REFLECTIONS

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UCLA Department of Physics & Astronomy

2018-2019 Year in Review

UCLA College | Physical Sciences
Physics & Astronomy

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On the cover: close-up of the interior of UCLA's Large Plasma Device.

Design by Landesmann Design

CHAIR'S MESSAGE

WE ARE HAPPY TO SHARE WITH YOU our reflections on the last academic year from the UCLA Department of Physics & Astronomy. The department has had a lively year with major-award-winning research, innovations in how we educate students, and wonderful outreach to the public. We produce this magazine for alumni: both current and future. And I use the word “alumni” inclusively: our staff, researchers, postdoctoral scholars, benefactors, students, faculty, and others who help the department are all the alumni of our community.

As you will read, we have exciting new research vistas opening up with several new faculty joining us. And that is not even the whole story, as three new faculty are set to arrive next summer — but you will have to wait until next year's issue to hear about them.

UCLA Physics and Astronomy is incredibly fortunate to have so many dedicated benefactors. I thank all of our supporters who have given and enabled our mission to expand with extra graduate students, postdoctoral fellows, endowed faculty chairs, and improved infrastructure. I wish to highlight the Chair's Discretionary Fund, for which you will find the usual discreet envelope herein. Just about everything extra we can do for our students comes from your support of this fund, from assistance for undergraduate clubs to well-timed help for graduate students. The fund also allows us to bring in special speakers and host one-time events that are essential but do not fit within any other budget source. We could not run the department without it.

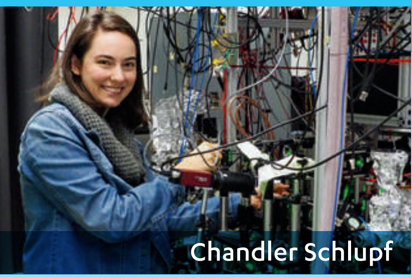
I'd also like to highlight several special opportunities for support of UCLA Physics and Astronomy that present themselves this year. Our departmental priorities include creating more distinguished (“named”) postdoctoral fellow appointments, providing a permanent fund for maintenance of the planetarium theater, developing a permanent endowment of summer research funds for our undergraduates, and purchasing a state-of-the-art computer-controlled mill for the Machine Shop / Instrument Fabrication Facility. Please contact me or the department if you would be interested in helping with these initiatives.

This magazine cannot cover everything. I invite you to visit our brand-new webpages at https://www.pa.ucla.edu/ to learn more about what our 150+ graduate students, 100+ undergraduates per year, 40+ researchers, 50+ postdoctoral scholars and staff have been doing to continue making this department excellent and unique.

DAVID SALTZBERG
Chair, Department of Physics and Astronomy

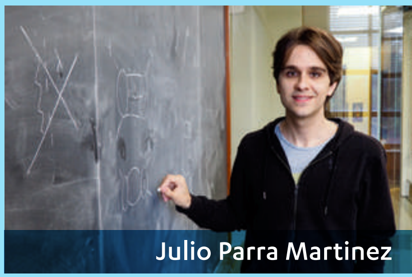
great grads

From teaching to research to community outreach, Physics and Astronomy graduate students are at the heart of the department.


Chandler Schlupf


Xu Liu


Janaki Sheth


Julio Parra Martinez


Kristian Barajas


Kevin Hayakawa


Peter Heuer


Jon Zink

FOR THE HUNDREDS OF UNDERGRADUATES WHO PASS THROUGH THE DEPARTMENT OF PHYSICS & ASTRONOMY EACH YEAR, graduate students are often their closest guides. These next-generation scientists are critical bridges between faculty mentors and younger students – undergrads whose future studies and careers may very well be determined by the interaction they have with those grad students. Within research labs, graduate students perform tireless research that helps to elevate their groups' work and, as a result, their areas of science.

GRADUATE STUDENTS LINK EVERY ASPECT OF THE PHYSICS & ASTRONOMY DEPARTMENT. THEIR VALUE IS IMMEASURABLE.

The Road to UCLA

"I have always been curious about how the world works, starting with asking my parents questions about the moon and stars when I was little. I loved watching the show 'The Universe' on the history channel growing up. I realized in high school if I wanted to understand the universe myself I should be a physics major!" — Chandler Schlupf

CHANDLER SCHLUPF'S STORY ISN'T AN UNUSUAL ONE for UCLA Physics & Astronomy graduate students. These young scientists come to the department with a drive for discovery.

Xu Liu's interest in physics stems from its ability to help explain many phenomena. Janaki Sheth chose to focus on biophysics out of an enthusiasm and curiosity to understand the natural and physical world.

"I work on reproducing aspects of the Earth's bow shock in the laboratory so that we can better understand the response of the magnetosphere to events like solar flares. Within the group, I'm responsible for a series of experiments studying the formation of parallel collisionless shocks in the laboratory."

Peter Heuer
Christoph Niemann / UCLA High Energy Density Physics group

"The universe is a confusing place, but the realization that behind the confusion there exist simple mathematical rules that explain how things work, and that one can use their life trying to discover such rules, motivated me to pursue a career in science," explained Julio Parra Martinez.

Schlupf is the first in her family to pursue a Ph.D. She shares this distinction with peers Kristian Barajas, Kevin Hayakawa, Jon Zink, Xu Liu, and Janaki Sheth.

The variety of home town and undergraduate experiences these students share upon their arrival at UCLA enrich both the department and the university. Schlupf grew up in a small town in Massachusetts, then stayed close for her undergraduate degree at MIT. Hayakawa grew up in Rowland Heights, California, and received his bachelor's degree from UC Berkeley in 2016, where he was inspired to pursue astronomy as a career thanks to a GE course he took there.

