The Adolph C. and Mary Sprague
MILLER INSTITUTE
for Basic Research in Science
Newsletter
Winter 2021

Structuring Nanomaterials for Optics

Miller Fellow Focus: Danqing Wang

Nowadays, nanoscale materials have wide applications varying from medicine, clothing, electronics to information technologies. The discovery of nanostructured materials goes back to the Lycurgus Cup in the 4th century, which shows interestingly distinct colors when the light shines from the outside or the inside. These early examples of nanomaterials were based on craftsmen's empirical knowledge during high-temperature forging. It is not until 1857 that Michael Faraday identified the origin of the color in colloidal gold solutions from nanoparticle scattering of light. In 1959, Richard Feynman's renowned lecture, *"There's Plenty of Room at the Bottom,"* highlights the immense possibilities offered by materials miniaturization. In recent years, the rapid development in nanoscience and advances in nanofabrication tools enable not only unconventional material architectures at the nanoscale, but also fundamental breakthroughs in fields such as optics, electronics, and energy.

Nanomaterials can be found all around us in nature. Researchers recently discovered that chameleons change color partly by active tuning of spacings in a lattice of guanine nanocrystals on their skin. The periodic lattices function as photonic crystals—dielectric nanostructures with ordered refractive index variation—to control the light flow. Specific wavelengths of light associated with the lattice spacings are reflected from the nanocrystals, while others are not, determining the colors we observe. This coloring mechanism based on surface structures is chemically stable and robust.

My Ph.D. thesis with Professor Teri W. Odom and Professor George C. Schatz at Northwestern University focused on structured nanoscale materials and miniaturized photonic devices. Inspired by the color change mechanism of chameleons, one of my graduate works achieved mechanical control of the color of lasing on the benchtop. Laser is a ubiquitously used light source in checkout counters at retail stores, computer printing, and medical therapy. However, the laser emission is typically fixed at the time of device fabrication, and the manipulation of output color requires intricate optical designs. We exploited a new lasing cavity design based on

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INSIDE THIS EDITION

"Being a Miller Professor in the 2019/20 academic year was one of the highlights of my 16 years at Berkeley. This was a very unusual year. There were interruptions due to fires and then the Covid-19 pandemic in the last four months of the academic year resulted in all of us working remotely. Despite this, each Tuesday, either in person or remotely, I would look forward to the Miller Institute Lunch. Our University is amazing in its intellectual breadth and depth and it was great to hear, each week, an expert in a different field of science talk about their research. The Miller Fellows who worked in other fields were always willing to explain their science enthusiastically and patiently. It was also great to have a few of them act as coaches for my talk when it was my turn to present. The only sad part was that it had to end!"

- Iswar Hariharan
Miller Professor 2019-2020
Department Co-Chair and Professor of Cell & Developmental Biology, UC Berkeley

> CONTINUED FROM PAGE 1 [Miller Fellow Focus]

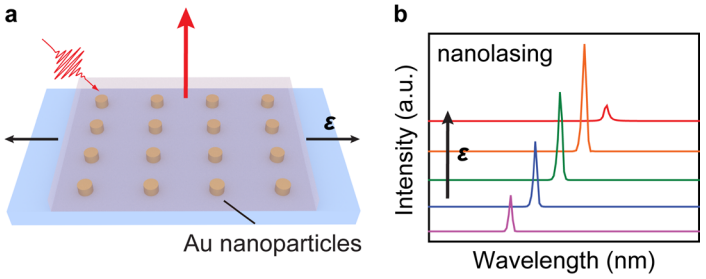

Figure 1: Stretchable nanolasing based on metal nanoparticles integrated with liquid gain materials. (a) Scheme of a stretchable nanolaser with a gold nanoparticle lattice on an elastomeric substrate. **(b)** Wavelength-tunable lasing with strain ε imposed on the substrate.

periodic arrays of nanoparticles in a stretchable, polymer matrix (**Figure 1a**). Liquid dye molecules dissolved in organic solvents were used as the gain media, ensuring close contact with the nanoparticles upon stretching of the substrate.

