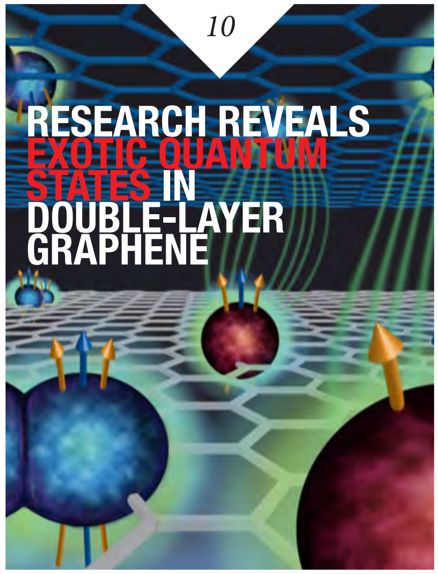
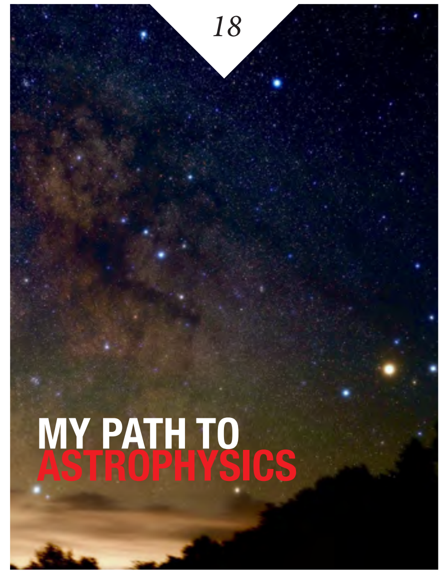
BROWN PHYSICS

imagine

SUMMER 2019

BROWN





In This Issue

Faculty & Research

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BROWN TOGETHER

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On the cover: Gaitskell Lab, photo by Nick Dentamaro

Greetings from the Chair...

The past academic year has been an exciting one for Brown's Physics Department. We just celebrated the graduation of our many concentrators, masters, and doctoral students. Our faculty enjoyed the presentations made by these students on their thesis projects and marveled at the quality and depth of their research. We are confident that our graduates will have successful careers in any endeavors that they pursue.

The department's faculty grew in size with the addition of two new tenure-track assistant professors, an experimentalist and a theorist both in condensed matter physics with a focus on quantum physics and materials. We have also enjoyed a significant increase in the number of post-docs, who have become a major group of researchers in all our subdisciplines.

Our faculty and associates have generated increasing amount of quality scholarship, some of which you are about to read in this issue of Imagine. We are becoming more successful in attracting external research funding, particularly in the area of quantum science which has become a major research initiative for US funding agencies and is a key focus area of Brown's Research Office.

More Brown students have been taking physics and astronomy courses due to our improved curriculum and the strong effort and commitment by our faculty. Our students are traveling more to attend and present their research at scientific conferences. Increasingly, they receive prestigious awards and fellowships from government agencies.

During the last year, I have met many of our alumni who have come to visit and attend our Degree Day outreach and we awarded our first annual Physics Alumni Awards to Jose Estabil '84 ScM '88 and Warren Galkin '51. It was great meeting all of you and we need your continued support as the faculty and I work to achieve our strategic goal for the department. Your generous support will help us train the future generation of diverse groups of physicists and produce cutting edge research of the highest quality. Thank you for being a member of our physics community.

Happy reading!

Gang Xiao

Chair, Department of Physics

A *celebration* OF MIKE KOSTERLITZ'S 75th *birthday*

The Physics Department celebrated Mike Kosterlitz's 75th birthday with a symposium on October 8-9, 2018 that featured talks by thirteen distinguished condensed matter theorists from across the US and the world. The speakers discussed the wide-ranging impact of Mike's Nobel Prize winning work on topological phase transitions and topological phases of matter. There was also a presentation on Mike's exploits and world-class achievements as a mountain climber (there is the "Fessura Kosterlitz", the Kosterlitz crack, in the Orco Valley of Italy which is very famous among climbers). The symposium was made possible by the Tony and Pat Houghton Conference Fund which supports annual conferences and symposia on condensed matter physics.

The symposium was organized by Prof. Bob Pelcovits, Tapio Ala-Nissila, Dima Feldman, Brad Marston and See-Chen Ying.

DEGREE RECIPIENTS

Mei Araki
Henry B. Belcaster
Ian W. Brown
Liam R. Carpenter-Urquhart
Jason C. S. Chan
Noah L. Cowan
Jenny Andrine M. Evang
Ciaran L. Godfrey
Joshua C. Greene
Osbaldo J. Hernandez
Kairy M. Herrera
Elise D. Hinkle
Jamie E. Holber
Rahul Jayaraman
Heesoo Kim
Charles D. Kocher
Yamini Mandava
Hope E. McGovern
Sven S. Ostertag
David A. Paasche
Anthony V. Papol
Pedro R. Polanco
Kaitlin M. Sandmann
Benjamin A. Seifert
Emily R. Tunkel

2019

STUDENT AWARDS

R. Bruce Lindsay Prize
for Excellence in Physics

Charles D. Kocher

Mildred Widgoff Prize
for Excellence in Thesis Preparation

Elise D. Hinkle
Jamie E. Holber
Heesoo Kim

Chair's Award
for Excellence in Scholarship & Service to the Physics Department

Elise D. Hinkle
Jamie E. Holber

REFLECTION : SENIOR THESIS RESEARCH EXPERIENCE

Henry Belcaster ‘19 Sc.B. Physics/Astrophysics Track

"

The Music of TRAPPIST-1 and Other Exoplanet Systems: An investigation of orbits, sound, and music’s unique ability to explain complex structure in the universe

"

When I was tasked with writing a senior thesis I got nervous -- I hadn’t done hardcore, institutional research. I had spent my summers working on personal businesses and travelling around the world, and I felt inferior to my physics peers with aspirations of graduate school, PhDs, and high-falutin plans to change the physical sciences. But then I thought about an influential book become course I took while at Brown (The Jazz of Physics; written and taught by Stephon Alexander) and tapped into an important venn diagram in my life -- that narrow spot in the middle intersection of two circles where my interest in physics perfectly overlaps with my love of music. This was where I would begin my search for a topic that mattered to me.

The Genesis

Stephon Alexander, in his book (and now course) The Jazz of Physics, helps shed light on the unconventional approach of relating theoretical cosmology to improvisational jazz. To get there, he first looks at how John Coltrane -- one of the most influential jazz saxophonists of our time -- used physics and geometry to guide his playing. Then, in a leap far beyond what we’re taught in a classical physics classroom, Alexander goes on to describe how Coltrane’s findings, paired with the early findings of philosopher astronomers such as Pythagoras and Kepler, can be used to explain extraordinarily complex structures in the far reaches of the universe. After all, the strings on a piano or an upright bass resonate much the same as those proposed in a hypothetical string theory -- the universe and its structure may not be nearly as random as we think; music and jazz may not be nearly as exclusive as we’re taught.

Then I thought, much like Johannes Kepler in the early 17th century when he composed songs that ‘played’ the orbits of the planets in our solar system, what would the orbits of exoplanet systems sound like if they were transcribed to a piano? What perfect or imperfect intervals might we see that help explain stability, harmony, and/or disorder in systems Kepler would have never imagined to have existed? What followed was an investigation of orbits, sound, and music’s unique ability to explain complex structure in the universe.

Outcomes

With these tools in my belt, I began searching for new ways to introduce jazz theory to the universe. As mentioned, that led me to study the orbits of exoplanet systems in search for the sounds they played together. Then, I discussed what these exoplanet songs may be able to tell us about how these systems are similar or different from our own.

What’s important to note is that classical music theory, much like a lot of classical physics, was not sufficient in explaining the resulting intervals I found from looking at the orbits of exoplanets. Jazz theory, much like new fields developing in physics, in its improvisational mode of thought, was paramount in explaining the intrinsic songs the planets of far-away solar systems Physics, like jazz, must be improvised.

Above all, I hope I encouraged a notion of thinking that doesn’t say the physical sciences and the fine arts must be mutually exclusive disciplines, but, rather, two fields that, when paired together, can riff off of and harmonize with one another.

Henry Belcaster, a Chicago native, is a recent astrophysics graduate of Brown University. Born an entrepreneur, having deep interests in music and the fine arts, and trained as a physicist, Henry always hopes to be doing something at the intersection of all three fields. Now, he’s taking what he’s learned as an entrepreneur and a physicist to create businesses that solve complex, social problems. You can see some of Henry’s most recent work at www.henrybelcaster.com

MASTERS OF SCIENCE

Fares AlAmri
Abdulwahab Al Luhaibi
Amjad Alqahtani
Hong Cai
Zikun Cao
Chun (Ginger) Cheng
Mengxin Du
Louis Hamaide
Zhixian Han
Oliver Isik
Hui Ma
Forest Mathieu
Athira Sanal
Bradley Shapiro
Tianqi Tang
Michael Toomey
Vuong Truong
Fanfei Wang
Michael Warnock
Patchara Wongsutthikoson
Boyuan Xu
Weishi Yuan
Li Zheng
Xiao Zhou
Junjie Zhu

STUDENT AWARDS

Master's Research Excellence

Michael Warnock

Outstanding Academic Accomplishment in Master's Program

Oliver Isik

Engaged Citizenship and Community Service to the Physics Department

Athira Sanal

Graduate Student Contribution to Community Life Award

Athira Sanal

This award is given by the Division of Campus Life on behalf of the Corporation Committee on Campus Life and recognized a select group of students who have contributed in a significant way to the sense of community at Brown.

STUDENT AWARDS

Physics Merit Dissertation Fellowship 2018-2019

Igor Prlina

Galkin Foundation Fellowship Award 2018-2019

Wenyang Li

Beyer Award for Excellence in Scholarship & Service

Brian Kilpatrick

Forrest Award for Excellence in Work Related to Experimental Apparatus

John Hakala, Joshua Kerrigan

Award for Excellence as a Graduate Teaching Assistant

Darshil Doshi, Isabelle Goldstein, Theodora Kuniki, Daniel Li, Michael Lukasik, Angela Pizzuto, Charles Snider

Sigma Xi Award

Brian Kilpatrick

DOCTOR OF PHILOSOPHY

Jordan Bell *Advisor: Jay Tang*

Wenzhe Chen *Advisor: Gang Xiao*

John Hakala *Advisor: Greg Landsberg*

Joshua Kerrigan *Advisor: Jonathan Pober*

Brian Kilpatrick *Advisor: Greg Tucker*

Igor Prlina *Advisor: Marcus Spradlin*

Robert Sims *Advisor: Stephon Alexander*

Stephen Sirisky *Advisor: Humphrey Maris*

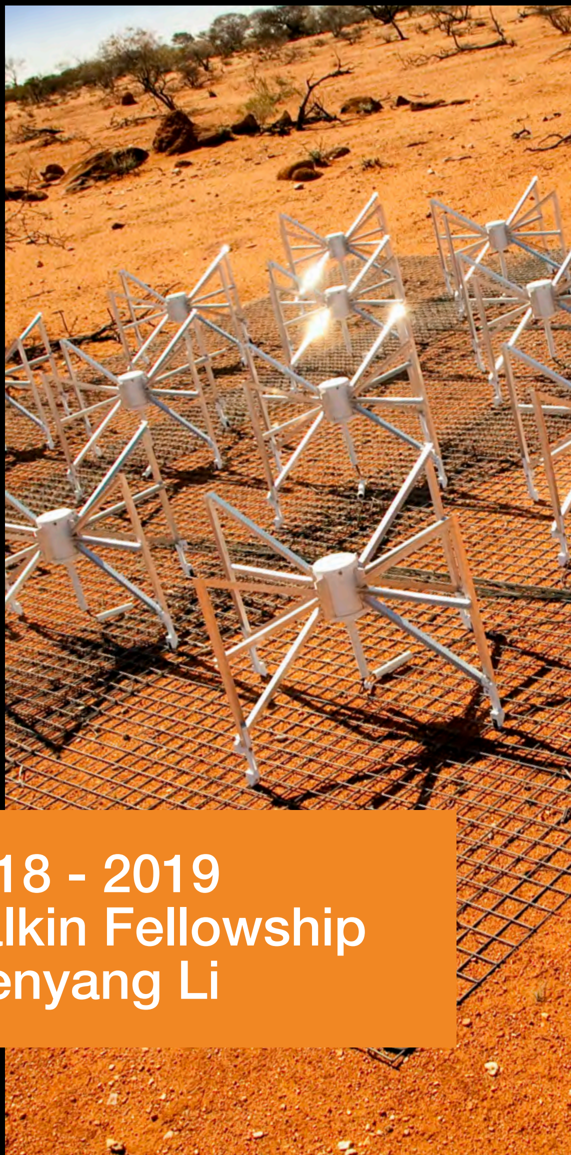
Joseph Skitka *Advisor: Brad Marston*

Rizki Syarif *Advisor: Meenakshi Narain*

Benjamin Wiener *Advisor: Derek Stein*

Yiming Yang *Advisor: Humphrey Maris*

Xue Zhang *Advisor: James Valles Jr.*



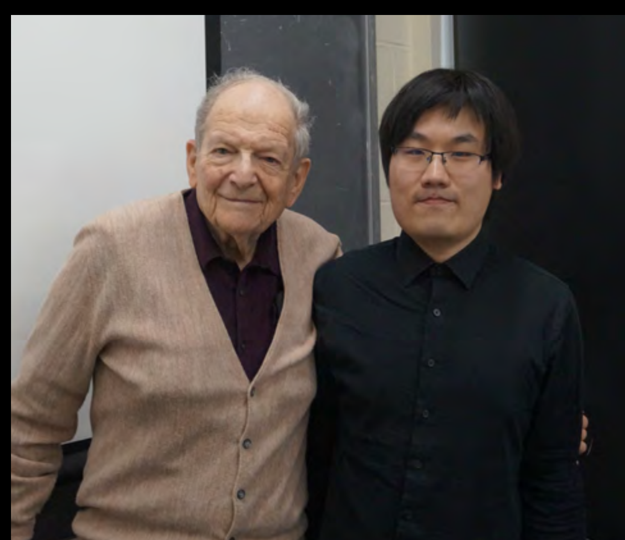
2018 - 2019 Galkin Fellowship Wenyang Li

After the big bang, the universe was filled with a hot ionized plasma tightly coupled with photons. As the universe expanded and cooled down, the ions of the plasma combined together to form neutral Hydrogen. At this time, the photons decoupled from matter and started free streaming: the universe becomes neutral and opaque. Approximately 100 million years later, the first generation of luminous objects form from the gravitational collapse of initially small perturbations. Once these objects emit enough ionizing photons, the predominately neutral intergalactic medium (IGM) once again starts to become ionized. This drives the universe into a phase transition from fully neutral to fully ionized. We name this period as the Epoch of Reionization (EoR).