Sheth grew up in Bombay, India, and received a bachelor's degree in Engineering Physics from IIT Bombay. Liu grew up in China, receiving her undergraduate degree at University of Science and Technology of China.

Another shared perspective comes from having parents who are educators and scientists themselves. Parra Martinez grew up in Valencia, Spain, among a family of teachers, including his mother, who is a professor of mathematics. "Watching her work as I was growing up had a long-lasting influence on me, and gave the opportunity to witness what a life as a researcher is like." He began his journey as a scientist with an undergraduate degree in physics from the University of Valencia, followed by a master's degree from Cambridge University.

Peter Heuer's father is a professor of chemistry. Heuer grew up in Annapolis, Maryland and completed his undergraduate work at the University of Rochester, where he was drawn to plasma physics by the promise of fusion energy, the high-energy experimental facilities, and the applications to space and astrophysics.

UCLA's Physics & Astronomy department is benefitting from first-generation college students. Kristian Barajas grew up in Forest Grove, Oregon, and received his undergraduate degree from Willamette University in Salem, Oregon. He is the first in his family to graduate with a college degree.

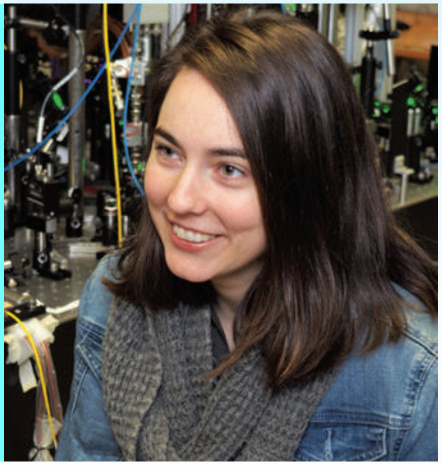
Sharing in UCLA's legacy of welcoming students who haven't followed traditional paths is Jon Zink. Born and raised outside of Detroit, Michigan, Zink didn't feel that college was for him. After graduating high school, he worked as a traveling musician for five years. "Once the appeal of this died down, I decided to return to school," he said. His journey began at Orange Coast Community College, which allowed him to transfer to UCLA, where he completed his bachelor's in Astrophysics.

Driven to become the first in his family to pursue a degree beyond a bachelor's, and fed by a desire to increase his research experience, Zink then earned a master's degree in Physics before returning to UCLA, where he is working to complete his Ph.D. in Astronomy and Astrophysics.

While these graduate students hail from a wide range of places, there is a very similar tone to their responses to the question, "Why did you decide to come to UCLA?" The graduate students were excited by the feeling of a tight-knit community, the reputation of the university in a variety of subfields, and mentorship provided to junior researchers by scientists who are pioneers in their fields.

"I am building an ultracold atomic force sensor using ytterbium atoms in an optical lattice to search for ultralight dark matter."

Chandler Schlupf
Paul Hamilton / Atomic Molecular Optics group



The American Physical Society's (APS) Bridge Program gave Barajas the opportunity to connect with UCLA for his graduate education. "As an independent student through college, I took various extended leaves to earn my living and pay for school. By the time I reached my fourth year, I knew I wanted to continue to graduate school, but I was short on funding and time to go through the costly application process," Barajas explained.

The Bridge Program was created by APS to increase diversity and inclusivity within physics by providing underrepresented minority students with a free application to specific sites like UCLA. The program sends these applications to each of its partnering graduate programs to find the right match for the student.

"After completing the Bridge program, UCLA Physics has generously given me the opportunity to continue in the graduate program as a doctoral student," Barajas said.

A Day in the Life

OVER THE DECADES that graduate students have been a part of the Department of Physics & Astronomy and UCLA's 100 years of scientific leadership, their day-to-day has likely not changed much. But the ways in which each student contributes to the classroom or the lab are unique, while the challenges they address reflect the scientific advances made by generations before.

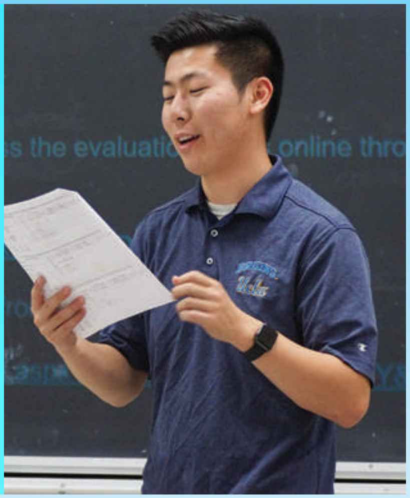
Schlupf's typical day is research focused – aligning optics, coding simulations, designing new systems or running an experiment. A good deal of Parra Martinez's time is allotted to calculations, which can often take him through the early hours of the morning. Hayakawa may run simulations of solar systems on the UCLA Hoffman2 cluster.

"I'm interested in designing trapped-ion Coulomb crystals for quantum computing that allow for more direct control over the mediation of information exchange, improving the efficiency and fidelity of quantum gate operations over long-range qubit pairs."

Kristian Barajas
Alex Levine and Wes Campbell research groups

"I specialize in studying the connection between exoplanets and debris disks. Debris disks are extrasolar analogues of the Asteroid Belt and Kuiper Belt within our own Solar System, and provide clues to the history of the Solar System."

Kevin Hayakawa
Brad Hansen research group



Heuer's daily work is split between analyzing data from previous experiments and preparing papers and presentations to disseminate the results of that analysis. That changes for several weeks each year when experiments are running on UCLA's Large Plasma Device (LAPD), when Heuer works full time in the lab, setting up hardware and diagnostics to collect new data.

Depending on her current project, Liu may use Mathematica to do symbol derivation, or rely on Python to do numerical calculations. "In the afternoon, if I have a meeting with my supervisor, we will sit down and discuss problems together on the whiteboard. This is the most exciting part because brainstorming always facilitates our projects and brings us new ideas," Liu said.