The laser device harnesses plasmons—collective oscillations of conduction electrons—on the surface of gold nanoparticles. The light is confined to tiny regions smaller than half of its wavelength (the diffraction limit), a challenge for conventional photonic devices. Large metal nanoparticles (260 nm in diameter) arranged in a lattice (600 nm in spacing) produce high-quality cavity modes with narrow resonance linewidth (< 5 nm). The cavity resonance originates from collective coupling of metal nanoparticles in a lattice. Hence, small changes in strain modify the interparticle distance and directly induce a change in the lasing emission color.

When pumped with a pulsed laser, the single-color nanolaser emits at the near-infrared regime normal to the sample surface. The lasing peak shifts toward the longer wavelength side when the device is stretched, and exhibits excellent recovery after releasing the strain (**Figure 1b**). By stretching and relaxing the substrate, we could control the lasing emission color at will [*Nano Letters* **18**, 4549–4555 (2018)]. The mechanically tunable nanolaser could provide advances in future wearable and flexible optical displays in devices such as televisions and cellphones.

Competition of different modes for the gain available is a typical problem for lasers, and strict mode-selection rules are exploited to ensure stable output at single wavelengths. Multi-modal lasers that can simultaneously emit at different wavelengths are essential for applications ranging from multiplexed signal processing to multi-color biomedical imaging. To achieve multi-wavelength capabilities, however, single-color lasers need to be operated as an array of lasers, which dramatically increases the unit cost and precludes their integration with compact photonic devices.

Working on another project, we realized multi-modal lasing with control over the different colors in a single device [*Nature Nanotechnology* **12**, 889 (2017)]. Nanoparticle superlattices—finite-arrays of metal nanoparticles grouped into microscale arrays—integrated with liquid gain offer a platform to produce multiple lasing colors (**Figure 2a**). Compared to traditional lasers, the superlattice cavities exhibit distinctive characteristics including stable multi-modal lasing and well-controlled output. Varying superlattice geometries provides a robust way to manipulate the emission wavelengths, numbers of lasing beams, and angles at which the beam emits from the surface (**Figure 2b**). Our research offers critical insights into the design of multi-modal lasing based on manipulating the physical geometry and related optical band structures of nanoparticle lattices.

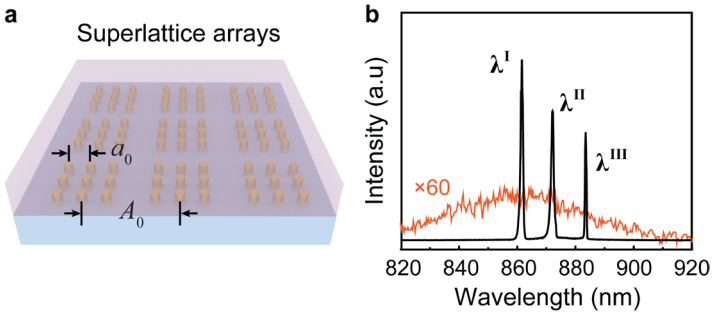

Figure 2. Multi-modal lasing was achieved in multi-scale nanoparticle superlattices. (a) Scheme of gold nanoparticle superlattices surrounded by liquid dye solutions. The multi-scale superlattice arrays sustain a submicron interparticle spacing a_0 and a microscale patch spacing A_0. **(b)** Lasing emission profile (in black) and dye emission profile (in orange) of the nanolaser, where multiple lasing modes λ^I, λ^{II} and λ^{III} were observed.

Continuous-wave lasing at room temperature is critical for integration with optoelectronic devices and facile modulation of optical interactions. Insufficient gain concerning losses and thermal instabilities in nanocavities, however, have limited nanoscale lasers to pulsed pump sources and low-temperature operation. The synergy of stable gain materials under continuous-wave pump and high-quality optical nanocavities is critical for achieving low-threshold nanoscale lasing.