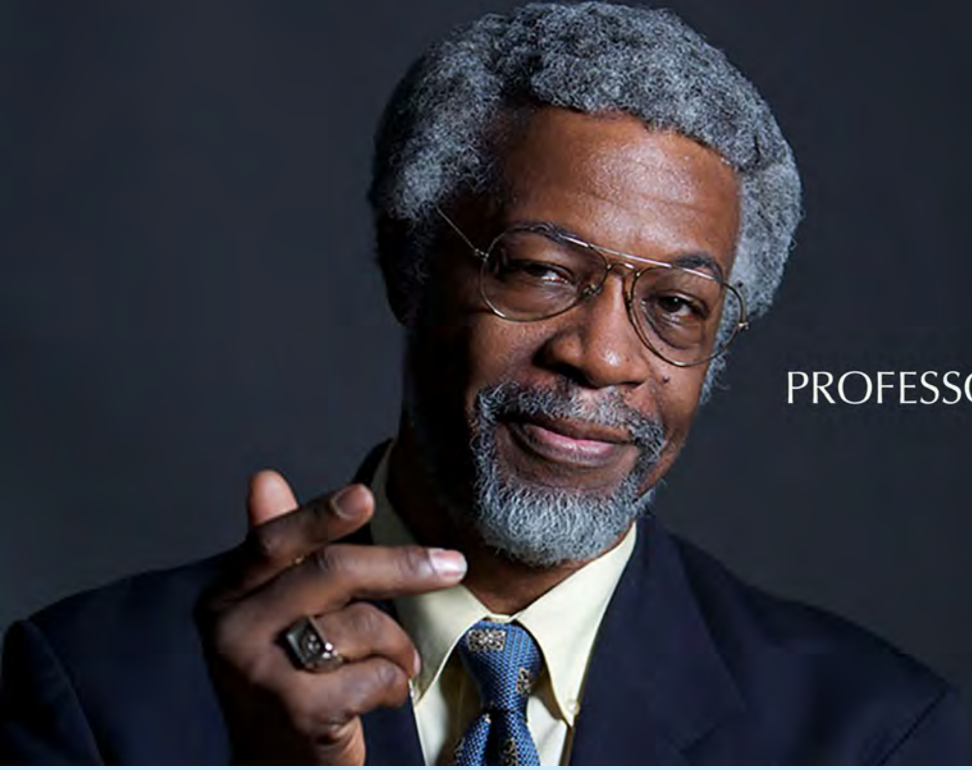
The detailed physics of the first luminous objects and the subsequent EoR remain largely unknown. The most promising approach for placing observational constraints on the EoR is to detect the 21cm emission from hyper-fine spin flip transition in neutral Hydrogen. By observing the redshifted 21cm emission from the neutral IGM we are potentially able to make a 3D map of structure evolution. However, current experiments do not have sensitivity to directly image the 21cm signal. We instead use a statistical interpretation which is the 21cm power spectrum, quantifying the 21cm power at various spatial scales. To make these measurements, we use a technique known as radio interferometry. Every pair of antenna elements of a radio interferometric array on the ground is sensitive to a specific spatial mode determined by the separation of the two antenna elements.

Wenyang Li, the 2018-2019 Galkin Foundation Fellow, with his advisor, Professor Jonathan Pober, have been working with the EoR experiment conducted by the Murchison Widefield Array (MWA) in Western Australia. Wenyang mainly focused on the recent Phase II upgrade to the MWA, which consists of 128 antenna elements. The MWA and similar experiments face major difficulties such as limited instrument sensitivities, overwhelmingly strong foreground contamination, and radio frequency interference (RFI).

Wenyang has spent his PhD work developing new analysis techniques to remedy the contamination from foregrounds, RFI, and instrument specific artifacts. He developed a hybrid interferometric calibration technique that combines more traditional sky-model-based instrument calibration with redundant calibration, along with an improved bandpass smoothing technique and cable reflection mode capturing. By applying these new techniques, the errors in traditional calibration have been mitigated, and the power spectrum has been improved. Wenyang further developed multiple data quality evaluation metrics, which better exclude corrupted observations that can potentially contaminate the power spectrum. With his efforts to analyze 40 hours of 2016 Phase II MWA observations, he obtained new EoR power spectrum upper limits at redshift 7.1, 6.8, and 6.5.



Warren Galkin '51 and Wenyang Li



PROFESSOR ELECTED VICE PRESIDENT of APS PHYSICS

Brown University physics professor S. James Gates Jr. has been elected to the presidential line of the American Physical Society, a nonprofit that represents more than 55,000 physicists in higher education, national laboratories and industry in the U.S. and across the world.

Gates will serve as the society's vice president in 2019, president-elect in 2020 and president in 2021. The APS president leads the society's board of directors, which has the ultimate responsibility for the actions of the society. The society's mission is to advance and diffuse the knowledge of physics through its research journals, scientific meetings, and education, outreach, advocacy and international activities.

Gates says he's honored to have been elected by his fellow physicists and that he sees this as a critical time to be taking on this new role.

"Now is a time when all good citizens need to come to the aid of our nation's future," he said. "This can be done best, in my opinion, by providing service to the mission of rededicating efforts to the bridging of chasms that have appeared in our nation. Some of these exist between portions of the public and the science community, and we must not let these deleterious processes go unchallenged."

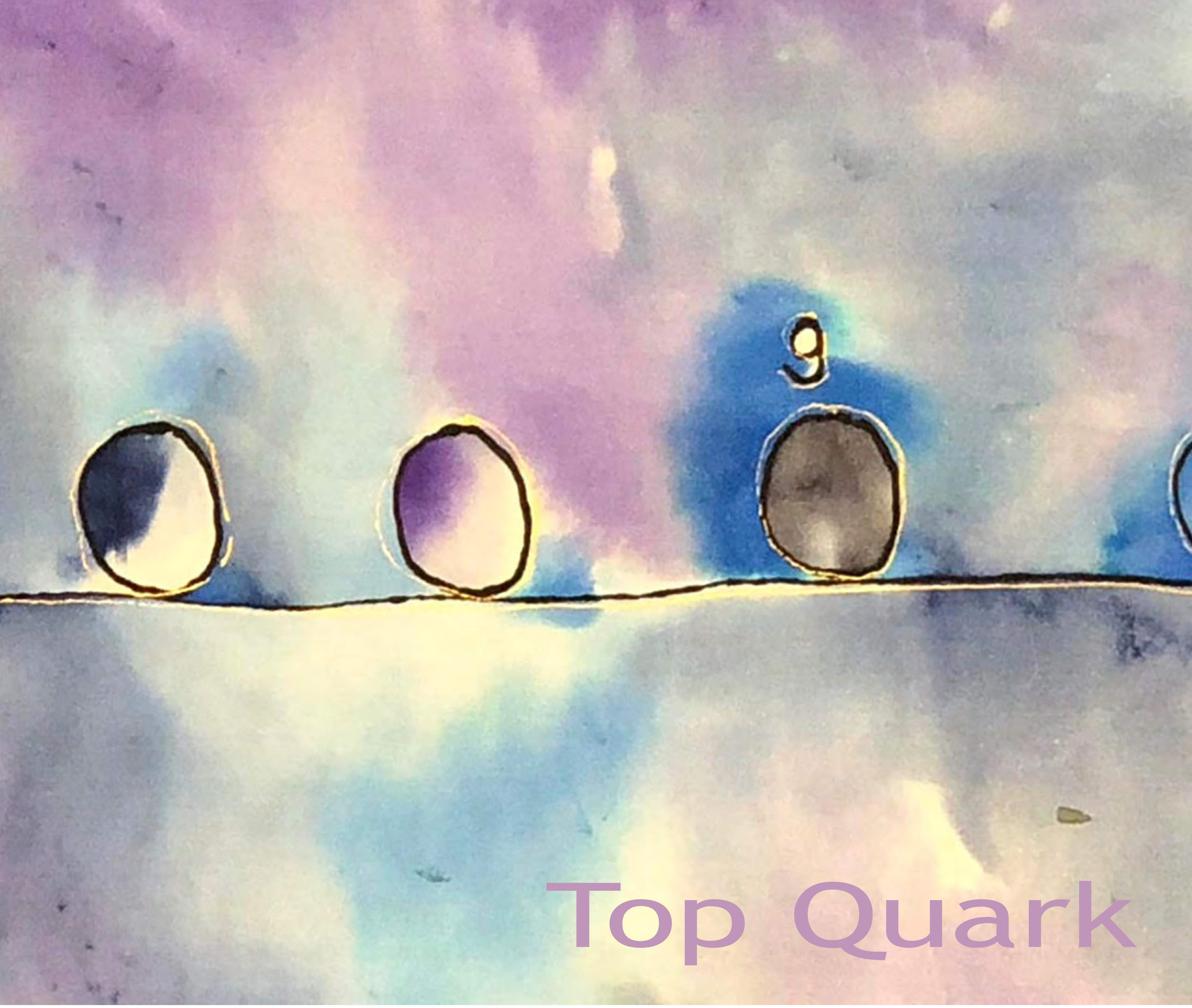
Gates joined the Brown faculty as the Ford Foundation Professor of Physics in May 2017, after 33 years on the faculty at the University of Maryland. He is known for pioneering work in theoretical physics, including the areas of supersymmetry and supergravity. Gates has earned numerous awards during his academic career including the National Medal of Science, the highest honor bestowed upon American scientists and engineers by the U.S. president. He's a member of the National Academy of Sciences, serves on the board of trustees of Society for Science and the Public and was a member of the President's Council of Advisors on Science and Technology under Barack Obama.

Gates is also a highly visible communicator of science, having appeared as an expert on numerous television news broadcasts and as a regular contributor to the PBS science series, "NOVA." Gates says he sees science communication as a critical role for physicists and the APS.

"A vital component of this must be our continuous improvement as effective communicators in realms from thought-leaders, policymakers to the public," Gates said in his candidacy statement for the APS presidency. "As an organization that draws greater than 50,000 members from the realms of academia, national laboratories, and corporate domains, the society must be the voice for these and the discipline. It needs to afford its membership opportunities to successfully engage this challenge. I hope to bring to bear my experiences to project this voice and represent our community."

Gates assumed the post of vice president on Jan. 1, 2019.

APS physics™



Top Quark

When Evan Coleman was wrapping up his undergraduate studies in physics at Brown University, he wanted to find something special to give his mentor, Meenakshi Narain. "How do you get a gift for someone who has defined your career?" Coleman says.

When he started at Brown, Coleman was undecided about whether to major in physics, engineering or computer science. At a math department event, he met one of Narain's students, who recommended Coleman talk to her about a research position in her lab. He later discovered he was already good friends with Narain's son.

"Given the serendipity of it all, I figured I'd better give physics research a try," Coleman says. In Narain's lab, he analyzed data from the Compact Muon Solenoid (CMS) experiment at the Large Hadron Collider at CERN.

Narain has a history with particle collider experiments. In the early 1990s, she joined the DZero experiment at the Tevatron collider at the US Department of Energy's Fermi National Accelerator Laboratory. At the time, physicists had discovered five of the six quarks—only the heaviest, the top quark, remained hidden. Narain was a part of the group that, in 1995, finally found that last piece of the quark puzzle.

When Coleman joined Narain's lab, she was focused on the top quark once again—this time, measuring its width with extreme precision. "Meenakshi really taught me and mentored me from the ground up," Coleman says. "Her mentorship really changed everything. The environment in her lab was super positive, and I felt like I had gained a second family."

After graduating from Brown in August, Coleman began a doctoral program in physics at Stanford University, where he is a National Science Foundation graduate fellow.

Coleman discussed what to give Narain as a parting gift with his mom, Kate Mulligan. Mulligan, who is a graphic designer, says she loves textiles and thought a silk scarf depicting an equation would be the ideal gift. Inspired, Coleman

Couture

Evan Coleman '18 is an aspiring scientist pursuing a career in High Energy Physics. In his time at Brown, he worked on the CMS Experiment at CERN, and performed one of the first measurements of the top quark lifetime which used data from the Large Hadron Collider. He has also published peer-reviewed research in particle phenomenology, and wrote his thesis on modern topics in string theory, advised by Prof. Antal Jevicki. He is a Goldwater and Astronaut Scholar, and an NSF Fellow at Stanford.

showed his mom sketches of Feynman diagrams. Named for their creator, physicist Richard Feynman, the diagrams tell a science story in symbols. Through lines and loops, they illustrate the often complicated transformations that occur when elementary particles interact.

"Mom picked up the Feynman diagrams pretty quickly," Coleman says. They chose one that demonstrates the production and decay of the top quark.