Apart from research, these graduate students often fill significant roles as teaching assistants, where they take on discussion or lab sections each quarter. Office hours are another way in which the graduate students give back, helping undergraduates strengthen their abilities to solve physics problems.

"I enjoy talking with students from diverse backgrounds. In the process, I have learned a lot about how to explain a topic from different perspectives and how to illustrate complex ideas by giving some examples or using graphics," Liu explained.

For Liu and the others, interacting with peers is a priority as well, whether over lunch or coffee and during meetings of the journal club.

As a Bridge student taking the first-year course sequence, Barajas' typical day is a bit different. After arriving at UCLA on the Big Blue Bus, he spends most days in lecture, followed by studying.

He also contributes to classroom experiences by teaching 5AL labs where he is able to show life science students why the physics they're learning in class is interesting. Meetings are also important to Barajas, whether with his graduate mentor, research advisers, or Women in Physics and Astronomy (WiPA) mentees.

"These are the best parts of my day, when I get to interact, meet, or collaborate with other folks," Barajas said. "This is a prominent, yet underrated, aspect of a physics career that I'm very fortunate to do here at UCLA with some very fabulous folks within the department."

So much of what these graduate students have dedicated time and energy to comes down to the good of the department as a whole. For example, Heuer developed a software suite for analyzing large high-repetition rate datasets that he hopes will be used by future students.

Barajas, Schlupf, and Parra Martinez have all served on the Physics & Astronomy Diversity Committee, where brainstorming occurs on how the department can make recruitment processes and practices more equitable for potential students. Time is also volunteered on the Comprehensive Exam Review Committee and Graduate Council.

"I think our job as graduate students goes beyond locking ourselves up in our offices and working hard on our research," Parra Martinez said. "As a junior graduate student, I benefited greatly from the mentoring of more senior grads and I have tried to do the same when my turn came."

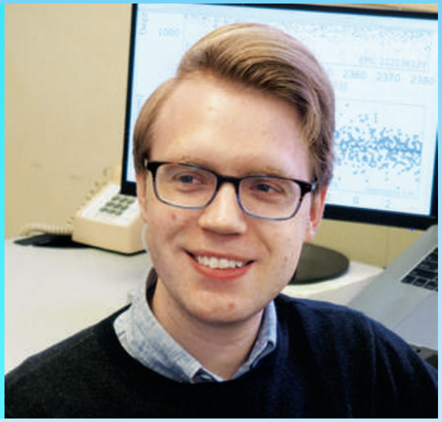
The work of these students often has benefit beyond the department's boundaries. "As an educator, I've had countless opportunities to further the careers of astrophysicists and non-majors alike," said Hayakawa.

"I work in the field of condensed matter theory, which is devoted to the study of systems with many particles where quantum effects are important. I am working on the classification of quantum matters like the topological classification of Floquet systems which is governed by periodic, time-dependent Hamiltonians."

Xu Liu
Rahul Roy research group

"I work on understanding the population of exoplanets to determine how unique our solar system is compared to the rest of the systems in our galaxy."

Jon Zink
Brad Hansen research group



Public outreach is as rewarding to these students as it is important for empowering children to know that they, too, may become scientists one day, and for generating goodwill among the public for how much science benefits all our lives.

When asked what he feels has been his biggest contribution to the Physics & Astronomy department, Zink's immediate response is being part of Exploring Your Universe (EYU). The campus-wide event is a free, day-long science fair serving the greater Los Angeles community, and Zink served on its organizing committee. "With nearly 10,000 people attending the event, we can make science more accessible to people who found many of these fields too difficult in the past," he said.

An Undeniable Impact

WHEN IT COMES TO THE ripple effect their work will have well into the future, these graduate students have much to be proud about. Schlupf values the teaching assistant award she received in 2019. "I really enjoyed teaching the introductory physics courses because I got to be the first person to show them how awesome physics is. I have developed mentor-mentee relationships with many students, and even had some of them work in my lab," she said.

Sheth is proud of the positive impact her outreach activities have made, from organizing the Conference for Undergraduate Women in Physics, which was hosted by UCLA in 2017, to mentoring undergrad and grad students around her. She is also a staff writer for UCLA's FEM Magazine, focusing on topics that affect minorities and graduate students in particular.

In the research realm, Heuer is proud of helping to lead a series of experiments that made the

> "I study how our inner ear processes sound robustly yet with incredible finesse using methods from statistical mechanics and dynamical systems."
>
> **Janaki Sheth**
> *Dolores Bozovic and Alex Levine research groups*

first laboratory measurements of an ion/ion beam instability, which plays an important role in the formation of shocks in space and astrophysics. Liu's research work in Floquet systems and Chern insulators has solved problems that are both interesting and useful. She's appreciative of how much the process has helped her grow. "I gradually learned how to raise questions, come up with an idea, write papers, and give talks, with the help of my group members and my supervisor."

Parra Martinez has found it most fulfilling to see the same passion for physics subjects in students he has taught. "I wish I have been able to inspire them at least a fraction of what great teachers inspired me in the past," he said. "Whenever I had to teach, I put in all my effort, and I always end up learning much more than I expected."

Zink is most proud of the work he's done with the help of citizen scientists. Using the Zooniverse platform, citizens from around the world helped parse through more than 200,000 data files to identified new planet signals. "I was able to lead this paper, where we identified 28 new planet candidates," he said.

The Sum of All Parts

EACH OF THESE STUDENTS is working towards personal goals that are a continuation of their work in the Department of Physics & Astronomy.

Hayakawa's goal is to become a dedicated teaching professor at either a California State University or community college upon completing his Ph.D. Zink, too, feels a calling to use his knowledge of Astronomy to educate future generations by becoming a college professor.