We developed a materials platform to realize continuous-wave upconverting lasing at room temperature with record-low thresholds and high photostability (**Figure 3a**). Selective, single-color lasing was observed based on Yb^{3+}/Er^{3+}-co-doped upconverting nanoparticles conformally coated on silver nanopillar arrays (**Figure 3b**). The intense electromagnetic fields localized in the vicinity of the nanopillars (**Figure 3c**) result in a record-low lasing threshold, orders of magnitude smaller than other small lasers [*Nature Materials* **18**, 1172–1176 (2019)]. Our upconverting lasers provide a directional, ultra-stable output at visible wavelengths under near-infrared pumping, which offers prospects in medicine, quantum science, and next-generation photonic devices.

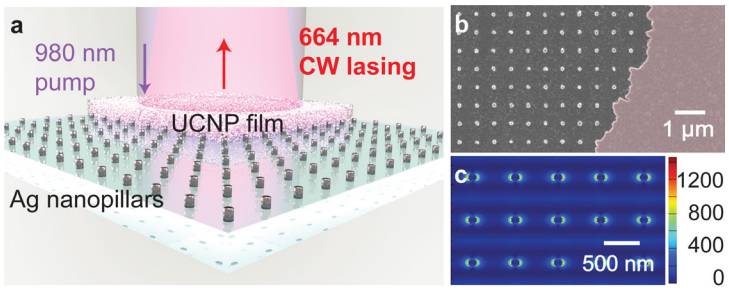

Figure 3. Continuous-wave (CW) upconverting nanolasing at room temperature. (a) Scheme of the upconverting nanolaser based on upconverting nanoparticles (UCNPs) coated on top of silver nanopillar arrays. **(b)** Scanning electron micrograph image showing the nanopillars with partial conformal coating with a UCNP thin film (right). **(c)** Near-field $|E|^2$ plot for the 450-nm spaced silver nanopillars at cavity resonance.

As a Miller Fellow, I am currently focusing on materials development and structural designs for engineering optical behaviors at the nanoscale, hosted by Professor Junqiao Wu in the Department of Materials Science and Engineering. Dielectric constant (epsilon) is one of the fundamental materials properties that lays the foundation for the optical responses. Materials and structures with a near-zero permittivity (epsilon-near-zero, ENZ) have driven new applications varying from geometry-invariant optical tunneling and optical cloaking to thermal emission manipulation.

We are exploring the analogy to the superconducting proximity effect in optical systems based on indium tin oxide thin films, where ENZ happens at the materials plasma frequency. We have observed strongly enhanced electromagnetic fields within the ENZ thin films at sub-wavelength scales in numerical simulations. The optical coupling between ENZ thin films is sustained over long distances up to tens of microns. Interestingly, the oscillatory behavior of optical field intensities within neighboring ENZ bilayers with increased interlayer distance resembles that of superconductor heterostructures. Such exotic, long-range optical interactions can offer prospects in enhanced nonlinear optics, optical communications, and large-scale quantum coherence. I will also expand current research to thermal and electronic properties of nanomaterials, and explore optical interactions at the quantum level. It has been an enjoyable year since I joined Berkeley, and I am looking forward to exploring more possibilities in the emerging field of structured nanomaterials.

Danqing was born in China, and her hometown (Bozhou, Anhui province) is a beautiful city known for traditional Chinese herbal medicine. Danqing received her Ph.D. degree in Applied Physics from Northwestern University in 2019, co-advised by Professor Teri W. Odom and Professor George C. Schatz. She started in fall 2019 as a Miller Fellow, hosted by Professor Junqiao Wu in the Department of Materials Science and Engineering. Her research interest is on unconventional optical behaviors of functional and structured nanomaterials, and applications in energy harvesting and quantum communications. In her spare time, Danqing enjoys reading, writing, and exploring local places and food.