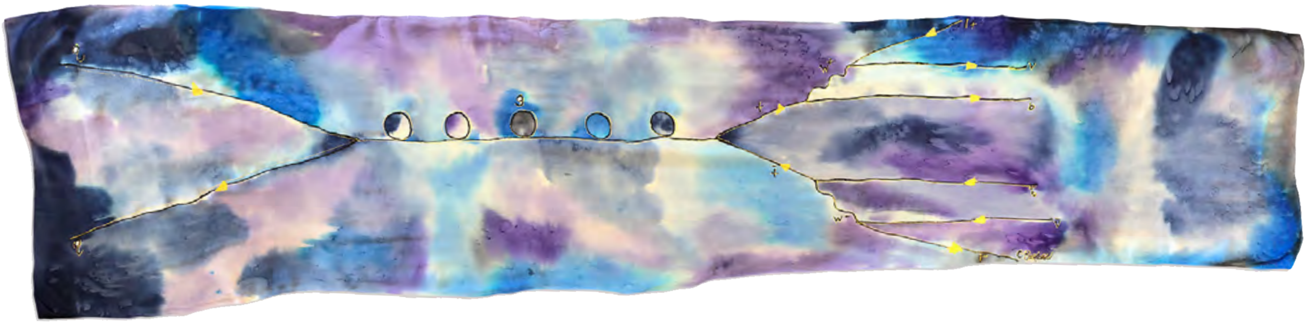
"We were interested in making this very unique, and specific to Meenakshi," Mulligan says. She knew a silk artist, Carol Baker, whose father happened to have been a physicist as well, and she commissioned Baker to create the piece.

The scarf is over 5 feet long. Against its turbulent background of blues and purples, a quark and an antiquark smash into one another and fuse to form a gluon. The gluon spirals across the middle of the scarf before decaying into a top quark and an anti-top quark, which themselves deteriorate into pairs of W bosons and bottom quarks. Finally, the W bosons each decay into a lepton and a neutrino.

Narain says that she sees science-themed attire as a way to promote science and make it feel less exclusive. "It's a valuable outreach mechanism," she says. "Science 'fashion' takes science to large audiences who are not necessarily science-minded."

And the scarf is certainly unique—and specific to Narain in more than one way, she says. "The scarf captures my passions about promoting intersections between art and science."

—JIM DALEY, SYMMETRY MAGAZINE



Jia (Leo) Li

Research reveals exotic quantum states in double-layer graphene

A new study reveals a suite of quantum Hall states that have not been seen previously, shedding new light on the nature of electron interactions in quantum systems and establishing a potential new platform for future quantum computers.

Researchers from Brown and Columbia Universities have demonstrated previously unknown states of matter that arise in double-layer stacks of graphene, a two-dimensional nanomaterial. These new states, manifestations of what's known as the fractional quantum Hall effect, arise from the complex interactions of electrons both within each graphene layer as well as across layers.

"The findings show that stacking 2D materials together in close proximity generates entirely new physics," said Jia Li, assistant professor of physics at Brown, who initiated this work as a postdoctoral researcher at Columbia working with Cory Dean, professor of physics and Jim Hone, professor of mechanical engineering. "In terms of materials engineering, this work shows that these layered systems could be viable in creating new types of electronic devices that take advantage of these new quantum Hall states." The research is published in the journal Nature Physics.

The Hall effect, discovered in 1879, emerges when a magnetic field is applied to a conducting material in a perpendicular direction to a current flow. The magnetic field causes the current to deflect, creating a voltage in the transverse direction called the Hall voltage. The strength of the Hall voltage increases with the strength of the magnetic field.

The quantum version of the Hall effect, whose 1980s discovery was awarded a Nobel Prize, was found in experiments performed at low temperatures and with strong magnetic fields. The experiments showed that, rather than increasing smoothly with magnetic field strength, the Hall voltage increases in stepwise (or quantized) fashion. These steps are integer multiples of fundamental constants of nature and are entirely independent of the physical makeup of the material used in the experiments.

A few years later, researchers working at temperatures near absolute zero and with very strong magnetic fields found new types of quantum Hall states in which the quantum steps in Hall voltage correspond to fractional numbers, hence the name fractional quantum Hall effect. The discovery of the fractional quantum Hall effect won another Nobel Prize, in 1998. Theorists later posited that the fractional quantum Hall effect is related to the formation of quasi-particles called composite fermions. In this state, each electron combines with a quantum of magnetic flux to form a composite fermion carrying a fraction of an electron charge, giving rise to the fractional values in Hall voltage.

The composite fermion theory has been successful in explaining a myriad of phenomenon observed in single quantum well systems. This new research used double-layer graphene to investigate what happens when two quantum wells are brought close together. Theory had suggested that the interaction between two layers would lead to a new type of composite fermion, but it had never been observed in experiments.

For the experiments, the team built on many years of work at Columbia to improve the quality of graphene devices, creating ultra-clean devices entirely from atomically flat 2D materials. The core of the structure consisted of two graphene layers separated by a thin layer of hexagonal boron nitride as an insulating barrier. The double-layer structure was encapsulated by hexagonal boron nitride as a protective insulator, and graphite as a conductive gate to change the charge carrier density in the channel.

"Once again the incredible versatility of graphene has allowed us to push the boundaries of device structures beyond what was previously possible." says Cory Dean, a professor of Physics at Columbia University. "The precision and tunability with which we can make these devices is now allowing us to explore an entire realm of physics that was just recently thought to be totally inaccessible. "

The graphene structures were then exposed to strong magnetic fields — millions of times stronger than Earth's magnetic field. The research produced a range of fractional quantum Hall states — some of which demonstrate excellent agreement with the composite fermion model, and some of which had never been predicted or seen.

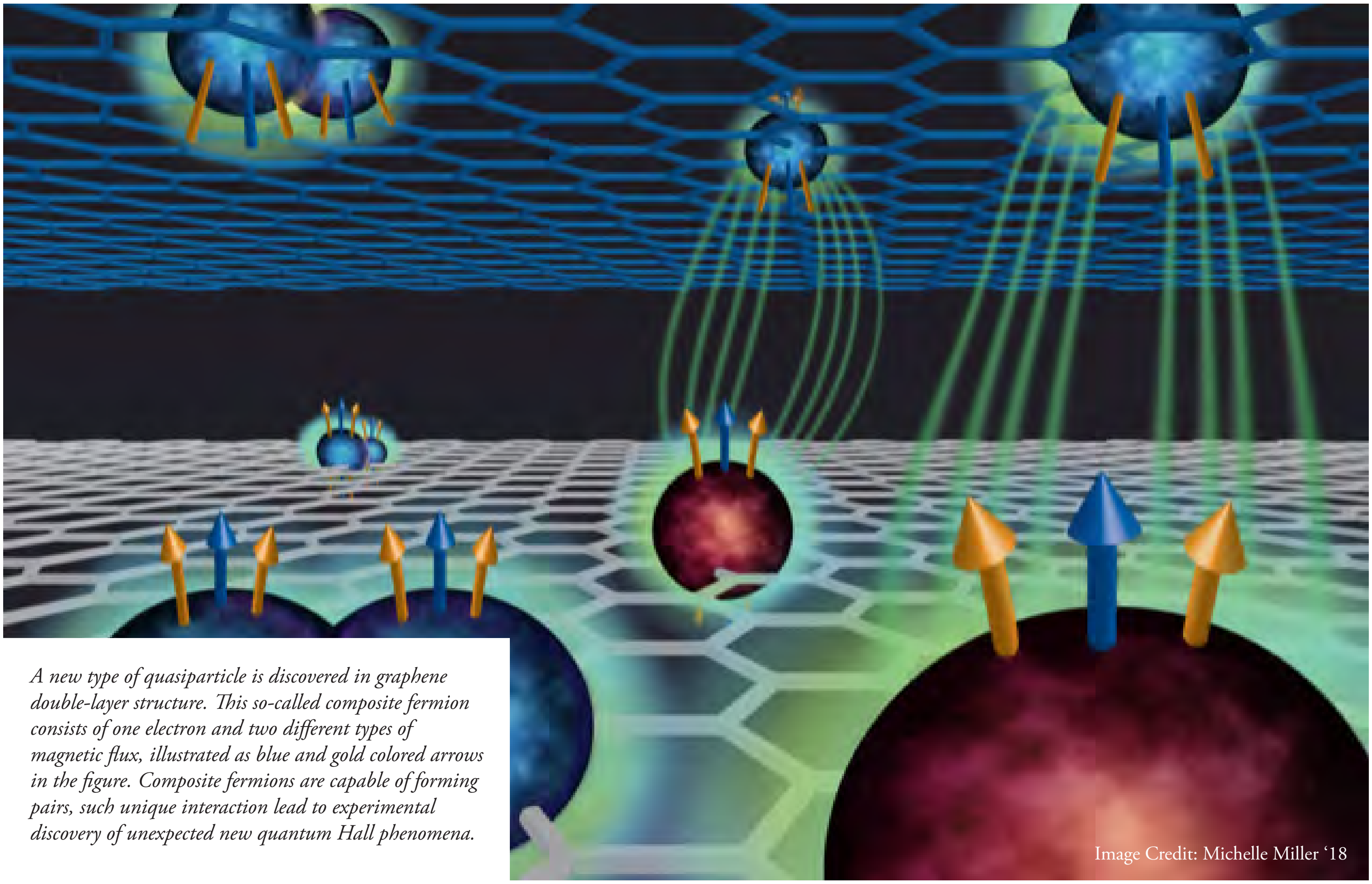
"Apart from the interlayer composite fermions, we observed other features that cannot be explained within the composite fermion model," said Qianhui Shi, the paper's co-first author and a postdoctoral researcher at Columbia University. "A more careful study revealed that, to our surprise, these new states result from pairing between composite fermions. Pairing interaction between adjacent layers and within the same layer give rise to a variety of new quantum phenomena, making double-layer graphene an exciting platform to study."

"Of particular interest", says Jim Hone, professor of mechanical engineering at Columbia, "are several new states that have the potential of hosting non-Abelian wavefunctions — states that don't quite fit the traditional composite fermion model and that could be useful in making ultra-fast quantum computers." In non-abelian states, electrons maintain a kind of "memory" of their past positions relative to each other. That has potential in enabling quantum computers that don't require error correction, which is currently a major stumbling block in the field.

"These are the first new candidates for non-Abelian states in 30 years," Dean said. "It's really exciting to see new physics emerge from our experiments."

Other coauthors on the paper were Qianhui Shi, Yihang Zeng, Kenji Watanabe, Takashi Taniguchi, James Hone and Cory Dean. The research was supported by the National Science Foundation (DMR-1507788), the David and Lucille Packard Foundation and the Department of Energy (DE-SC0016703). The magnetic field experiments were done at the National High Magnetic Field Laboratory in Tallahassee, Florida, a nationally funded user facility.

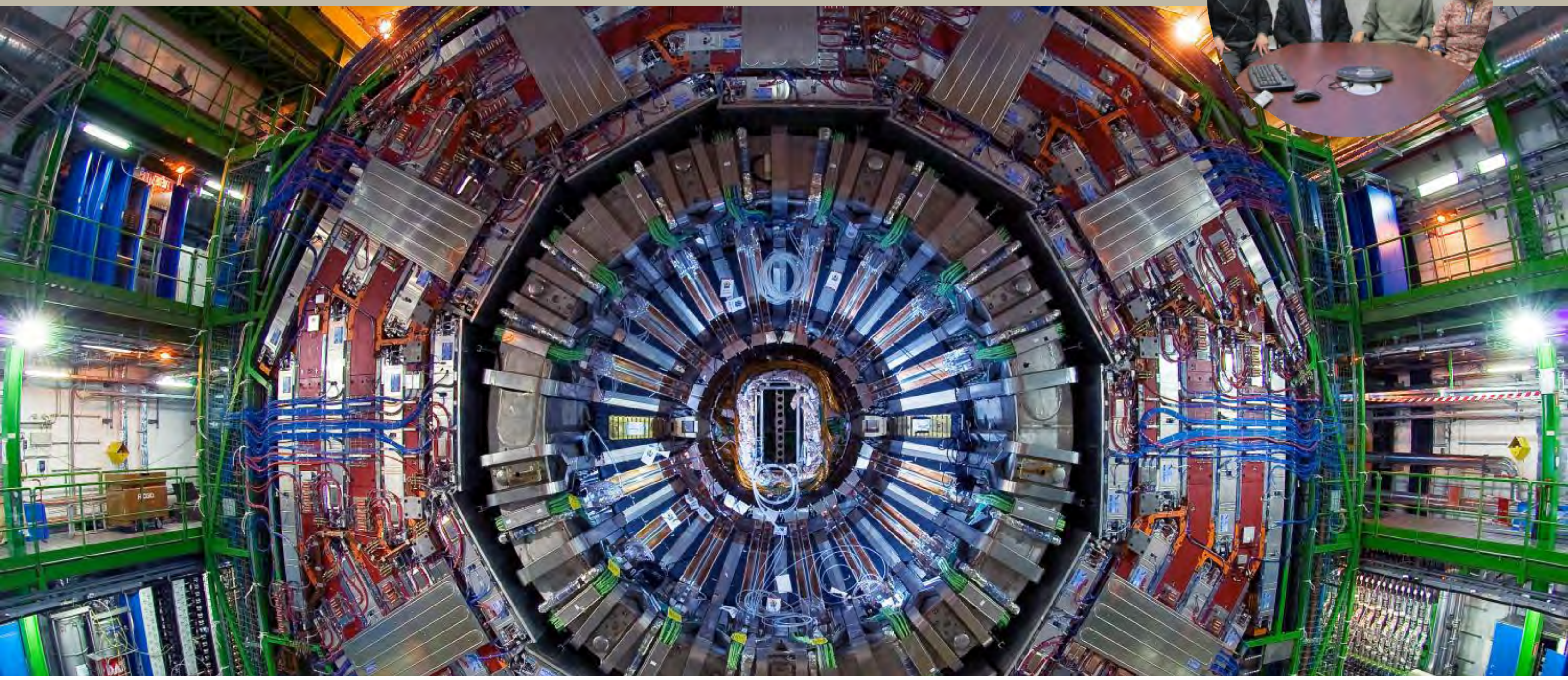
—KEVIN STACEY



A new type of quasiparticle is discovered in graphene double-layer structure. This so-called composite fermion consists of one electron and two different types of magnetic flux, illustrated as blue and gold colored arrows in the figure. Composite fermions are capable of forming pairs, such unique interaction lead to experimental discovery of unexpected new quantum Hall phenomena.