Parra Martinez was recently awarded a postdoctoral Burke Fellowship at Caltech. "I'm very excited to join the group there and looking forward to start new collaborations and also continue working with the people at UCLA," he said.

Heuer is pursuing post-doctoral positions in which he hopes to continue studying magnetized plasmas for both laboratory astrophysics and fusion energy applications.

Schlupf will be headed to SpaceX after graduation, where she will be working on the optical system for the Starlink satellite constellation. "This will be directly using the technical skills I learned in lab during my PhD," she said

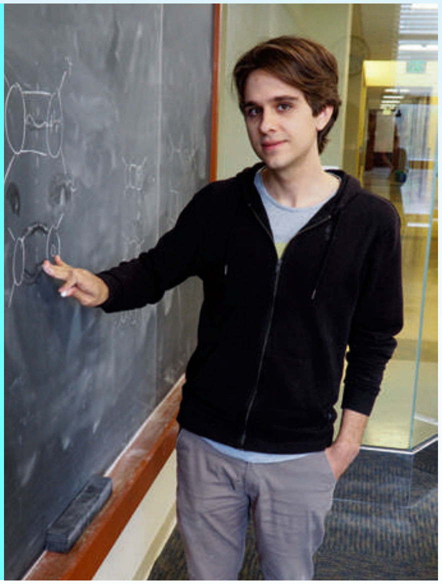
"My long-term objective is to seek a teaching and research position in a research or academic institution after finishing my Ph.D.," Liu said. "I would like the opportunity to communicate and discuss with students and people in the physics community."

Sheth wants to continue doing research, but isn't sure whether to choose industry or academia. To that end, she's headed to IBM for an internship this coming summer before she graduates, after which she will move to the University of Pennsylvania for a postdoctoral fellowship.

But before they begin the post-UCLA stage of life, these graduate students will continue to be vital contributors to all aspects of the department's progress and excellence. All of them know they are a part of the greater whole.

"The current state of the department and its atmosphere is the result of the work and dedication of many people," said Parra Martinez.

> "I study the mathematical structure of scattering amplitudes, which are the probability amplitudes of scattering events at particle colliders, both in gauge theories, such as the Standard Model, and in Einstein's Gravity."
>
> **Julio Parra Martinez**
> *Zvi Bern research group / Mani L. Bhaumik Institute for Theoretical Physics*



Investing in Student Support

"This award enabled me to focus on research to finish my degree and created enough space and time for me to find my true passion for education and outreach."

– Xinnan Du, recent Ph.D. graduate

GRADUATE STUDENTS ARE ESSENTIAL to maintaining a high caliber of education for undergraduate students and helping faculty make significant breakthroughs in their research. As UCLA continues to be the #1 applied-to university in the nation, it is critical we have the means to recruit and maintain top candidates from around the world to our program.

"I had reached the limit of T.A. appointments I could hold, and my advisor didn't have funding to support me. The fellowship allowed me to stay in L.A. and finish my Ph.D., for which I'm very grateful."

– David Bauer, recent Ph.D. graduate

"This scholarship makes it possible for me to study something I love and meet likeminded people who love the same things, to look at research and career opportunities, and interact with experts in these areas without taking on heavy debt."

– Obed Camacho, current graduate student

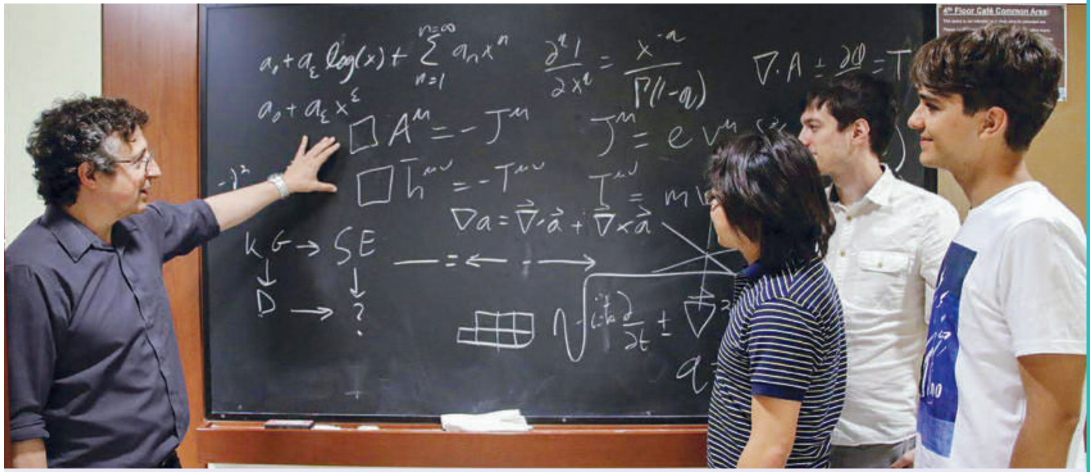





THIS YEAR WE CELEBRATED THE INSTALLATION OF FOUR ENDOWED FACULTY CHAIRS, recognizing the leadership and profound difference Mani L. Bhaumik, Arthur E. Levine and Lauren B. Leichtman, and Howard and Astrid Preston have made through philanthropy to ensure the Department of Physics and Astronomy remains one of the strongest programs in the country for generations to come.

Top row of photos, from left to right:
Mani L. Bhaumik Institute Directorship held by Prof. Zvi Bern
Mani L. Bhaumik Presidential Term Chair held by Prof. Thomas Dumitrescu
Lauren B. Leichtman and Arthur E. Levine Centennial Chair in Astrophysics held by Prof. Andrea Ghez
Howard and Astrid Preston Term Chair in Astrophysics held by Prof. Smadar Naoz

Bottom row of photos, from left to right: Celebration of our benefactors who created endowed chairs. Left: Mani Bhaumik (second from left) with Dean of Physical Sciences Miguel García-Garibay (far left), Chancellor Gene Block (3rd), and Chair David Saltzberg (far right). Center: Lauren Leichtman and Arthur Levine (far left) with Chancellor Block and Dean García-Garibay. Right: Astrid and Howard Preston (center) with Chancellor Block and Dean García-Garibay.