Contact: danqing.wang@berkeley.edu

In the News

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

AAAS
AMERICAN ASSOCIATION FOR THE ADVANCEMENT OF SCIENCE

Miller Members Elected as 2020 AAAS Fellows

In the top row, left to right are: **Yi Cui** (MF 2003-2005), **William Dichtel** (VMP 2016), **Jiaxing Huang** (MF 2004-2007), **Prashant K. Jain** (MF 2008-2011), **Norman Murray** (VMP 2003).
In the bottom row, left to right are: **Talat Rahman** (VMP 2018), **Robert Ritchie** (MF 1974-1976), **Jason E. Stajich** (MF 2006-2009), **Rory Waterman** (MF 2004-2007), **Peidong Yang** (MP 2009).

Sarah Keller (Somorjai Visiting Miller Professor 2015-2016) was named a **2021 Fellow of the Biophysical Society** *"for pioneering, fundamental experimental contributions to the understanding of miscibility phase transitions in membrane systems."*

Chang Liu (Miller Fellow 2009-2012) is a co-principal investigator of the research study where an in vitro technology that can rapidly hypermutate antibodies has been developed. This method can be used to target the SARS-CoV-2 virus.

Mikhail Shapiro (Miller Fellow 2011-2013) was awarded a $1 million **grant from the Chan Zuckerberg Initiative (CZI)** to fund his research into acoustic biosensors.

Danqing Wang (Miller Fellow 2019-2022) was selected to be on the **Forbes 30 Under 30 list in Science for 2021**.

Alex Filippenko (Miller Senior Fellow 2017-Present) was recently featured on Lex Fridman's popular series of interviews, in an episode titled *"Supernovae, Dark Energy, Aliens & the Expanding Universe."*

Alison Galvani (Miller Fellow 2002-2004) was featured in *The Lancet* as "an international star in the field of modelling of infectious diseases."

Kelly Nguyen (Miller Fellow 2016-2019) was honored with a **Suffrage Science award**. The award celebrates women in science and engineering.

William R. Dichtel (Visiting Miller Professor 2016) was a **2020 Winner of the Blavatnik Award for Young Chemists** for pioneering methods to create novel, porous materials from simple, carbon-based building blocks.

NEWS CONTINUED ON PAGE 5 >

Miller Research Competitions: Awards

On December 1, 2020, 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: Steven Block (Physics, Stanford University), Luis Caffarelli (Mathematics, University of Texas, Austin), Feryal Özel (Astronomy & Physics, University of Arizona) and Tim Stearns (Biology, Stanford University); and four internal Executive Committee members: Executive Director Marla Feller (Molecular & Cell Biology), Stephen Leone (Chemistry/Physics), Roland Bürgmann (Earth & Planetary Science) and Yun Song (EECS/Statistics/IB). The Board is chaired by Chancellor Carol Christ.

The Miller Institute is proud to announce the awards for Professorship terms during the Academic Year 2021-2022. 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

David Drubin
Molecular & Cell Biology

Jeffrey Long
Chemistry / Chemical and Biomolecular Engineering

Gabriel Orebi Gann
Physics

Visiting Miller Professorship Awards

Tanja Bosak
Earth & Planetary Science
Host: David Shuster
Home Institution: MIT

Yi Cui
Somorjai Visiting Miller Professor
Chemistry
Host: Peidong Yang
Home Institution: Stanford University

Radhakrishnan Mahadevan
Chemical and Biomolecular Engineering
Host: Jay Keasling
Home Institution: University of Toronto

Adrian Buganza Tepole
Mechanical Engineering
Host: Mohammad Mofrad
Home Institution: Purdue University

Edward Stolper
Earth & Planetary Science
Host: Donald DePaolo
Home Institution: Caltech

Ivan Corwin
Mathematics
Host: Alan Hammond
Home Institution: Columbia University

Kerstin Tackmann
Physics
Host: Heather Gray
Home Institution: University of Hamburg/DESY