Image Credit: Michelle Miller '18

High Energy Experimental Group



Researchers at the Large Hadron Collider find key Higgs decay process

Brown University researchers at the LHC made important contributions to a finding that reveals the fate of the majority of Higgs particles.

On Tuesday, Aug. 28, researchers with the two large-scale experiments at the Large Hadron Collider, CMS and ATLAS, announced the observation of the Higgs boson decaying to two bottom quarks.

That process is critical in understanding the properties of the Higgs boson, the manifestation of a field that enables other fundamental particles to acquire their mass. Its existence had been predicted for years, but it wasn't until 2012 that the particle was first observed at the Large Hadron Collider (LHC).

When a Higgs boson is produced in an LHC collision, it lasts only a septillionth of a second before it decays into a cascade of other particles. The Standard Model — the scientific theory that describes the behavior of subatomic particles — predicts that transformation to two bottom quarks is the most common Higgs decay pathway, so confirming it experimentally has been a priority for CMS and ATLAS researchers. The CMS measurement of the Higgs boson decay to bottom quarks is consistent with the expectations from the Standard Model. It strengthens the case that the Higgs boson couples to a class of particles called fermions, including the up and down quarks, which make up the familiar protons and neutrons. Brown researchers David Cutts, Ulrich Heintz, Greg Landsberg and Meenakshi Narain have been active in the CMS experiment for years. The Brown team contributed significantly to the discovery of the Higgs boson with Landsberg as physics coordinator, directing the overall physics analysis effort of CMS. Narain contributed to b-quark identification and the search for Higgs decays to Z boson pairs. She was recently named chair of the collaboration board of U.S. CMS scientists. Heintz led the internal review of one of the discovery analyses.

Xavier Coubez, a postdoctoral researcher working with Narain, played a key role in this latest Higgs decay discovery. Here, he discusses the new findings.

Q: Why is it important for physicists to understand how the Higgs decays?

The Higgs discovery in 2012 opened a new era in particle physics. The Standard Model, which describes our understanding of the universe based on a set of fundamental particles, is now complete. However, theoretical considerations as well as experimental observations indicate that the Standard Model is only an effective theory from which a more general theory could be constructed. It is then important to test the validity of the model, for example, by measuring the coupling of the Higgs boson to various particles, either through the associated production of the Higgs boson with these particles or through the decays of the Higgs boson.

Q: What's so special about the particular decay pathway described in today's announcement?

Generally speaking, particles in the Standard Model fall into two categories: bosons and fermions. The Higgs boson was discovered through its decays into other bosons. While these decays have a clean signature inside the CMS detector, they represent only a small fraction of Higgs boson decays. In the Standard Model, the Higgs boson can also couple to fermions (leptons and quarks), with a coupling strength proportional to the fermion mass.

The rate of Higgs decays to fermions is related to the coupling strength squared, and the study of these decays is the focus of our research. Although the decay of the Higgs boson to two bottom quarks (H→bb for short) is actually the most frequent one of all possible Higgs decays — accounting for about 60 percent of Higgs decays — it has been a real experimental challenge to observe it. This is because there is an overwhelmingly large number of other Standard Model processes, which we refer to as background, that can mimic the experimental signature characterized by the appearance of a bottom and an anti-bottom quark. The observation announced today, based on the study of 2017 data together with previous years, is therefore both an impressive technical success and a confirmation of the validity of the Standard Model.

Q: Can you describe what kind of work goes into making a discovery like this?

Such a discovery involves the work of a collaborative team, and a lot of actors deserve credit. First, the accelerator needs to provide collisions at a rate that allows us to study rare processes. The LHC accelerator performance exceeded expectations and provided the experiments the large data sets needed to perform an ambitious physics program.

The next step is the operation of the detector, which images the proton-proton collisions. Based on the information recorded by the detector, the particles are identified and their momentum and energy are measured. The imaging of the bottom and anti-bottom quarks from the decays of the Higgs boson produced in the collision relies in particular on the precision of the tracker, the central part of the detector, which is used to reconstruct the trajectories of charged particles in the magnetic field and the hadron calorimeter, which records the energy of the particles. The Brown University group is involved in the operations of both the tracker and the hadron calorimeter.

Finally, analysis teams use the events reconstructed following the above steps and try to isolate the small signals from the physics process of interest — in our case H→bb — from the billions of background events. Many of the techniques used to identify the particles and extract the small signal rely on innovative algorithms, for example, deep machine learning methods.

Q: What was the biggest challenge the research team had to overcome?

The main challenge of the H→bb analysis was to overcome the overwhelming background and extract the signal from the many events that have a similar signature. One way to proceed is to use the associated production of the Higgs boson with a vector boson, which leaves a clean signature in the detector. Beyond the ability to reconstruct this boson, the main ingredient of the analysis is the identification of the jets of particles originating from the decay of the b-quarks produced in the Higgs boson decays — the so-called b-jets. Since we do not identify the charge of the b-quarks, we do not distinguish between b-quark and anti-bquark from the Higgs boson and generically label them both as b-jets.

Q: What, specifically, was your role in the research?

I worked on the identification and calibration of the b-quarks. Once we identify two b-jets produced in the collision, the next step is to establish that they are from the decay of the Higgs boson, as opposed to other particles such as Z boson decays, or top quark pair production or directly produced in proton-proton collisions. There could be also be more than two b-jets in the event due to other sources. I worked on optimization of the algorithm to associate b-jets to Higgs boson candidates, defining the selection of the base set of events for this study.

The b-quarks are identified through their physical properties — large mass, characteristic lifetime —translated to physical observables. New techniques have been developed recently in order to identify b-jets inside the CMS detector using deep neural networks. Professor Narain has led the decade-long involvement of Brown University in the CMS heavy flavor identification group and the study of the performance of such algorithms. In addition to my contributions towards heavy flavor (b and c-quark) identification, graduate students Rizki Syarif and Mary Hadley (Narain group), and Eric Scotti and Jangbae Lee (Heintz group) have been working on various aspects of b-jet studies. Martin Kwok and David Yu (Landsberg group) contributed to a previous search using a different production mode that was included in the final result.

Q: Where does the work go from here? What's the next big question you'll be working on?

To date, the Higgs boson couplings that have been measured are to third generation fermions (tau lepton, top and b-quarks). The next step is to study the coupling of the Higgs boson to c-quarks second generation fermions, which are lighter in mass and have shorter lifetimes than the b-quarks. Together with Brown graduate student Jangbae Lee, we are collaborating with RWTH Aachen in Germany in setting up the analysis for a first CMS measurement of the coupling of the Higgs boson to c-quarks. The much shorter lifetime of the c-quarks compared to the b-quarks makes their identification in the detector more complicated, as much higher precision is needed to measure their short flight from the point where they are produced.

While this study is technically more challenging than studying the coupling of the Higgs to b-quarks, the observation announced today shows what can be achieved with the current state-of-the-art techniques and give us hope that meaningful results are within our reach. We will greatly benefit from the experience acquired working on the H→bb analysis.

In parallel, the study of the coupling of the Higgs boson to b-quarks will continue, in order to provide measurements with better precision and to probe possible deviations from the Standard Model. The continuing work by the Brown team will benefit the H→bb analysis by improving the handling of b- and c-jet identification and by probing a challenging signature closely related to the H→bb signature.

—KEVIN STACEY

James Valles Jr.

Repelling charges prevent Cooper pairs from 'island hopping' in insulating state

Superconductors are able to conduct electricity with zero resistance thanks to Cooper pairs, electron duos that team up and skate through a material unimpeded. In 2007, Brown University researchers made the surprising discovery that Cooper pairs can also exist in insulating materials, helping to block the flow of current rather than enabling it. Now that same lab group has revealed the forces involved in these "Cooper pair insulators."

In a paper published in Physical Review Letters, the researchers show that in the insulating phase, Cooper pairs are held in check by the repulsive interactions between the pairs themselves, not by any disorder in the atomic lattice of the material. That insight could be important in designing materials or devices that take advantage of the superconducting-insulating transition - a superconducting switch, for example.

"Essential to electronics is manipulating how electrons flow, so finding new ways in which electrons flow leads to new manipulation methods for implementation in novel devices," said Jim Valles, a professor of physics at Brown and senior author on the paper. "This work gives us new information about Cooper pair propagation, which could be helpful in manipulating them in new devices." In their 2007 paper, Valles and his colleagues performed experiments on thin films made from amorphous bismuth. Thick blocks of amorphous bismuth act as superconductors, but when pared down into slices just a few atoms thick, the material becomes an insulator.

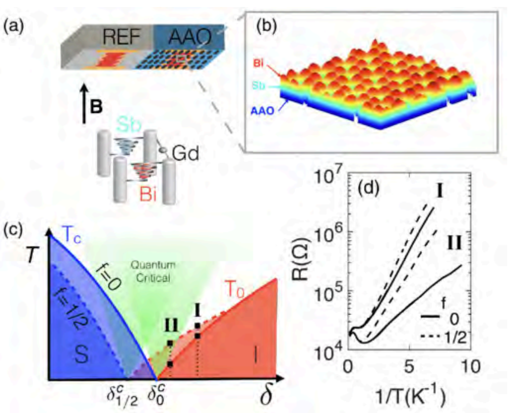
The initial research by Valles and his colleagues showed that Cooper pairs (which are named for Brown physicist Leon Cooper, who won a Nobel prize for describing their dynamics) were present in these films. But instead of moving freely as they do in the superconducting state, the Cooper pairs in the films became marooned on tiny islands within the material, unable to hop to the next island. It wasn't clear, however, what forces were holding the pairs in place. That's what Valles and his colleagues hoped to find with this new study.

One possibility for what holds the Cooper pairs in place is their charge. Each pair has a strong negative charge, and particles with the same charge repel each other. It could be that a Cooper pair has a hard time hopping to the next island because that island is already occupied by another Cooper pair that's pushing back. This creates a charge-related traffic jam that prevents a current from moving across the material.

Valles and his colleagues aimed to test that scenario. For the study, they sprinkled gadolinium atoms into the atomic structure of their bismuth insulators. Gadolinium is magnetic, and magnetism weakens Cooper pair coupling — potentially causing them to break apart into individual electrons. If a few Cooper pairs broke apart even for an instant, it could free up some island space and give intact pairs room to hop. So if more pairs start hopping as more gadolinium is added, it would be clear signal that resistance in these material is driven by this charge-related traffic jam. And that's exactly what the experiments showed.

"It's this combination of those little islands in the films and the barriers between those islands created by the repulsive interaction of the Cooper pairs that gives rise to this resistance," Valles said.

This is the first time anyone has been able to rule out other factors that may contribute to resistance. One other possibility was a phenomenon known as Anderson localization, which has to do with disorder in the structure of a material. Anderson effects may be important at temperatures near absolute zero, where they contribute to an even more exotic state known as superinsulation, in which resistance becomes



infinite. But at relatively higher temperatures, this study shows that it's the charge that's important. And that could have implications for the design of new electronic devices — perhaps superconducting switches for logic gates.

"It's possible we could get a low-temperature switch out of this," Valles said. "Or if we could get this behavior out of a high-temperature superconductor, we might get a higher-temperature version, which might have even more practical use."

Valles's co-authors on the paper are Xue Zhang, James C. Joy, Chunshu Wu, Jin Ho Kim and J. M. Xu. The work was supported by the National Science Foundation (DMR-1307290, DMR-1408743) and the Air Force Office of Scientific Research.

—KEVIN STACEY

Massive new dark matter detector gets its 'eyes'

The LUX-ZEPLIN (LZ) dark matter detector, which will soon start its search for the elusive particles thought to account for a majority of matter in the universe, had the first of its "eyes" delivered late last week.

The first of two large arrays of photomultiplier tubes (PMTs) — powerful light sensors that can detect the faintest of flashes arrived last Thursday at the Sanford Underground Research Facility (SURF) in Lead, South Dakota, where LZ is scheduled to begin its dark matter search in 2020. The second array will arrive in January. When the detector is completed and switched on, the PMT arrays will keep careful watch on LZ's 10-ton tank of liquid xenon, looking for the telltale twin flashes of light produced if a dark matter particle bumps into a xenon atom inside the tank.

The two arrays, each about 5 feet in diameter and holding a total of 494 PMTs, were shipped to South Dakota via truck from Providence, Rhode Island, where a team of researchers and technicians from Brown University spent the past six months painstakingly assembling them.

"The delivery of these arrays is the pinnacle of an enormous assembly effort that we've executed here in our cleanroom at the Brown Department of Physics," said Rick Gaitskell, a professor of physics at Brown University who oversaw the construction of the arrays. "For the last two years, we've been making sure that every piece that's going into the devices is working as expected. Only by doing that can we be confident that everything will perform the way we want when the detector is switched on."

The Brown team has worked with researchers and engineers from the U.S. Department of Energy's Lawrence Berkeley National Laboratory (Berkeley Lab) and from Imperial College London to design, procure, test, and assemble all of the components of the array. Testing of the PMTs, which are manufactured by the Hamamatsu Corporation in Japan, was performed at Brown and at Imperial College.

"The PMTs have already qualified for significant air miles, even before they started their 2,000-mile journey by road from Rhode Island to South Dakota," Gaitskell said.

Catching a WIMP

Nobody knows exactly what dark matter is. Scientists can see the effects of its gravity in the rotation of galaxies and in the way light bends as it travels across the universe, but no one has directly detected a dark matter particle. The leading theoretical candidate for a dark matter particle is the WIMP, or weakly interacting massive particle. WIMPs can't be seen because they don't absorb, emit or reflect light. And they interact with normal matter only on very rare occasions, which is why they're so hard to detect even when millions of them may be traveling through the Earth and everything on it each second.

The LZ experiment, a collaboration of more than 250 scientists worldwide, aims to capture one of those fleetingly rare WIMP interactions, and thereby characterize the particles thought to make up more than 80 percent of the matter in the universe. The detector will be the most sensitive ever built, 50 times more sensitive than the LUX detector, which wrapped up its dark matter search at SURF in 2016.