Faculty are critical to UCLA's mission. They engage in pioneering research that seeks to solve some of humanity's biggest problems and answer questions that seem unanswerable, they provide exceptional education to students, and they fulfill the university's commitment to service through an array of creative programs. Endowed chairs are essential to recruit, retain and support those faculty who help make UCLA the #1 public university in the United States.

Matching Funds

IF YOU ARE INTERESTED in making an endowment-level gift, UCLA Physical Sciences Dean Miguel García-Garibay will match your endowment gift of $100,000 - $1,000,000 on a one-to-one basis, while funds last. Now is the time to double the impact of your gift and ensure greater support for students, faculty and staff for generations to come! Join us by investing in the future as we embark on our next 100 years, ensuring the UCLA Division of Physical Sciences continues to be one of the best in the world.

The Centennial Campaign for UCLA – like UCLA's donors – surpassed all expectations. Thank you to all who participated in this tremendously successful campaign. We counted on you to reach an ambitious goal of $4.2 Billion and we are currently over $5 Billion and counting! For more information about the campaign visit www.lettherebe.ucla.edu.

To make a gift, or to learn more about the Dean's Gift Matching Program, please contact Amber Buggs at amberbuggs@support.ucla.edu or (310) 267-5194.

Donors to the Department of Physics & Astronomy who have given $25K+ since the inception of the UCLA Centennial Campaign*

Ron and Jeryl Abelmann
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Diana R. Arman
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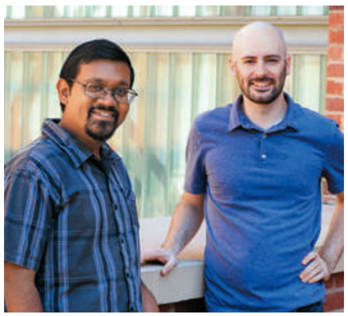
Guy and Eveline Weyl
Dorothy P. Wong
Byron T. Wright

*as of Sept. 18, 2019

Graduate Students working at the Large Hadron Collider

Faculty advisors: Michalis Bachtis, Robert Cousins, Jay Hauser, and David Saltzberg

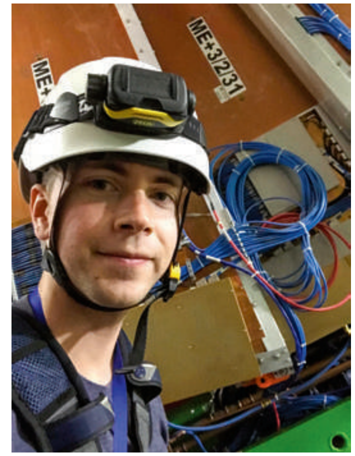
The UCLA group is a founding member of the Compact Muon Solenoid Experiment at the Large Hadron Collider at CERN outside Geneva, the highest energy particle collider ever built. UCLA graduate students, who are funded mostly through the Department of Energy, play a key role in building apparatus, keeping things running, and analyzing data to search for new phenomena.



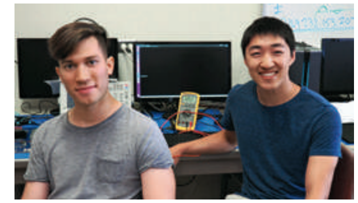
RIJU DASGUPTA looked for heavy long-lived particles, signaled by a displaced pair of charged particles. Chris and Riju together used an intense gamma source at CERN, as well as neutrons created during CMS running, to predict the longevity of UCLA's muon detectors over the next two decades. Both received their Ph.D.s this year. **CHRIS SCHNAIBLE** looked for a "Z prime particle," a heavy partner of the Z boson, which itself is a heavy partner of the massless photon.

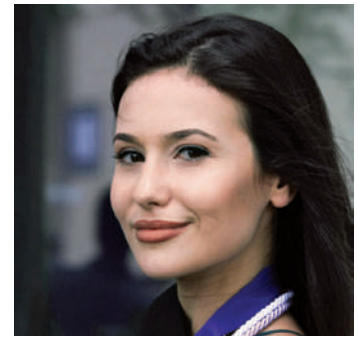
BRENT STONE looked for a new heavy resonance decaying into a pair of Higgs bosons. He also tested new muon detectors based on new technology based on perforated foils.

MARCOS FLORES searched for the rare, but predicted, conversion of high-energy gamma rays into muon pairs as they traverse the CMS detector.

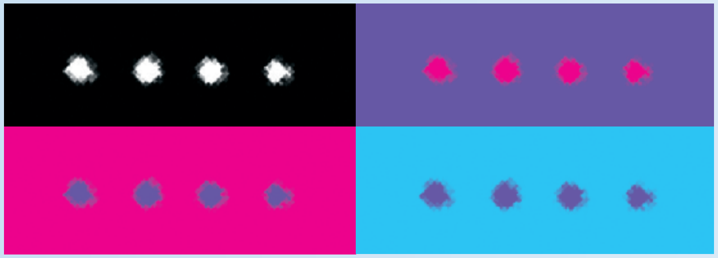


WILL NASH began extending the search for heavy long-lived particles. He and **CAMERON BRAVO** developed a new higher-resolution muon pattern-finding algorithm for the CMS muon trigger. Cameron received his Ph.D. this academic year for searching for the "sphaleron process," which could explain the matter-antimatter asymmetry of the universe.