Next Steps

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

Lou Barreau (Miller Fellow 2018-2020)
Assistant Professor
Institut des Sciences Moléculaires d'Orsay (ISMO)
University Paris Saclay, France

Ruby Fu (Miller Fellow 2018-2020)
Assistant Professor
Department of Mechanical & Civil Engineering
Caltech

Pengfei Ji (Miller Fellow 2019-2020)
Assistant Professor
Department of Chemistry
Zhejiang University

Eva Maria Schmid (Miller Fellow 2008-2011)
Head of Scientific Training
Vienna Biocenter, Austria

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In the News

Peidong Yang (Miller Professor 2009) was awarded the **2020 Global Energy Prize**.

Anna Ho (Miller Fellow 2020-2023) wrote the cover article for December 2020's edition of *Scientific American.* She studies the catastrophic deaths of massive stars.

Ambika Kamath (Miller Fellow 2018-2021) was featured in a *New York Times* article entitled *"Scientific Journals Commit to Diversity but Lack the Data."*

Cara Brook (Miller Fellow 2017-2020) was named a **L'Oréal For Women in Science Fellow** for her research on understanding wild bats & on seeking development of therapeutics to combat SARS-CoV-2.

Vayu Maini Rekdal (Miller Fellow 2020-2023) was one of six young scientists chosen as laureates of the **International Birnstiel Award for Doctoral Studies in the Molecular Life Sciences**.

Rebekah Dawson (Miller Fellow 2013-2015) was awarded the **2020 Harold C. Urey Prize** by the Division for Planetary Sciences of the American Astronomical Society (DPS) in recognition of her outstanding achievements in planetary science.

Alex Turner (Miller Fellow 2017-2020) was honored with the **2020 AGU James R. Holton Award**. This award recognizes early-career scientists with exceptional scientific research contributions and accomplishments.

Former Miller Fellows **Prashant Jain** (2008-2011) and **Mikhail Shapiro** (2011-2013) were featured as two of the ten "Scientists to watch" by Science News. All of this year's honorees are age 40 and under, and all were nominated by Nobel laureates, recently elected members of the U.S. National Academy of Sciences or previous SN 10 scientists.

Bin Yu (Miller Professor 2004, 2016-2017) and her team at Berkeley have developed novel statistical machine learning approaches and are combining their work with the domain expertise of collaborators to solve important problems in the fields of neuroscience, genomics and precision medicine. **Professor Yu** is also a co-principal investigator of the project, the **Collaboration on the Theoretical Foundations of Deep Learning**, awarded by the National Science Foundation (NSF) and Simons Foundation to a UC Berkeley-led program to gain a theoretical understanding of deep learning.

Ron Cohen (Miller Professor 2015-2016) discussed results of the study on Monitoring Urban Greenhouse Gases during the COVID-19 pandemic in *"Nature Communications."* **Alex Turner** (Miller Fellow 2017-2020) is a coauthor of the study.

Michael Jordan (Miller Professor 2008, 2017-2018, Miller Senior Fellow 2019-present) and **Bin Yu** (Miller Professor 2004, 2016-2017) are both UC Berkeley co-PIs at the new multidisciplinary Institute, called the Foundations of Data Science Institute (FODSI) - a collaboration between UC Berkeley and MIT to improve our understanding of critical issues in data science.

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.

Gifts to the Miller Institute

The Miller Institute gratefully acknowledges the following contributors to the Miller Institute programs in 2020. 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.

Anonymous
Rachel Akeson
Anna Behrensmeyer
Roger Blandford
Michael Botchan - In Honor of Randy Schekman
Justin Brown
Mary (Beth) Burnside
Kathy Day (2)

Hilary Jacobsen
Ray Jayawardhana
Jonas Peters
Jasper Rine
Jason Stajich
Kirsten Swan
Jesse Thaler
Rebecca Bishop White

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
Steven Brenner
Justin Brown
W. Craig Carter
Kathryn Day - In Memory of Vaughan Jones
Rebecca Duncan
Marla Feller
Gilbert Hawkins

Arash Komeili
Michael Manga
Christopher McKee
Barbara Meyer
Jerry Mitrovica
Andrew Ogg
Eve Ostriker
Kenneth Wachter

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.