The PMT arrays are a critical part of the experiment. Each PMT is a six-inch-long cylinder that is roughly the diameter of a soda can. To form arrays large enough to monitor the entire LZ xenon target, hundreds of PMTs are assembled together within a circular titanium matrix. The array that will sit on top of the xenon target has 253 PMTs, while the lower array has 241.

PMTs are designed to amplify weak light signals. When individual photons (particles of light) enter a PMT, they strike a photocathode. If the photon has sufficient energy, it causes the photocathode to eject one or more electrons. Those electrons strike then an electrode, which ejects more electrons. By cascading through a series of electrodes the original signal is amplified by over a factor of a million to create a detectable signal. LZ's PMT arrays will need every bit of that sensitivity to catch the flashes associated with a WIMP interaction.

"We could be looking for events emitting as few as 20 photons in a huge tank containing 10 tons of xenon, which is something that the human visual system wouldn't be able to do," Gaitskell said. "But it's something these arrays can do, and we'll need them to do it in order to see the signal from rare particle events."

The photons are produced by what's known as a nuclear recoil event, which produces two distinct flashes. The first comes at the moment a WIMP bumps into a xenon nucleus. The second, which comes a few hundred microseconds afterward, is produced by the ricochet of the xenon atom that was struck. It bounces into the atoms surrounding it, which knocks a few electrons free. The electrons are then drifted by an electric field to the top of the tank, *Richard Gaitskell*

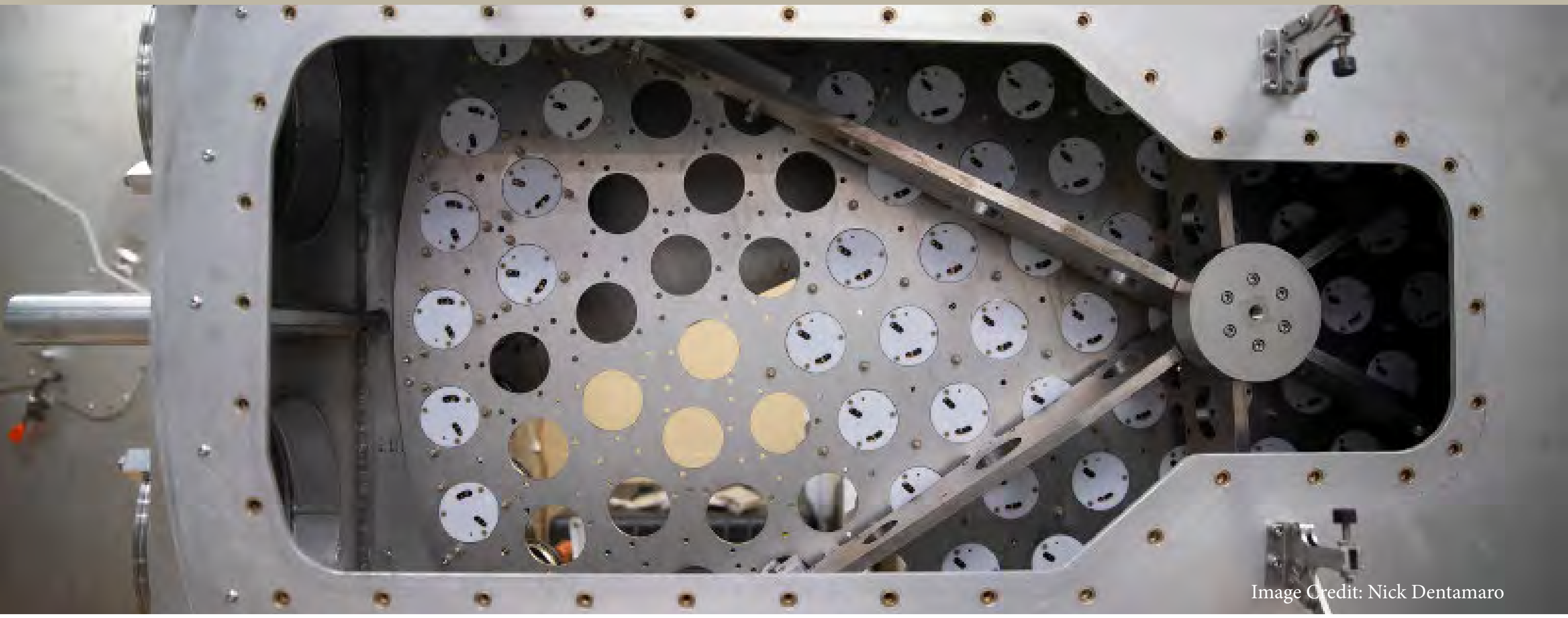


Image Credit: Nick Dentamaro

where they reach a thin layer of xenon gas that converts them into light.

In order for those tiny flashes to be distinguishable from unwanted background events, the detector needs to be protected from cosmic rays and other kinds of radiation, which also cause liquid xenon to light up. That's why the experiment takes place underground at SURF, a former gold mine, where the detector will be shielded by about a mile of rock to limit interference.

A clean start

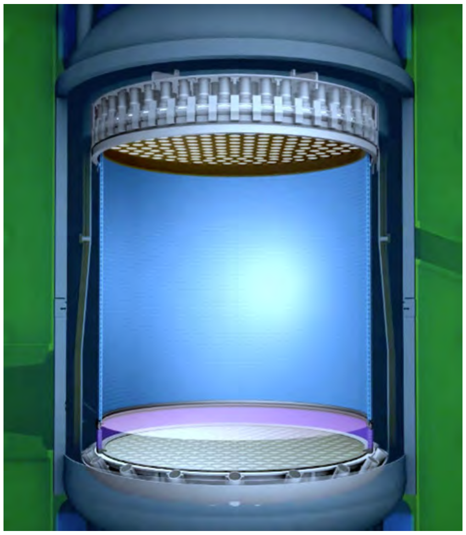
The need to limit interference is also the reason that the Brown University team was obsessed with cleanliness while they assembled the arrays. The team's main enemy was plain old dust.

"When you're dealing with an instrument that's as sensitive as LZ, suddenly things you wouldn't normally care about become very serious," said Casey Rhyne, a Brown graduate student who had a leading role in building the arrays. "One of the biggest challenges we had to confront was minimizing ambient dust levels during assembly."

Each dust particle carries a minuscule amount of radioactive uranium and thorium decay products. The radiation is vanishingly small and poses no threat to people, but too many of those specks inside the LZ detector could be enough to interfere with a WIMP signal.

In fact, the dust budget for the LZ experiment calls for no more than one gram of dust in the entire 10-ton instrument. Because of all their nooks and crannies, the PMT arrays could be significant dust contributors if pains were not taken to keep them clean throughout construction.

The Brown team performed most of its work in a "class 1,000" cleanroom, which allows no more than 1,000 microscopic



dust particles per cubic foot of space. And within that cleanroom was an even more pristine space that the team dubbed "PALACE" (PMT Array Lifting And Commissioning Enclosure). PALACE was essentially an ultraclean exoskeleton where much of the actual array assembly took place. PALACE was a "class 10" space — no more than 10 dust particles bigger than one hundredth the width of a human hair per cubic foot.

But the radiation concerns didn't stop at dust. Before assembly of the arrays began, the team prescreened every part of every PMT tube to assess radiation levels.

"We had Hamamatsu send us all of the materials that they were going to use for the PMT construction, and we put them in an underground germanium detector," said Samuel Chan, a graduate student and PMT system team leader. "This detector is very good at detecting the radiation that the construction materials are emitting. If the intrinsic radiation levels were low enough in these materials, then we told Hamamatsu to go ahead and use them in the manufacture of these PMTs."

The team is hopeful that all the work contributed over the past six months will pay dividends when LZ starts its WIMP search.

"Getting everything right now will have a huge impact less than two years from now when we switch on the completed detector and we're taking data," Gaitskell said. "We'll be able to see directly from that data how good of a job we and other people have done."

Given the major increase in dark matter search sensitivity that the LUX-ZEPLIN detector can deliver compared to previous experiments, the team hopes that this detector will finally identify and characterize the vast sea of stuff that surrounds us all. So far, the dark stuff has remained maddeningly elusive.

-KEVIN STACY

PHILIP J. BRAY AWARD FOR EXCELLENCE IN TEACHING IN THE PHYSICAL SCIENCES

Professor of Physics, James Valles Jr., was awarded the 2019 Philip J. Bray Award for Excellence in Teaching in the Physical Sciences. The Faculty Teaching Excellence Awards recognize Brown faculty members for sustained and continued excellence in teaching. The award is named for past faculty members recognized for their teaching achievements.

Professor Valles is an experimental condensed matter physicist. He studies superconductivity and electron correlation effects in disordered metals and nanostructures. He also investigates the effects of strong magnetic fields in cell biology and bio-polymerization.

HENRY MERRITT WRISTON FELLOWSHIP

Assistant Professor of Physics, Jonathan Pober, has received the Henry Merritt Wriston Fellowship for 2019.

The committee received a significant number of strong applications this year and Professor Pober stood out not only for his innovative teaching, but also the range and originality of his scholarly accomplishments to date. The annual Wriston competition is one way the University recognizes young faculty who are fulfilling Brown's dual mission of excellence in both teaching and research.

Professor Pober is an experimental astrophysicist. His research focuses on the history of the universe through observations of neutral hydrogen on cosmic scales. He develops ultrasensitive radio telescopes for his astronomical observation.

EXCELLENCE IN RESEARCH MENTORING AWARD

Professor of Physics, Ian Dell'Antonio, was presented with the Excellence in Research Mentoring Award.

The Excellence in Research Mentoring (ERM) Award recognizes faculty members for their excellence in mentoring undergraduate researchers, as well as for their promotion, encouragement and training of diverse students in undergraduate research.

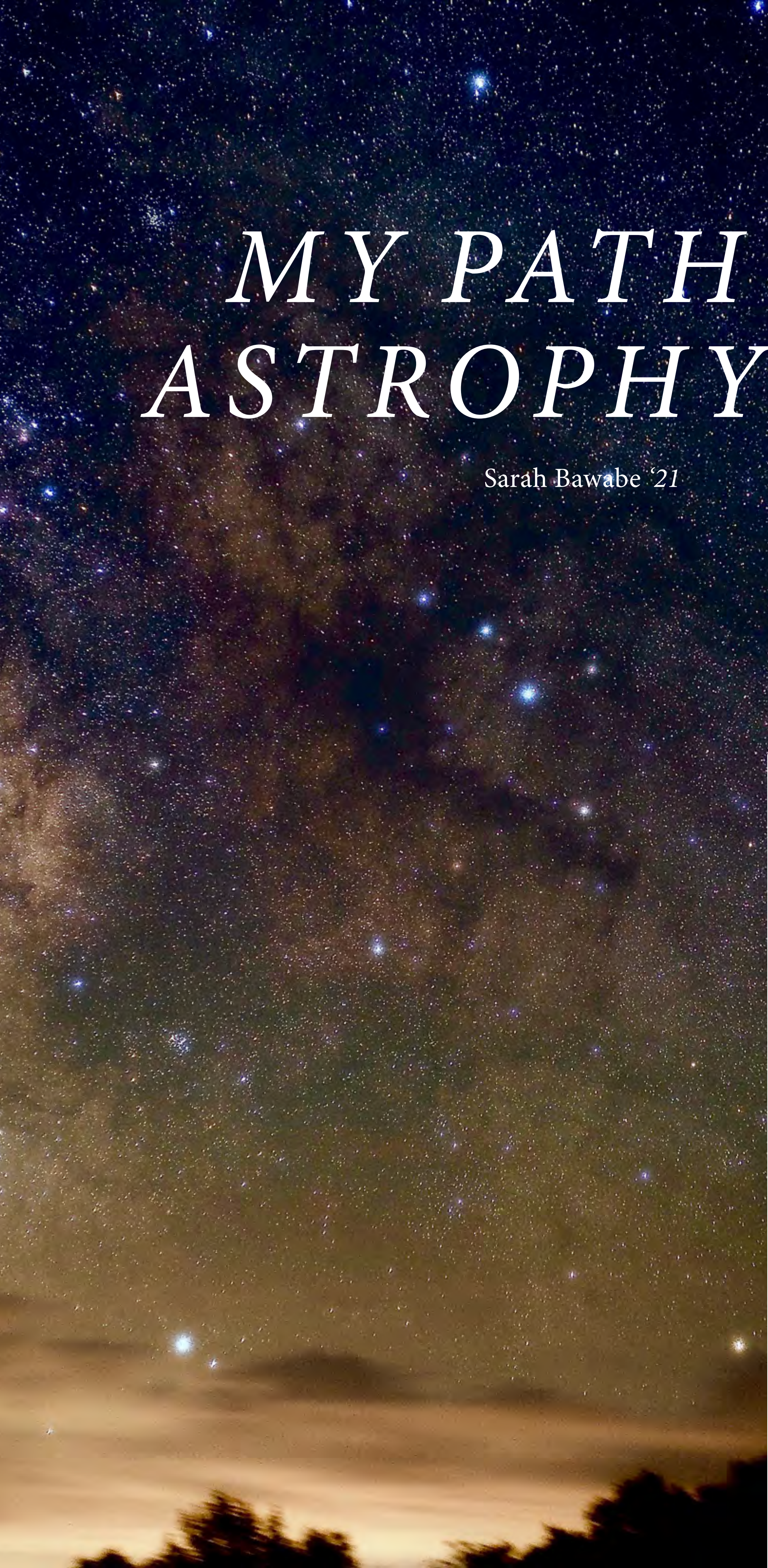
Professor Dell'Antonio's research centers on observational cosmology, the experimental measurement of the fundamental properties of the universe.

MARCUS SPRADLIN NAMED APS FELLOW

Marcus Spradlin, has been named a Fellow of the American Physical Society (APS).

Professor Spradlin's nomination came from the Division of Particles and Fields for contributions to the understanding of the mathematical structure of quantum field theory, in particular supersymmetric gauge theory.

Professor Spradlin is a theoretical high-energy physicist, working on string theory, quantum gravity, and mathematical aspects of quantum field theory.