DAVID HAMILTON also looked for a new heavy resonance, but decaying into a pair of W boson or Z boson weak-force carriers. **TYLER LAM** started a search for magnetic monopoles. Together with **LEAH PERRI**, they began designing a real-time muon selection ("trigger") system to upgrade what CMS has used to date.



Trapped barium-133 ions, imaged with laser-induced fluorescence.

Atomic Physics for Quantum Computing

Profs. Wes Campbell, Eric Hudson, and Paul Hamilton

THE ACCUMULATION, STORAGE, TRANSPORT, ERASURE, AND PROCESSING of information are all processes that can be traced to physical mechanisms, and they therefore obey the laws of physics. And since physical processes are subject to quantum theory, information, in its most general form, is a quantum mechanical entity. This generalization, known as quantum computing, is a powerful new tool that we do not yet understand.

In order to study quantum information, quantum bits ("qubits") can be made in the lab and the behavior and computational power of these qubits explored. A natural choice for qubits is laser-cooled atoms, and the Campbell and Hudson groups have recently been pursuing this approach with a new, synthetic atom, ^{133}Ba+.

UCLA researchers Justin Christensen and David Hucul have demonstrated that the state preparation and measurement (known as "SPAM" in quantum information jargon) fidelity of this qubit is the highest for any qubit of any type. To put it another way, UCLA has the world's best qubit. Our next step is to complete the requirements for building a quantum computer, and projections indicate that it will likewise be capable of achieving extremely high fidelity due to the favorable atomic structure of ^{133}Ba+. As quantum computers scale up to larger numbers of qubits, these advantages will be increasingly felt and UCLA will continue pushing the boundaries of what is possible.

Spintronics and Topological Materials

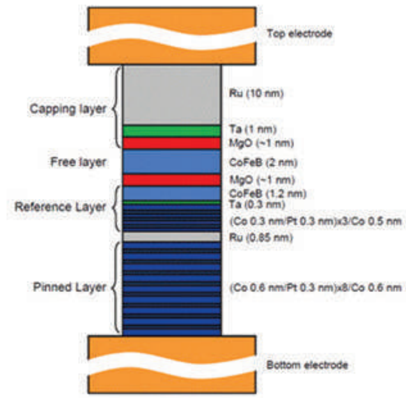
Prof. HongWen Jiang

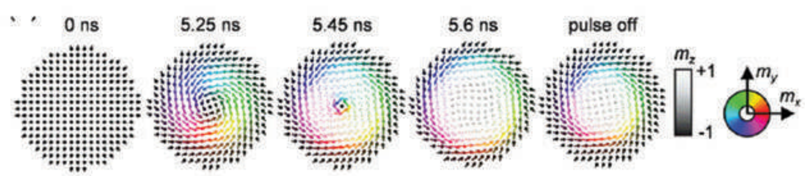
IN RECENT YEARS, it has been realized by condensed matter physics research that topology hidden inside certain materials can be excited electrically or magnetically, to design the next generation of electronics. The skyrmion, a nanoscale whirling magnetic pattern, is an example of such topological excitations in magnetic materials. The magnetic tunnel junction (MTJ) is arguably the most promising spintronics device, developed in the recent years, for data storage, sensing, and logic computation.

Normally, two opposite ferromagnetic states are used to store binary data in the MTJs. Professor HongWen Jiang's group is developing new ways to create, probe, and manipulate topological excitations in the MTJs as they can potentially consume less energy, operate at a higher speed, and be more robust against material disorder.

This year, the group has demonstrated that single skyrmions can be created in MTJs by using pulsed or microwave currents. Furthermore, they discovered the nucleation of a single skyrmion can be facilitated by a spatially non-uniform stray field, without the more conventional Dzyaloshinskii-Moriya interaction. This research has been published in the Physical Review Letters[1]. Graduate student Nicholas Penthorn, a Schwinger Fellow of the department, is the lead author of the paper.

[1]N. E. Penthorn, X. Hao, Z. Wang, Y. Huai, and H.W. Jiang, Experimental Observation of Single Skyrmion Signatures in a Magnetic Tunnel Junction, Phys. Rev. Lett. 122, 257201 (2019)





The layer cross-section of the MTJ sample, fabricated by Avalanche Technology, used in the UCLA experiment.

Bottom: a micro-magnetic simulation of the nucleation of a magnetic skyrmion by a short electrical pulse.

Nuclear Physics Experiments

Prof. Huan Huang

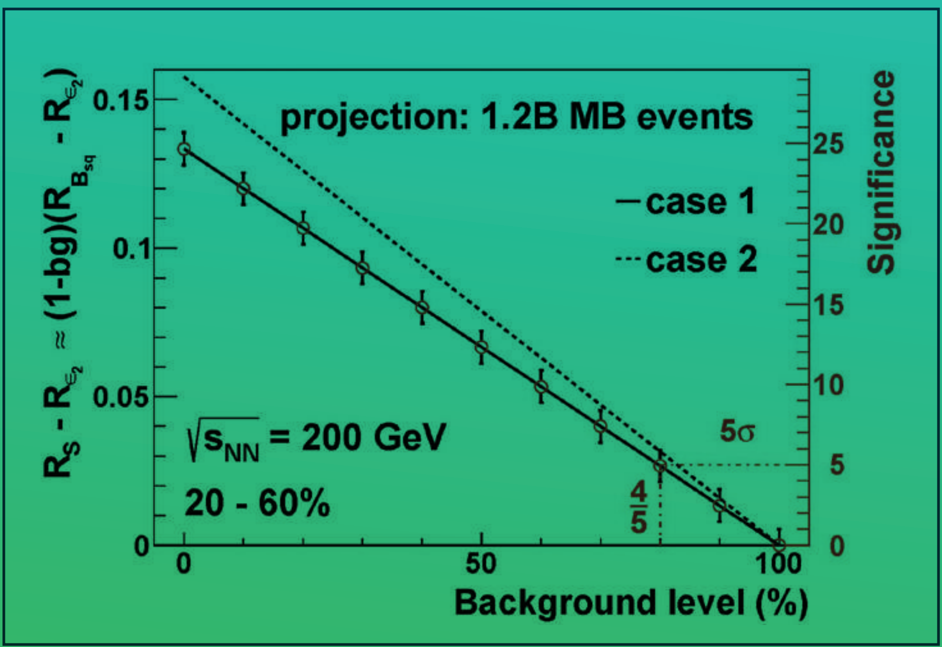
THE UCLA NUCLEAR PHYSICS GROUP (HUANG) has research programs on studies of hot QCD (Quantum ChromoDynamics) matter of quarks and gluons and on searches for neutrinoless double beta decays. The group has been active in both the STAR (Solenoidal Tracker at RHIC) experiment and the newly formed sPHENIX experiment at Relativistic Heavy Ion Collider (RHIC) at Brookhaven National Laboratory (BNL). The neutrino program centers on the CUORE experiment at Gran Sasso National Laboratory in Italy.