Ronald Johnson
Dan-Virgil Voiculescu

Statement of Values

As a community of scientists, with members from around the globe, we recognize the importance of supporting, protecting and standing with anyone who experiences discrimination. Scientific research is not immune from the devastating impacts of racism and we recognize the unique challenges that persons from underrepresented groups in this country face in the scientific disciplines. We believe that everyone deserves to live their life and pursue their chosen career free from persecution, violence and discrimination. And we recognize that as a society, we have a lot of work to do about systemic racism to make this vision a reality.

As we start a new year, we look forward to working as a community to foster greater equity in all scientific spaces, including the Miller Institute. Collaborating closely with our Fellows who have formed a Diversity, Equity, Inclusion and Belonging working group (see right), the Miller Institute is engaging in community building, outreach in support of science and assessing our practices to build a more inclusive and equitable Miller Institute for our current and future members. For the first time this competition cycle, Miller Fellows sent more than 150 personalized outreach emails to encourage faculty to nominate outstanding candidates who may not have otherwise known of the program. We are also actively ensuring that candidates from nontraditional academic backgrounds are brought to the final stages of consideration for the Fellowship. In the coming months and years ahead, we'll be delighted to share our continued progress in Diversity, Equity, Inclusion and Belonging at the Miller Institute.

- The Miller Institute Executive Committee and Staff Leadership

*A special thanks to Miller Fellows who have been leading and participating in the DEIB working group, subgroups and outreach activities (in alphabetical order): Adair Borges, Gray Chadwick, Alison Feder, Ruby Fu, Allie Gaudinier, Reza Gheissari**, Yu He, Sam Hopkins**, Dan Ibarra**, Ambika Kamath, Naomi Latorraca*, Vayu Maini Rekdal, Ekta Patel, Nick Rodd, Nayeli Rodriguez Briones, Danqing Wang, Qiong Zhang, Yong Zheng*, Alfred Zong*