MY PATH TO ASTROPHYSICS

Sarah Bawabe *'21*

One day, when I was about seven years old, my Dad came home with a telescope. His work would often reward employees with little gifts, and out of a catalogue of items, my dad chose a telescope—my mom rolled her eyes as he walked through the door with it. However, I was intrigued.

I grew up in a tiny town in Massachusetts, where you could see some stars on a clear night, but the light pollution from Boston unfortunately maintained a constant degree of separation from the full night sky. So, we brought the telescope up to our ski condo in Vermont—a place far away from the city lights. The sky up there was impossibly clear: almost every star and every constellation was visible, the Milky Way would proudly span the sky, and picking out the Big Dipper became as simple as picking out an apple from a bunch of oranges. On the coldest of nights, when it was too cold for clouds and nearly too cold to be outside, we would bundle up in our thickest jackets and coziest scarves and bring out the telescope to look at the Moon. I would watch as my Dad lined up the telescope, while my brother and I eagerly awaited our turns to look through.

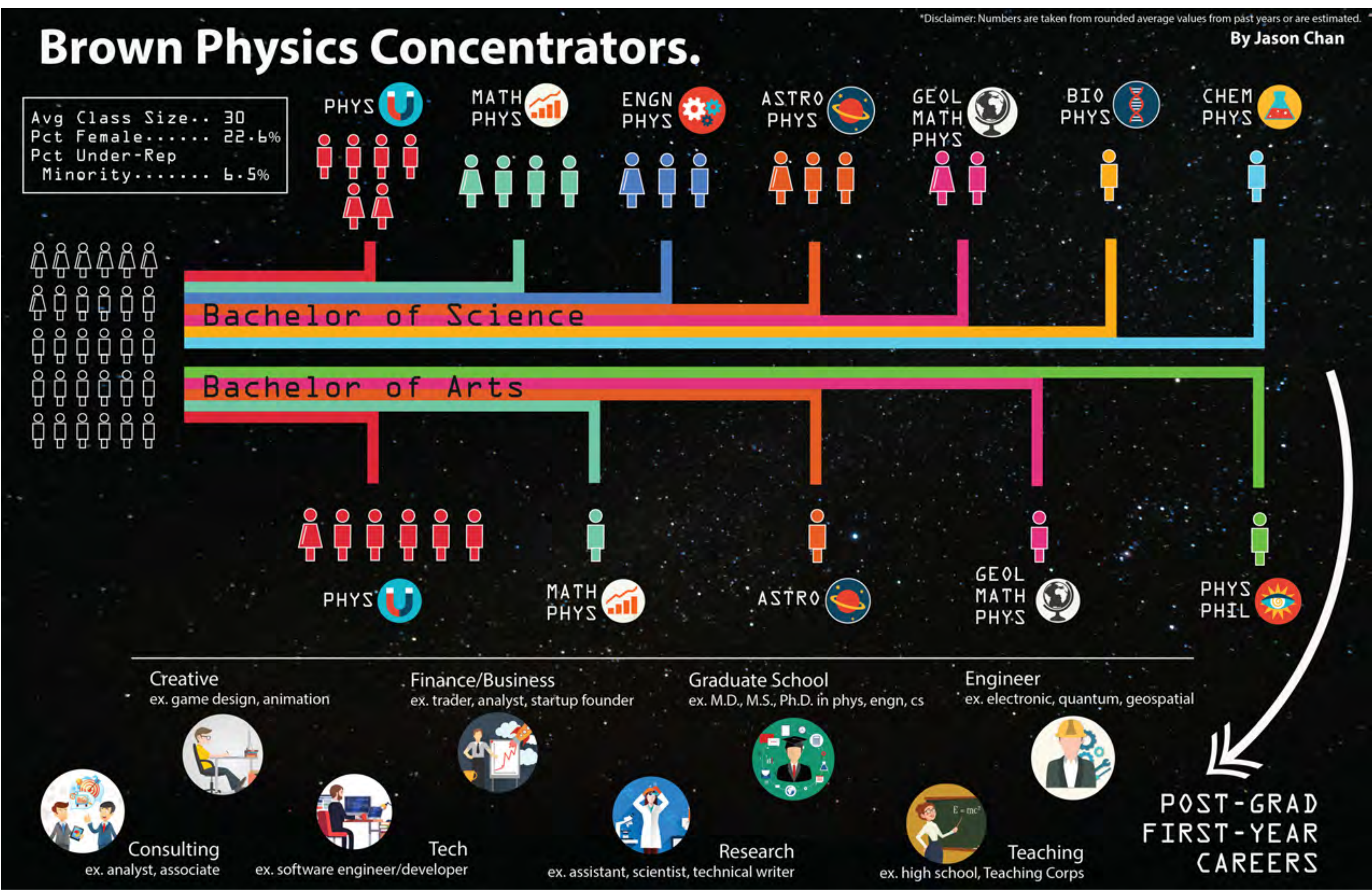
My parents told us stories about how astronauts walked on the Moon for the first time when they were kids—about Neil Armstrong taking "one small step for a man, one giant leap for mankind", about the Space Race, and about the American flag they planted there on the Moon. For a long time, I was convinced I could see that flag from our tiny little telescope (it was actually just a crater I was seeing, but my parents let me believe). It was then that I decided I wanted to be an astronaut.

A few years later, I realized how dangerous it is to go into space, how terrible my ears are on airplanes, and how unenjoyable some rollercoasters can be. If going into space was like riding on a long and very intense rollercoaster while the elevation steadily climbed, count me out. I decided then that I instead wanted to be the one helping these astronauts go into space. (But secretly, I'm not sure how I'd respond if NASA came knocking on my door looking for an astronaut.)

Many say that childhood dreams are just that—silly childhood fantasies, but I would argue that without my youthful curiosities I wouldn't be here today at Brown studying Astrophysics. That little telescope, this kid's book called Big! which revealed how the largest diamond in the world is actually a star fifty-two lightyears away named Lucy, my little NASA tee shirt that I got in Florida one time, the boys on the middle school Math Team talking about some mysterious "Stephen Hawking" while I sat there unaware of how much that man would one day inspire me—all of these seemingly small intricacies in my childhood together wove a lifelong love for space and of course, physics.

So now as I sit here writing to you, a soon-to-be junior in college who is still pursuing her childhood dream, I am thankful that I embraced my childhood curiosities and, of course, I am thankful that, from a catalogue of items, my Dad chose the telescope.

Sarah Bawabe is a student in Brown University's Class of 2021 who is currently studying Astrophysics. She plans to work alongside Brown University Professor Stephon Alexander this summer as he continues his research in theoretical cosmology. She hopes to attend grad school after graduation in order to help her pursue her dream of one day becoming either a professor or an astrophysicist.



Stephon Alexander Elected President of National Society of Black Physicists

Brown University physics professor Stephon Alexander has been elected president of the National Society of Black Physicists (NSBP), the nation's pre-eminent organization devoted to the African American physics community. His term begins this month.

Alexander joined NSBP 28 years ago as a first-year undergraduate student at Haverford College, where he was the only black physics student at the time. He says that through NSBP, he met countless people who would become his mentors and collaborators, including S. James Gates Jr., now also a professor at Brown.

"NSBP provided a community of scientists that shared similar experiences and a passion for physics, so I didn't feel as alone in my quest to become a physicist," Alexander said. "I never would have dreamt when I joined that I would one day have the opportunity to give back to NSBP serving as its president."

Formed in 1977, the organization works to bolster opportunities for African Americans in physics, as well as increasing their representation. NSBP also develops activities and programs that highlight the scientific contributions that African American physicists provide for the international community.

Alexander says he hopes to expand NSBP's visibility by working to add chapters in the U.S. and abroad. He also hopes to engage younger members to identify career and education challenges they face, and then engage senior members to help address those challenges through mentorship or other means.

Another area of emphasis will be encouraging non-traditional career paths for physicists. "Physicists have always been good at interfacing with other disciplines, whether it's in data science, technology or even the arts," Alexander said. "I want NSBP to explore those interfaces and hopefully expand opportunities for our younger members."

Alexander, who earned his Ph.D. in physics from Brown in 2000, joined the faculty in 2016. His research work focuses on the interface between cosmology and particle physics. In 2001, drawing on key concepts of string theory, he helped to develop a new model that may explain the accelerating expansion of the universe, known as cosmic inflation.

He is also an accomplished jazz musician and wrote a widely lauded book called "The Jazz of Physics," which explores surprising connections between theoretical physics and musical improvisation. Last year, he served as science advisor to Ava DuVernay's film adaptation of the children's classic "A Wrinkle in Time."

Alexander is also co-director of Brown's Presidential Scholars Program, which recruits, supports and provides research opportunities for students from economically and demographically diverse groups.

"The goals of NSBP reflect in some ways the things we're trying to do here at Brown to increase diversity and inclusion in STEM fields and elsewhere," Alexander said. "That makes me particularly proud as a Brounonian to take on this position."

—KEVIN STACEY

Physics DUG

It is the goal of the Physics DUG to build and foster an academic and social community among physics undergraduates that is inclusive, collaborative, and supportive. We consider this particularly important in the context of studies that show that such environments mitigate the exclusion of individuals from historically underrepresented groups in physics, allowing for more diverse perspectives to be represented in the field.

Events the DUG has held include:
High Energy Chocolate
Bad Physics Movie Night
Physics Book Club
Offish Hours
Barriers in Physics -- held jointly withWiSE (Women in Science and Engineering)
Concentration Declaration Celebration

Finally, we have also recently opened a Physics DUG Library, where common physics/maths textbooks are placed in Barus & Holley for students to use. This initiative aims to mitigate the high costs of textbooks for all students, particularly low-income students that may find the purchases difficult to manage. We have also recently joined the national Society of Physics Students and will be the local hosts for its Physics Congress 2019, held in Providence. DUG members also actively attend concentration fairs and A Day on College Hill to represent the department to both current and prospective students. Physics DUG hopes that its efforts will culminate in an increasingly welcoming and inclusive environment for all those who are interested in the field of physics.

-Jungho Daniel Choi '20,
Physics DUG Coordinator


UNDERGRADUATE SUMMER RESEARCH

During the summer months students participate in various research opportunities. These opportunities are made possible through the UTRA program, research grants, the SURE exchange program, the Cantabria exchange program and the Summer Student Theoretical Physics Research Session (SSTPRS) hosted by Prof. Jim Gates. Students come from across the US and around the world to participate in research study.

2019 UNDERGRADUATE TEACHING AND RESEARCH AWARDS (UTRA)

Deven Carmichael, Lexie Ekstrom, Kaushik Srinivasan Harith, Claire Hawkins, Alex Jacoby, Shubham Makharia, Jacob Migneault, Shray Mishra, Natalie Rugg, Jasper Solt, Willem Speckmann, Adam Tropper, Justin Voelker, Angela White

Undergraduate Teaching Assistant Program (UTA)

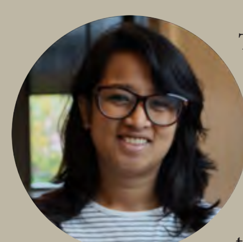
In 2018-2019, the physics department began recruiting undergraduate TAs to assist with problem solving sessions and drop-in hours. This is a program we plan on expanding to cover the majority of the core concentration classes in order to give students extra support for learning the material and a more informal support structure. In addition, having undergraduate TAs allows students to be more connected to the department community. We began the program with TAs for PHYS0070 and PHYS0470. The previous year's instructors were asked to identify students who had taken the class and would be good candidates for the position. We contacted all the candidates, and the current instructor then selected the TAs from the candidates. Reactions from the students, faculty, and the undergraduate TAs themselves has been very positive.

In 2019-2020, we will expand the program, aiming to provide undergraduate TAs for PHYS0050, PHYS0070, PHYS0470, and PHYS1410 in the fall, and PHYS0060, PHYS0160, PHYS0500 and possibly PHYS0560 in the spring. As resources allow, our hope is to see the undergraduate TA program expand even more in future years.

-Prof. Ian Dell'antonio

I really enjoyed being an undergraduate TA for PHYS 0470, Electricity and Magnetism. When I took the class the fall of my sophomore year, I remember really enjoying it, but definitely struggling along the way with some new and difficult material. I hope the students last year felt more comfortable taking the course knowing that they had the undergraduate TAs to support them. It can be intimidating to go to a professor for help, but the undergraduate TAs are fellow students who have experienced the course's challenges firsthand, which I think made us more approachable. As a TA, I really hope I was able to alleviate some of the confusion and frustration that I knew many students would feel taking the course so they could enjoy learning some incredible physics.

-Ellen Royal '20



The students were not only very enthusiastic and willing to learn but also very understanding when we made mistakes. This also helped me learn to accept that being a teaching assistant does not mean that you are always required to have all the answers. It gave me an opportunity to learn from my mistakes; it helped me be confident enough to own up to my shortcomings and work on them. Also, as undergraduate TAs, I believe that we were more relatable to the students and so they looked up to us. Thus, it gave me a chance to serve as a mentor to confused incoming first year students and possibly inspire a few of them. All in all, it was one of the best experiences I had in my sophomore year and if I had the chance, I would do it all over again!

-Shweta Majumder '21

The BIG BANG SCIENCE FAIR

Image Credit: Mike Cohea

On Saturday, September 22, the Big Bang Science Fair at WaterFire Providence brought many activities at the intersections between science and the arts to our community.

The idea, conceived by Brown Physics Professor, Meenakshi Narain, was to promote the role of science in society. Her vision for the event was to "broaden the public perspective of science in our world, highlight the diversity of scientific research, and encourage individuals to creatively engage in STEM fields." For one exciting day, scientists teamed up with musicians, programmers, artists, and chefs to explore the wonders of science.