The RHIC at BNL has initiated a new scientific campaign to investigate major outstanding questions in QCD: the quark chirality effects in Quark-Gluon Plasma (QGP) and searches for a possible critical point in QCD phase diagram. The UCLA Group continues to play a major role in these scientific endeavors. As an intrinsic QCD property, a chirality imbalance of quarks (unequal numbers of left-handed and right-handed quarks) can appear inside a QGP droplet owing to topological excitations of gluon fields. When coupled to the strong magnetic field (~10^{15} Tesla) created by spectator protons moving at the speed of light, the chirality imbalance induces novel chiral magnetic effect (CME). To disentangle the CME signal and the background, we have

The RHIC at BNL has initiated a new scientific campaign to investigate major outstanding questions in QCD...

been a major proponent of using isobaric nuclei, i.e. $^{96}_{44}$Ru and $^{96}_{40}$Zr, to study collisions with different magnitude of CME signals while maintaining the same background. The figure shows our projection of the significance of the signal observation vs background level. RHIC successfully carried out the isobaric collision run in 2018. Our group has been analyzing the isobar data.

Two graduate students, Liwen Wen and Roli Esha, finished their Ph.D. thesis research in 2019 working on studies of quark chirality effect and QCD phase diagram from previous STAR data. Currently, Liwen works in the finance industry and Roli is a postdoc at Stony Brook University.



This figure shows the expected signal significance as a function of background level in the measured correlator observable for 1.2 billion Minimum Bias events of isobar collision data. The isobar data are currently under analyses.

The Galactic Chimney

Prof. Mark Morris

IN THEIR X-RAY STUDY of the Galactic center region using the Chandra and XMM-Newton satellites, Professor Mark Morris and his European colleagues have discovered a large-scale feature that they term the "Galactic Center Chimney." Centered on the Galaxy's supermassive black hole, it is a cylindrical feature rising more than 1,000 light years above and below the midplane of the Galaxy.

Morris and his colleagues interpret it as a cylindrical exhaust vent that carries hot, X-ray-emitting gas vertically out of the Galactic center and into the Galactic halo. The hot gas is generated and expelled episodically by the vast energies released during accretion events centered on the black hole, by extreme star formation events at the center, and by supernovae that result from that star formation. The "walls" of the chimney are hypothesized to consist of the strong, vertical magnetic field that Morris has long been investigating.

See http://newsroom.ucla.edu/releases/x-ray-chimneys-exhaust-vents-milky-way.

Theory of Elementary Particles, Astroparticle Physics, and Phenomenology

Profs. Graciela Gelmini, Alexander Kusenko, and Terry Tomboulis

PROFESSOR GELMINI, UCLA postdoc Dr. Volodymyr Takhistov, and former UCLA student Sam Witte have proposed future directions for detection of geoneutrinos — neutrinos produced inside Earth, which can provide a unique insight into Earth's interior, its central engine and its formation history. They identified germanium as the most promising target element for future experiments and outlined the directions that can lead to important studies and discoveries in Earth's formation history.

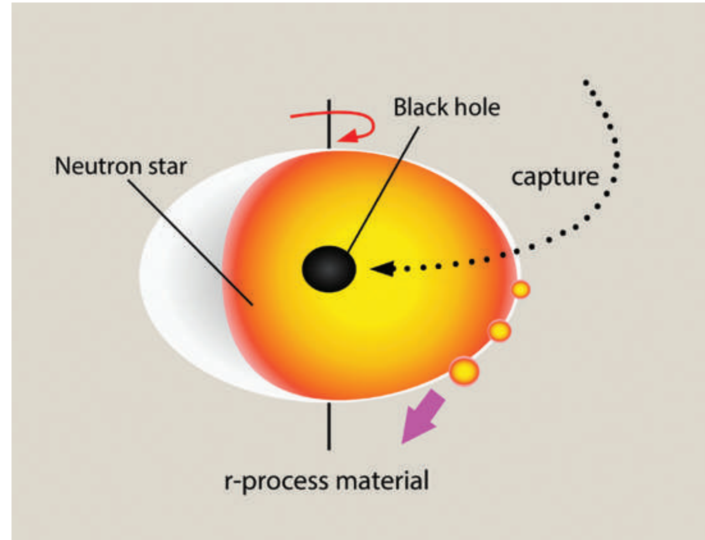
Measurements of the expansion rate of the universe based on the relatively nearby data disagree with the results-based cosmological data. Professor Gelmini, Professor Kusenko, and Takhistov have suggested a compelling explanation of this astronomical puzzle. They pointed out that the apparent discrepancy may be the first hint of a right-handed or "sterile" neutrino, which was produced in the early universe and then decayed, affecting the expansion rate.

