a **2019 NIH Distinguished Scholar Award** for her research on *"understanding how genetic and environmental insults alter the input to, computation in, and output of neural circuits to promote abnormal brain function and behavior."*

Venkat Guruswami (Miller Fellow 2001-2002) won a **2020 Simons Award in Theoretical Computer Science** for *"major advances in the theory of error-correcting codes, approximate optimization, pseudorandomness and related complexity-theoretic and mathematical aspects."*

Miller Members Among Newly Elected **2020 AAAS Fellows**:

- **Kathy Collins** (Miller Professor 2011)
- **Zahid Hasan** (Visiting Miller Professor 2017)
- **Philip Kim** (Miller Fellow 1999-2001)
- **Chung-Pei Ma** (Miller Professor 2019-2020)
- **Eve Ostriker** (Visiting Miller Professor 2009)
- **Philip Phillips** (Miller Fellow 1982-1984)
- **Richmond Sarpong** (Miller Professor 2014)

William Schafer (Visiting Miller Professor 2019) was elected a **Fellow of the Royal Society**.

Kelly Nguyen (Miller Fellow 2016-2019) was featured in the RNA Society's article about her scientific background and her current research that focuses on telomerase structure and biology.

Miller Members Among Newly Elected **2020 NAS Fellows**:

- **Anna K. Behrensmeyer** (Miller Fellow 1973-1975)
- **Joel Blum** (Visiting Miller Professor 2017)
- **Katherine Freese** (Visiting Miller Professor 2006)
- **Mark Kirkpatrick** (Miller Fellow 1983-1985 & Visiting Miller Professor 2009)
- **Arunava Majumdar** (Miller Professor 2003-2004)
- **Eliot Quataert** (Miller Professor 2009-2010, Executive Committee Member 2012-2013)
- **Dean Toste** (Miller Professor 2014)

Amy Shyer (Miller Fellow 2013-2016) was named a **2020 Searle Scholar** for her research on *"a multi-scale analysis of mechanics during skeletal morphogenesis."*

Ray Jayawardhana (Miller Fellow 2000-2002) was featured on NPR about his recently published children's book entitled *"Child of the Universe."*

Next Steps

The Miller Institute congratulates these Miller Fellows on their next endeavors:



Cara Brook

Branco Weiss Fellow @ UCB, Boots Lab.
Starting August 2021: Assistant Professor
Department of Ecology and Evolution
University of Chicago



Nikhil Bhatla

Postdoc @ UCB, Adesnik Lab
Department of Molecular and Cell Biology



Thibault de Poyferre de Cere

Starting January 2021: Postdoc @ Mathematical
Sciences Research Institute (MSRI)



Yu He

Assistant Professor
Applied Physics Department
Yale University



Louis Kang

Unit Leader
RIKEN Center for Brain Science
Japan



Grant Remmen

Fundamental Physics Fellow and Postdoc @ UCSB
and the Kavli Institute for Theoretical Physics



Alex Turner

Starting January 2021: Assistant Professor
Department of Atmospheric Sciences
University of Washington

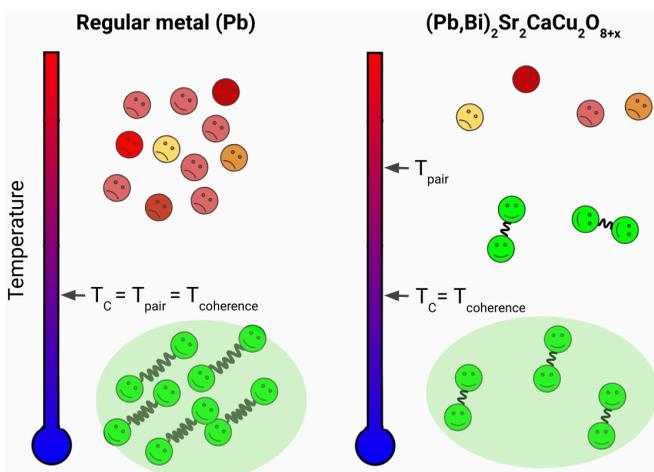
Birth Announcements

Ruby Fu (Miller Fellow 2018-2021) announced the birth of her son, Emery Ming, with husband Ryan Lewis on June 6th, 2020.



Stories of Collaboration

At its heart, the Miller Institute is a collaborative institution that brings together researchers from diverse fields to explore basic science. Here are two recent examples of Miller-inspired collaborations:

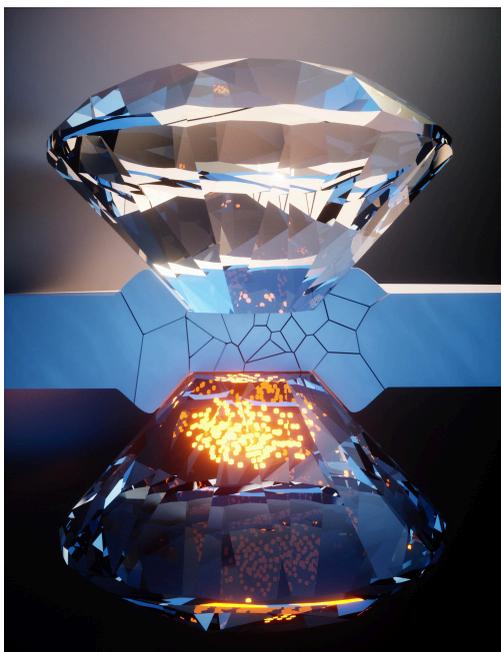


From Yu He (Miller Fellow 2019-2020):