Professor Narain organized a large team of volunteers from Brown and other institutions around the world. The event was co-organized by Professor Carlos Aizenman (Brown Brain/Neuroscience), Dr. Gelonia Dent (Director, Brown Science Center), Professors Ian Dell'Antonio (Brown Physics), Jim Gates (Brown Physics), and

Ulrich Heintz (Brown Physics), Connie Potter (CERN, Switzerland), and Geoffrey Gunter (Citizens Bank). Mary Ann Rotondo, Geeta Chougule, and Jessica Pontarelli (Brown University) provided essential organizational support to make the event possible. Over 170 graduate and undergraduate students from participating institutions and high-school students from local schools volunteered to motivate the audience.

The role of science in our daily lives was highlighted by stellar presentations from Professor Karla Kaun (Brown Neuroscience) on "How Drugs rewire your Brain" and Professor Jim Gates on "Understanding our Universe?," together with an interesting line-up of topics like "Find your way without using GPS," "Making Music from Real-Time Scientific Data," and "Science-fiction soundtracks & Espionage: The Theremin's Odyssey." Micky Dolenz (from the legendary band The Monkees) shared his enthusiasm about science with the public.

A Jazz performance by Professor Stephon Alexander (and the GOD PARTICLE band) capped the event.

Interactive workshops at THE LAB in Market Square engaged participants in designing their own games, talking to the BB-8 droid, defeating zombies, playing the Theremin musical instrument without touching it, and building cloud chambers to "see the cosmic rain." Throughout the evening, kids and adults alike were engaged in hands-on activities melding art and science in the Market Square. They explored concepts in neuroscience, computer science, physics, chemistry, the science of cooking and made their own gadgets through interactive exhibits. Astronomers captivated the public via a large number of telescopes lined up along the river. The audience was enthralled by the opportunity to snap selfies in the "tunnel" of the Large Hadron Collider and the artwork depicting the CMS detector at CERN, Switzerland.

The Brown University team was joined by colleagues from the CERN lab in Switzerland, the University of Durham, URI, Bryant University, UMass Amherst, RIMOSA, RIVR, and many individuals from the Providence community. The event was sponsored by the Office of the President, Provost, and many units within Brown University. Support was also provided by Citizens Bank and CS4RI.

-MEENAKSHI NARAIN

The Brown Theoretical Physics Center

As the fall welcomes the class of 2023, the Physics Department will welcome the opening of the "Brown Theoretical Physics Center" (BTPC) in the renovated Barus Building and expand the physical environment of the department by 2,100 square feet of space for offices, a presentation area, and a departmental "commons" where it is hoped all members of the physics community will see as their home.

Specifically the BTPC was created to nucleate faculty research teams bridging various areas of prominence in subfields of theoretical physics present already within the Physics Department, as well as cross departmental boundaries with other science, mathematics, and engineering departments. To fulfill this mission, BTPC has to function in two modes.

The Physics Department already has a strong national and international presence in three sub-disciplines of physics: Astrophysics-Cosmological Theory (ACT), Condensed Matter Theory (CMT), and High Energy Theory (HET). BTPC plans to coordinate in ways that amplify the activities and accomplishments within these three research directions. However, a second motive for the creation of the BTPC is to create a space for innovation between these three research directions.

The primary lever for doing the first is by providing dedicated physics department spaces within which the fine work of the ACT, CMT, and HET groups can interact and invite presentations by off campus experts. This may be in the forms of single special focus colloquia, seminar presentations, workshop conference hosting, or medium to long-term visitor space.

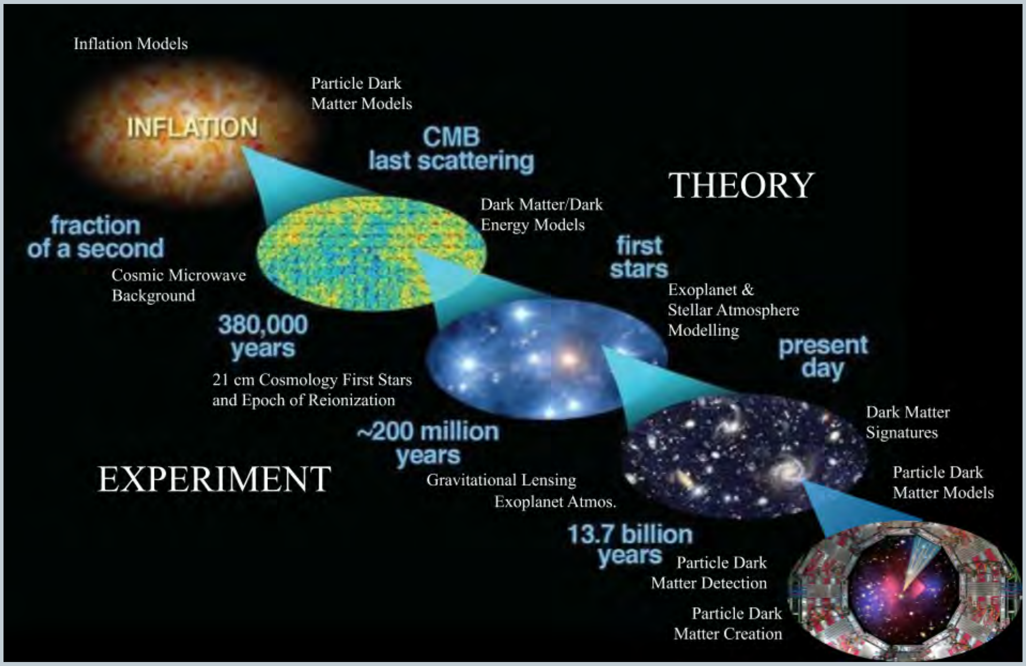
The primary lever of the second mode of BTPC activity will be the creation of a core of young researchers who will join the department and act as "new connective tissue" between the three pillars of strength and catalyze interactions that cut across traditional boundaries of the ACT, CMT, and HET campus activities.

An important departmental asset to be deployed will be the new Barus Hall which will be home to the BTPC. The renovation was planned to create an "innovation space" following models of best practice from around the country. The commons area aspires to become the physics department "community home." Approximately, forty percent of the departmental theorists are expected to move from current locations in Barus & Holley drawing membership from each of the current ACT, CMT, and HET groups. Placing this assortment of researchers in close proximity to one another is likely to stimulate discussions across existing boundaries within the sub-disciplines and open new avenues for collaboration. The BTPC also has a commitment to bring in colleagues from other departments across campus to create an even stronger climate of interdisciplinary and cross-disciplinary research.

-S. James Gates,
Director

The Center for the Fundamental Physics of the Universe

The new Center for the Fundamental Physics of the Universe (CFPU) at Brown brings together researchers engaged in experimental and theoretical work aimed at answering some of the major fundamental questions about the physics of the Universe. The roster includes faculty from various sub-disciplines: four from Astrophysics and Cosmology Experimental work (Dell'Antonio, Gaitskell, Pober, Tucker), three pursuing Astrophysics and Cosmology Theory and Phenomenology (Alexander, Fan, Koushiappas) and four High Energy Experimentalists (Cutts, Heintz, Landsberg, Narain). We are also working in conjunction with Faculty from Condensed Matter research and also Planetary Sciences.



We have a strong group of theorists working on problems relevant to astroparticle cosmology. As illustrated in the figure the theoretical work spans new models from the very earliest times addressing the inflationary phase at the start of the universe, through models of dark matter and dark energy controlling the evolution of the universe as important features at multiple distance scales are forming, to models addressing the potential production of dark matter at present-day particle accelerators. One of our major goals is to identify and develop new cross-disciplinary techniques for future experimental searches to better understand the dark matter and dark energy. We are encouraging full exploitation of the breadth and depth of the expertise at Brown to develop new experimental techniques, as well as new interpretations of the implications of current experimental data.

The CFPU will also significantly aid recruitment of junior researchers by further raising the profile of our very successful Particle, Astrophysics and Cosmological research programs for the potential new graduate students and postdocs. We must ensure that young researchers share the excitement of the Center's wide range of interconnected physics activities – attracting the very best researchers is critical to our efforts. The CFPU is providing funding to kick-start new research ideas spanning multiple faculty. The CFPU can also fulfill an important role by acting to coordinate future applications for large-scale funding in block grants/science centers programs.

In our initial start-up we have already been able to provide support for conferences and meetings covering dark matter direct detection (IDM2018), particle detector instrumentation development (CPAD2018) and the Murchison Widefield Array 21-cm signal experiment. We have also supported a new dark matter search proposal in Axion physics that exploits quantum-sensitive NMR techniques developed in the condensed matter research (Mitrovic) at the department. We identified and obtained funding from DOE to exploit deep neural network/machine learning to analyze research results coming from groups in dark matter lensing, dark matter direct detection and high energy accelerator particle searches. The Center is also sponsoring machine learning workshops for undergraduates and researchers at the department to ensure that a wide appreciation of what the new techniques can be used for most effectively.

We will continue to explore new potential synergies between our areas of experimental research. Our research groups are developing and fabricating new detector technologies in related areas of advance photodetectors, low noise detectors, fast electronics and data acquisition systems. We face the challenge of handling large >PB data sets and use similar analysis techniques, so we are developing a plan to best support these efforts. The CFPU is already playing a critical role at the Physics department and we are very optimistic about exploiting future research opportunities that can be carried out at Brown with new resources.

-Richard Gaitskell,
Director

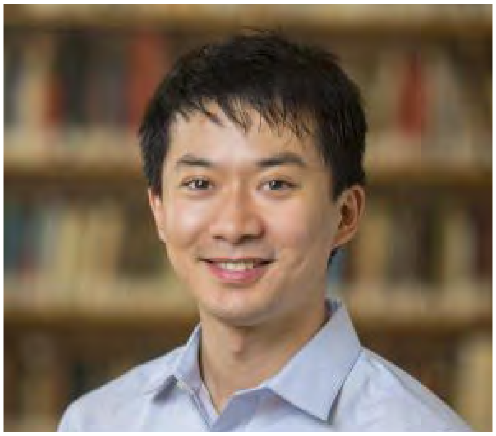
ANDREY GROMOV - ASSISTANT PROFESSOR

The Department of Physics welcomes Andrey Gromov to its Theoretical Condensed Matter Group. At Brown Gromov plans to address the question of why some quantum systems are easy to model, whereas others are not, using the language of quantum information and quantum complexity. According to Gromov, "it is possible that if we can quantify the complexity of a quantum many-body system in physics terms, we may get a better understanding of how to tackle difficult quantum problems."

Gromov was inspired to join the Brown Physics faculty in part because of its "long tradition of exceptional research in theoretical physics." Gromov cites former and current Brown researchers such as Lars Onsager, Leo Kadanoff, Leon Cooper, and Mike Kosterlitz as models for his own career. "One common theme in the careers of these researchers is the breadth of their interests and impact," says Gromov, "in my career I try to keep a broad perspective and utilize the ideas that originated in one branch of theoretical physics on seemingly unrelated problems."

Before joining Brown Physics, Gromov received his Ph.D. from Stony Brook University, followed by postdoctoral appointments at the University of Chicago and UC Berkeley. One of the factors that attracted Gromov to Brown Physics was, "the continued commitment of the Physics Department to foster interdisciplinary collaborations between theorists." He is particularly excited that his arrival coincides with the launch of the Brown Center for Theoretical physics. Gromov says Brown Physics "has an exceptionally vibrant and intellectually stimulating atmosphere that nurtures interaction between condensed matter theorists and experimentalists. I am particularly excited by the opportunity to collaborate with the two brilliant experimentalists that have just joined Brown Physics department, Leo Li and Kemp Plumb. We have had many stimulating discussions and crazy ideas, and I am really thrilled to have them as colleagues."

JIA (LEO) LI - ASSISTANT PROFESSOR



The Department of Physics welcomes Jia (Leo) Li, to its Experimental Condensed Matter Group. Li's lab uses the large family of 2D materials as building blocks to assemble designer structures consisting of various van der Waals materials in the 2D limit (one atomic layer) where novel quantum states of matter can be studied and engineered. According to Li, "these structures are assembled using a homemade transfer station, which allow us to manipulate each layer of material with x-y-z accuracy of about 1um (10^-5 of an inch)."

Li explains that "by assembling different 2D materials together, we create something that has completely different physical properties compared to the original materials. For example, putting two non-magnetic semiconductors together could result in a ferromagnetic material. It is not unlike building new materials." Further, "…these new materials produce novel quantum phases of matter at low temperatures, some of these quantum phases are key to the realization of a fault-tolerant quantum computer."

Before joining Brown's Department of Physics, Li received his Ph.D. from Northwestern University, followed by a postdoctoral appointment at Columbia University. Besides friendly colleagues, helpful staff members, and wonderful students, one of the things that attracted Li to Brown Physics was the successful interaction between experimentalists and theorists. "In the short amount of time I've been here, I've already benefited from conversation with my theoretical colleagues. Dima [Feldman] is an expert on physics in the quantum Hall effect regime, especially on heat transport behavior and non-Abelian physics. This happens to be the focus of my on-going research. I'm sure going forward, there will be more constructive conversations and brain-storming between us."

Why Stargaze?

"Let me list the reasons," an astronomer tells an inquiring young person.

by Francine Jackson

RECENTLY, A HIGH SCHOOL STUDENT emailed the Ladd Observatory asking why someone would want to become an amateur astronomer. Eventually, it reached my desk. In his note, he asked for at least two reasons. I gave him six.

1 First, just going outside and savoring the night. In addition to the beauty of the sky, you might hear many sounds of nature not present during the day, such as the chirp of crickets or the hoot of an owl declaring its territory. Also, for many the night air has a cleaner, fresher scent of its own.

2 Looking up, you are immediately gazing back in time. You're seeing planets and stars as they appeared from just a few minutes to possibly thousands of years ago.

3 The constellation patterns are part of our history and that of cultures around the world. Different peoples have connected the stars differently, and the myths they created about them and share with their children are closely aligned to their various societies.

4 The stars were also, for thousands of years, the only way people had for finding their way around the world. Long before GPS, any adventurers having to travel far from home — and return — had to depend upon their knowledge of the sky.

5 Today, for many people with high-pressure jobs, peering up and savoring the beauty of the night sky is an incredible way to unwind and let the troubles of the world slip away. A friend who is a retired international pilot emphasized this to me once. While still working, he'd be gone for several days at a time, and when he returned the first thing he'd do was pull his telescope out of the garage, set it up in his driveway, point it upward, and relax. The world and he himself were now at peace.