* Leader **Sub-group leader

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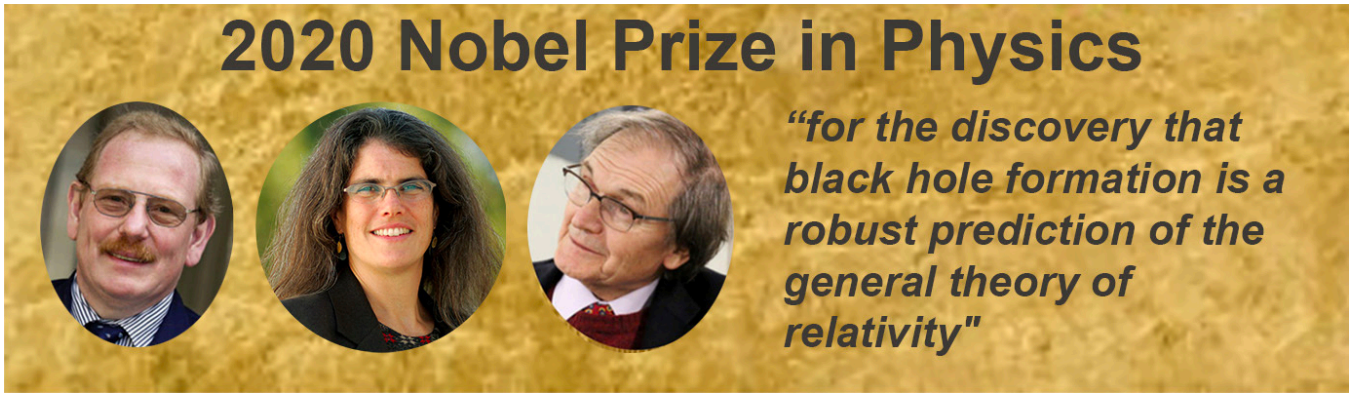
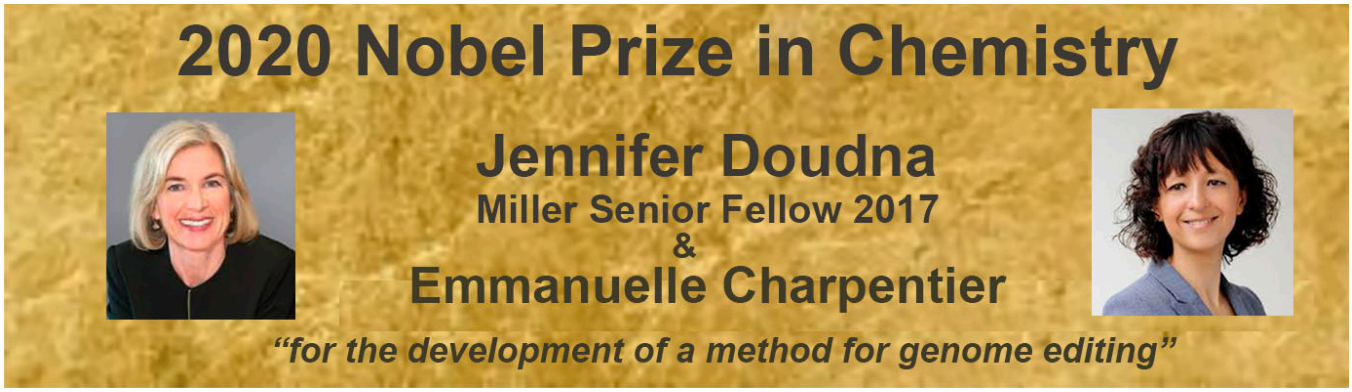
In the News: 2020 Nobel Prizes



Reinhard Genzel (Miller Fellow 1980-1982), Andrea Ghez **& Roger Penrose** (Visiting Miller Professor 1978-1979) shared the **2020 Nobel Prize in Physics** *"for the discovery of a supermassive compact object at the centre of our galaxy."*



Jennifer Doudna (Miller Senior Fellow 2017) & Emmanuelle Charpentier were awarded the **2020 Nobel Prize in Chemistry** *"for the development of a method for genome editing."*

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Welcome Vrinda!

Vrinda Khanna joined the Miller Institute staff team in November as the new **Finance and Operations Administrator**, having most recently worked in the nonprofit sector. She has experience in development, grant writing, marketing, communications, and PR that has helped organizations grow their operations. She holds a BA in Art History with minors in English and History from Hamilton College in Clinton, NY. In her spare time, she enjoys reading mystery and science fiction novels, exploring different nature trails in the Bay Area, and coming up with creative gift ideas.

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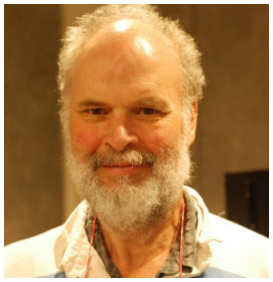
In Memory



We were saddened by the news that **Sir Vaughan F. R. Jones** passed away on Sept. 6th 2020. Professor Jones was involved in the Miller Institute in many capacities, starting with his Miller Professorship term (1992). He also served terms on both the Miller Institute Executive Committee and Advisory Board. Professor Jones was a longtime supporter and friend to the Miller Institute, and he will be greatly missed.

William Clemens, Miller Professor 1982-1983, expert on fossil mammals, died on November 17, 2020. Professor Clemens was a longstanding figure at UC Berkeley for 35 years in the Paleontology and later Integrative Biology departments. May he rest in peace.

For More Information:

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+ millerinstitute@berkeley.edu | miller.berkeley.edu