My host Prof. Birgeneau and I have been keenly interested in learning how superconductivity - a form of electron organization that facilitates lossless electricity transmission - appears in a class of high performance copper oxides. One key feature of this magic property is that it only manifests below a certain critical temperature in materials. Experimentally we discovered thermodynamic signatures of "nascent" superconductivity surviving even up to 40% above this critical temperature, which is extremely hard to understand within most existing theoretical frameworks. During one of my chats with theoretician Prof. **Dunghai Lee** (Miller Professor 1999), I learned that he worked with his post-doc Zi-Xiang Li on a computational method, which can solve for a highly relevant model in a numerically exact way. We didn't hesitate and jumped into collaboration right before covid-19 hit. A month later, while we and our computers were all sheltered at home, exciting preliminary results came out, which surprisingly pointed to a long-overlooked electronic contribution as the source of this "surviving" superconductivity at high temperatures. Currently we are not only combining the experiment and theory for a joint manuscript, but also looking to expand the computation efforts to a full-fledged stand-alone work.

Metals become superconducting when electron pairs (balls and springs) become globally phase-coherent (green shade). Here, we investigate an exotic intermediate temperature range, where electrons are already paired but still lack phase-coherence (right panel) in a complex copper-oxide high-Tc superconductor.

From Raymond Jeanloz (Miller Senior Fellow 2011-2016, Executive Director 1998-2003, Executive Committee Member 1994-2004, Miller Professor 1992):



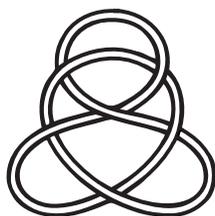
Diamond is a beautiful material. The hardest, stiffest crystal known at ambient conditions, diamond is also an exceptional window, such that - squeezed between the points of two gem-quality diamonds (often called diamond anvils) - samples can be characterized by spectroscopy, diffraction and other methods to the extremes of pressure and temperature existing deep inside planets. This is why Senior Miller Fellow **Raymond Jeanloz** (UCB Earth and Planetary Science, Astronomy) uses diamonds to study matter at high enough pressures that physical and chemical properties of materials are profoundly altered.

At the same time, Former Miller Postdoctoral Fellow **Norman Yao** (now Assistant Professor at UCB in Physics) studies a specific type of impurity inside the diamond lattice - the so-called Nitrogen-Vacancy (NV) center. As its name suggests, this particular impurity is composed of a nitrogen atom (substituting a native carbon atom of the diamond lattice) adjacent to a vacant lattice site. By using laser spectroscopy to interrogate the NV center, one can utilize it as an exquisite sensor of stress, temperature, magnetic fields and more. So, it was only natural that the two should join with former Miller Professor **Joel Moore** (Physics) in a Miller-inspired collaboration to design a novel detector that integrates NV centers into diamond anvils.

A schematic depicting Nitrogen-Vacancy centers embedded inside a diamond anvil cell. The NV sensors are placed approximately ~5 nanometers below the surface of the diamond anvil and emit fluorescence under laser excitation. This fluorescence can be used to characterize the shear stresses present in materials under high pressure. (Credits: Norman Yao/Berkeley Lab; Ella Marushchenko.)

By embedding NV centers into the tip of a diamond anvil, their groups were able for the first time to measure the shear stresses present in materials under high pressure [S. Hsieh, et al., *Science*, **366**, 1349 (2019)]. This is important for characterizing how the interiors of planets deform, and more generally for understanding why solids break. Compression suppresses fracturing, with materials becoming ductile under pressure, so the joint team can now disentangle the key reasons why materials rupture at Earth-

surface conditions. (The diamond anvil sensing technique can also be used to investigate novel low-temperature phenomena that become more apparent under high pressure, such as some kinds of superconductivity.) The work is providing insights into why certain earthquakes take place deep inside our planet: the cause of "deep-focus" earthquakes has been a mystery for over a century, and the combined use of diamond - as an anvil, a window and a sensor - is now revealing the link between these seismic events and material transformations at depth.



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Make a Gift to the Miller Institute

In this time of global pandemic, the world is relying on researchers to answer the most pressing questions about the SARS-CoV-2 virus and the spread of COVID-19. Some Miller members have joined the world-wide group of scientists who are researching the origins of this virus and tracking its spread (see Director’s message on page 4.) Basic research continues and needs your support now more than ever.



One way to contribute directly to the future of research is to give a gift to the **Kathryn A. Day Miller Postdoctoral Fellowship fund**. Named for retired Chief Administrative Officer Kathy Day, this fund will support a future

fellow for the entire cost of their fellowship, including their stipend, benefits and unrestricted research fund. Did you know that funding one Miller Research Fellow for their 3-year term costs nearly \$290,000? Help us grow this fund so it can sustain a fellow for their entire term, and invest in the future leaders of basic science research!

To make a gift online, please visit miller.berkeley.edu/gift.

Thank you for your contributions!



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For More Information:

+ Staff: Emily Birman, Donata Hubert, Hilary Jacobsen.
+ millerinstitute@berkeley.edu | miller.berkeley.edu