6 Finally, many people enjoy being part of the amateur astronomy community. Many of them have little basic knowledge of the subject but want to commune with others and learn about the stars. And sometimes amateur astronomers discover a new object or see something no one has previously recorded, thereby aiding in the advancement of the science and possibly even gaining fame for themselves.

The student did send me a thank-you note, but as yet he doesn't appear to have visited any of the neighborhood observatories. I do hope that in the future, when perhaps the pressures of school are behind him, he can come, observe, and be welcomed into the wondrous world of amateur astronomy.

FRANCINE JACKSON is the staff astronomer at Brown University's Ladd Observatory. A long-time member of Skyscrapers, Inc., Rhode Island's amateur astronomy association, she likes nothing more than to see young people become interested in amateur astronomy.

Article originally published by Sky and Telescope Magazine May 2019.

WORLD'S LEADING DARK MATTER PHYSICISTS CONVENE AT BROWN

More than 150 research physicists from across the world gathered at Brown to discuss the ongoing search for dark matter, the mysterious stuff thought to account for most of the matter in the universe.

The 2018 Identification of Dark Matter Conference (IDM2018) is an opportunity for scientists to review the latest data from dark matter searches, discuss the direction of future searches and share new theoretical ideas about the potential properties of dark matter particles. This is the 12th in a long-standing conference series, which originally started in 1996 in the U.K. and has since been held in Stockholm, Amsterdam, Chicago and elsewhere. This is the first time it's been held at Brown.

Brown physics professor Rick Gaitskell was chair of the organizing committee for the 2018 event.

Q: Could you give us a quick recap on what dark matter is and how we know it's out there?

Dark matter dominates the universe, accounting for over five-sixths of its mass. The protons, neutrons and electrons you and I are made of are merely the flotsam and jetsam on the ocean of dark matter. The dark matter is responsible for forming the structure of all galaxies, including our own, in the early universe. Theories based on the dynamic gravitational behavior of dark matter do a very good job of predicting the observational data we have of our universe. However, the challenge that we have faced for my entire research career is trying to identify the fundamental nature of the dark matter. What processes created it? How does it interact beyond simple gravitation? Does it interact, decay or annihilate with itself? This conference is dedicated to trying to answer those questions. We are looking for new results that will provide a key to explaining dark matter. A leading theoretical candidate for what a dark matter particle might be is the WIMP (weakly interacting massive particle). These are particles that don't emit or reflect light and only interact with other forms of matter on extremely rare occasions. They pervade the universe. There are literally millions of WIMPs passing through your body right now. The trick is detecting one of the rare occasions on which a WIMP does interact with ordinary matter.

Q: A number of presentations at IDM2018 centered on dark matter searches that are active now. What is the state of those searches?

Highly competitive! For instance, the search for dark matter using direct detection has been ongoing for over 30 years. During that time, we have been building more and more sensitive experiments. The latest generation of detectors is over a million times more sensitive than the first-generation detectors. That's an amazing rate of improvement for any experimental program. Since the early detectors were built, several new ideas about what dark matter could be have been proposed.
At IDM2018, we've heard from projects looking at high-mass WIMPs, low-mass WIMPs as well as non-WIMP candidates like axions, sterile neutrinos and a maelstrom of other possible dark matter particles. Amazingly, we still have no conclusive, unambiguous evidence of direct detection of dark matter, from any of them.

Q: Most dark matter searches to date have focused on WIMPs — yet as you mention, there's been no definitive detection. Is the dominance of the WIMP model starting to waver?

The idea of the WIMP and WIMP-like particles grows out of the theory of supersymmetry (SUSY), which has been favored for more than 30 years. Tim Tait, a professor at the University of California Irvine and one of the opening speakers at the conference, showed a sketch of a stained glass window that celebrates SUSY. He was at pains to point out that it will be hung in the cathedral of dark matter, not the mausoleum. In spite of SUSY's age, it remains a compelling model. We continue to test the multitude of models that it inspires. That said, there are other theories for dark matter candidates that allow for different signals to look for. Perhaps the most notable is the axion, but even more exotic candidates exist. The great thing about the upcoming LZ experiment and others like it is that they are sensitive to many potential candidates. So while WIMPs are the focus, we can and will perform an array of other searches as well. New WIMP models continue to be tested. Based on projection from many talks at the conference, they will continue to be tested over the next 10 years plus.

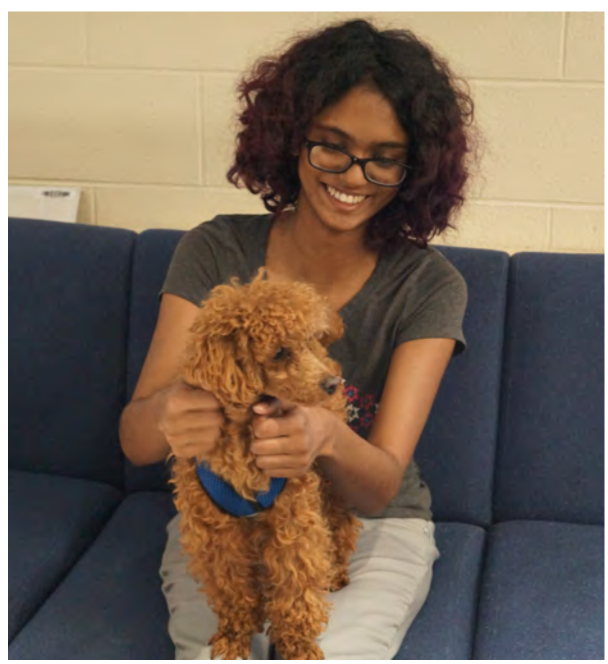
Q: What has been the highlight of the conference so far?

From a physics point of view, the talks have all been great. Precision observations from the Gaia satellite are now being exploited to go beyond simple gravitational models of dark matter to learn something about fundamental physics of dark matter. We are seeing the same finesse and sensitivity being applied in the analysis of cosmic microwave background (CMB) and 21-cm radio wave measurements associated with hydrogen line emission in the early universe.
We have seen the analyses of data from direct detection experiments exploited in a number of new ways to look for more exotic models of dark matter. We have to search under every possible stone to find the first new signature of its fundamental nature. There have also been a number of very elegant talks about improved ways of how to differentiate dark matter signal in detector from other background process. This is vital if we are to convince the community that when we do get the first positive signals for the detection of dark matter (beyond gravitation) that we really are measuring it, and not some unexpected manifestation of a more conventional background. From a non-physics perspective, these conferences are always great for discussing new ideas and forging new collaborations. The tour of the RISD gave the global astroparticle physics community the possibility to discuss the intersection between dark matter and the abstract expressionism of Rothko. It was stirring stuff.

—KEVIN STACEY

BUILDING
C O M M U N I T Y

Lunar New Year Celebration



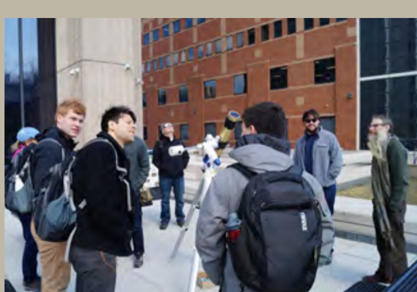
De-stress Coffee Hour

9th Annual Art Show

Department Picnic

Pi Day Celebration

Summer Social



Spring Equinox

Girl Scout's Outreach

HOPE MCGOVERN '19 AWARDED FULBRIGHT-AUSTRIAN MARSHALL PLAN RESEARCH AWARD

Going into my senior year, a familiar anxiety about my future resurfaced. At Brown, I had launched myself into exploring everything from physics to Ancient Greek to space engineering to modern literature, yet I had no idea how to channel my wide array of academic interests into a career which would both be satisfying to me and beneficial to my community. My plan had been to pursue a PhD in electrical engineering immediately after undergrad, but in scraping together a few applications, I quickly realized my motivation for applying was out of a sense of obligation and a desire for prestige than a true driving passion.

At a Brown scholarship office information session, I learned about the Fulbright grant and was attracted to the idea of spending a year not only pursuing research in another country, but immersing myself in a new culture. What's so unique about a Fulbright is that it is an investment in a person for learning how to bridge cultures rather than just funding to complete a certain project. My background as a musician and my penchant for studying cultural touchstones drew me to Vienna, Austria in particular, and I was fortunate enough to find a research group there working in a field I have experience in — nanophotonics — but gearing their work towards the immediate application of biomedical imaging. Next year, while learning German and singing in a chamber choir, I plan to work with the NanoBioPhotonics group at the Institute of Sciences and Technology Austria, applying my experience in nanophotonics and artificial intelligence to explore new techniques for super-high-resolution tissue imaging.

Although I know it will be busy with research, traveling, and cultural immersion, I'm viewing my Fulbright year as a retreat — a time to wind down from four years of non-stop academic and social pressure; a time to take stock of how I want to use my unique educational experience to serve others, and then to pursue that path with a singular focus. I'm very grateful to all of the professors, TAs, and administrators at Brown who have mentored me during my undergraduate program, as well as to my family, friends, and faith community, without whom I would not have had the confidence to pursue a year in a city I've never been to and whose language I don't speak! Above all, I'm looking forward to a year of being pushed far outside of my comfort zone and hopefully returning home with renewed energy and vision for my next steps.

-Hope McGovern '19

BRIAN KILPATRICK AWARDED THE FIRST EVER EXOPLANET SCIENCE PRIZE FELLOWSHIP

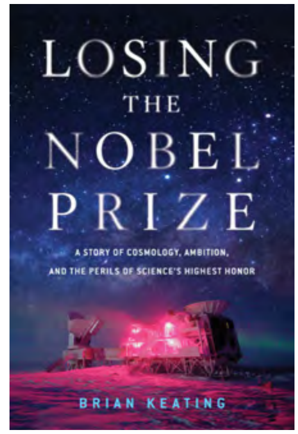
Brian Kilpatrick PhD '19, has been awarded the first ever Exoplanet Science Prize Fellowship at the Space Telescope Science Institute (STScI).

STScI serves as the Science Operations Center for the Hubble Space Telescope and the James Webb Space Telescope, and supports the archives for Kepler/K2 and TESS. The goal of this Fellowship is to allow outstanding postdoctoral researchers working on innovative scientific studies to conduct independent research in the field of exoplanetary science leveraging the vast resources of the Institute. Dr. Kilpatrick studied under Professor Greg Tucker.

ANTHONY PAPOL '19 PUBLISHED IN THE ASTRONOMICAL SOCIETY OF THE PACIFIC CONFERENCE SERIES VOLUME 516

Anthony Papol '19 was recently published in the Astronomical Society of the Pacific Conference Series Volume 516 titled "Celebrating the 2017 Great American Eclipse: Lessons Learned from the Path of Totality." His article is titled "Effects of the Great American Eclipse on Weather Phenomena Across the Contiguous United States," which describes the relationship between the total solar eclipse and temperature, wind speed, and wind direction.

BRIAN KEATING (PhD '95) *"LOSING THE NOBEL PRIZE"*



Alum Brian Keating's book *"Losing the Nobel Prize"* earned placement on numerous "Best Science Books of 2018" lists, including Forbes, Physics Today, Science News, and Science Friday, as well as high praise from Brian Greene, Sir Roger Penrose, and others. Keating draws on his own experience as a cosmologist and designer of the Background Imaging of Cosmic Extragalactic Polarization (BICEP) telescope to argue that the Nobel Prize fosters ferocious and sometimes destructive competition for scarce resources among scientists, that the prizes are biased against the work of female and younger scientists, and that the prize today conflicts with the principles laid out in Alfred Nobel's will. In order to make the prize consistent with Nobel's wishes in the 21st century, Keating contends that entire teams of researchers should be eligible to share a prize rather than only three individuals. He also suggests eliminating the prohibition on awarding the prize posthumously. More provocatively, Keating argues that only serendipitous findings should be recognized with the prize. In other words, if researchers confirm a theoretical prediction they have been attempting to verify (the discovery of the Higgs boson being a recent example) the discovery should not be eligible. Keating contends these changes would encourage more scientists to think outside the box, encourage deeper collaborations, and discourage cut-throat competition.

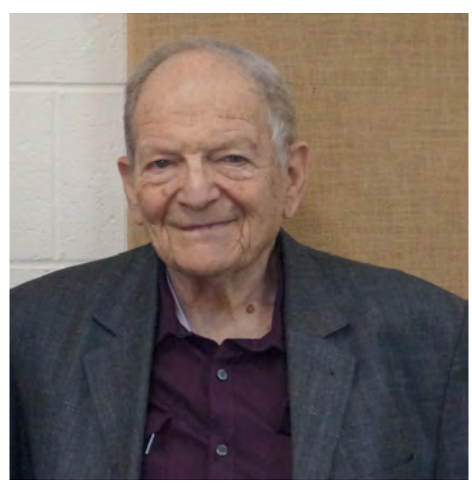
DEGREE DAY 2019

The Physics Department welcomed alumni back to campus for a day of presentations and networking. A group of panelists represented by alums, Jeremy Chapman, PhD'14, Alan Correia Gabel, ScB'08, Kara Hartig, ScB'18, Alexander Hirsch, ScB'18, and Jeffery Snow, ScB'90, answered questions from an audience composed of alums, faculty and current students. Presenters included Prof. Jim Gates, Prof. Rick Gaitskell and Prof. Mike Kosterlitz. A small poster session was held during a networking break.

ALUMNI AWARDS

The Physics Department honored Jose Estabil '84 ScM '88 and Warren Galkin '51 with the first annual department Alumni Award presented at commencement.

Warren Galkin was unable to be present at this year's ceremony.



BROWN
Department of Physics
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Providence, RI 02912

Astronomy students found a clear day to capture images of the sun using a solar telescope at Brown's Ladd Observatory. This stunning image, created as part of the students' course, is a compilation of about 500 individual frames. The black sun spot visible on the right side of the image is roughly the size of Earth.