In a paper published in Physical Review Letters, Professor Kusenko and Dr. Takhistov, in collaboration with two astrophysicists from Princeton and UCSD, pointed out that mergers of neutron stars produce a population of positrons that can be studied with the help of X-ray telescopes. In particular, the mysterious observed 511-keV line from the Galactic center can be explained by the history of neutron star collisions. The association of the 511-keV line with neutron star mergers opens a new way to study these events, which are believed to be the sights of synthesis of heavy elements, including gold, platinum and uranium.

Professor Kusenko, UCLA student Eric Cotner, and Takhistov, in collaboration with a Japanese astrophysicist Misao Sasaki, have advanced the theory of black hole formation in the early universe. As Kusenko and collaborators pointed out in their earlier work, a population of black holes produced at the time of Big Bang, before the stars and galaxies had formed, could account for part of all of cosmological dark matter. This recent work shows that formation of black holes is a fairly generic phenomenon, which does not require any strong assumptions about underlying physics, and which works in a broad variety of inflationary models. The basic assumption is the existence of a scalar field, such as the Higgs field or one of the scalar fields predicted by supersymmetry. Interestingly, if supersymmetry is at play, the predicted mass range for primordial black holes is consistent with the mass window 10^{20}-10^{23}g, in which the black holes can account for 100% of dark matter in the universe.

Primordial black holes can destroy neutron stars and release large quantities of neutron-rich material which can contribute to synthesis of heavy elements. This study, published in Physical Review Letters by Professor Kusenko, Dr. Takhistov and Professor George Fuller (UCSD) points out an intriguing new link between dark matter and astrophysics.

Dark matter can also be made up of sterile neutrinos with a keV mass. If these particles are produced in decays of a Higgs singlet at the electroweak scale, the predicted dark matter abundance matches the observations remarkably well. In collaboration with Professor Kev Abazajian (UCI), Professor Kusenko has explored a number of effects on cosmological structure formation that can help discover this form of dark matter.



Neutron stars may capture primordial black holes and make many of the heavy elements in the Universe.

Professor Tomboulis and UCLA student Paokuan Chin have studied fundamental properties of quantum field theories manifest in the scattering of particles with non-local interactions.

Professor Kusenko, UCLA student Eric Cotner, and Takhistov, in collaboration with a Japanese astrophysicist Misao Sasaki, have advanced the theory of black hole formation in the early universe.

Public engagement and astronomy field trip

Prof. Matthew Malkan

THIS LAST YEAR has been particularly active in Education and Public Outreach for Professor Matthew Malkan. For the first time ever, thanks to the generous donation of a loyal friend and supporter of the Department, Michael Thacher, Malkan led a group of 20 UCLA Astronomy majors on a unique trip—a night of observing on the world famous 100-inch telescope at Mount Wilson.

Malkan continues to give popular lectures, for example on "The Universe in Reverse: The Keck Time Machines" to a capacity crowd at Gates Performing Arts Center in Hawaii this February. He also continues working with the Sloan Foundation Screenwriting program at UCLA. His talks on "Weird Science: Science in Media and Popular Culture" have become a popular tradition at the Sloan Symposium.

Malkan mentors writers working on screenplays involving science (some of which have gone on to be produced as films) and selects the UCLA screenplays for the prestigious Sloan Screenwriting and Directing Fellowship awards.

Prof. Malkan also co-produced and appeared in an original documentary "Birth of the Solar System" for Curiositystream, which was one of their highest rated shows of 2018.

Planets and Exoplanets

Prof. Jean-Luc Margot

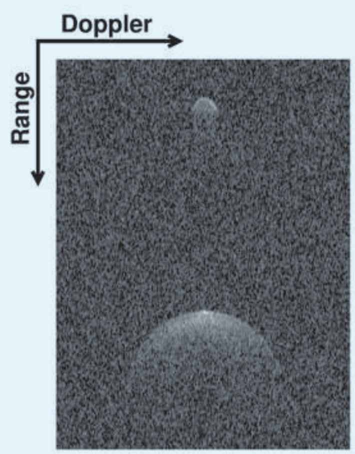
OUR RESEARCH GROUP MEMBERS measure the spin states, sizes, shapes, gravity fields, and orbits of planetary bodies with a variety of telescopes and spacecraft.

We observed a few near-Earth asteroids with the Arecibo Planetary Radar this year. The asteroid known as 1999 KW4 is notable for several reasons: its perihelion precesses by 22 arcseconds per century, it is a binary system, and the components of the binary experience strong spin-orbit coupling. Our observations will improve knowledge of the heliocentric orbit, binary orbit, and the fascinating spin dynamics. We have also been observing 2010 NY65 over the past few years with the goal of quantifying sunlight-induced changes in its spin rate, an effect known as the YORP effect.

Margot obtained additional spin state measurements of Venus. The data obtained since 2006 yield an unambiguous detection of the precession of the spin axis. These observations are important because they will provide the first measurement of the moment of inertia of the planet and the first estimate of the size of its core.

UCLA graduate student Paul Pinchuk published results of our search for technosignatures near TRAPPIST-1 and other planetary systems with the Green Bank Telescope. No signal of extraterrestrial origin has been detected to date, but our data-processing pipeline continues to improve. About 20 students took the UCLA SETI (Search for Extraterrestrial Intelligence) course in Spring 2019 and contributed to the search. We will offer this course again in Spring 2020.

Read about our progress at http://seti.ucla.edu.



Left: An Arecibo radar image of the binary near-Earth asteroid 1999 KW4 at 30 m range resolution.

Right: UCLA Graduate Student Sanjana Prabhu Desai and Margot observed near-Earth asteroids at the Arecibo Observatory.

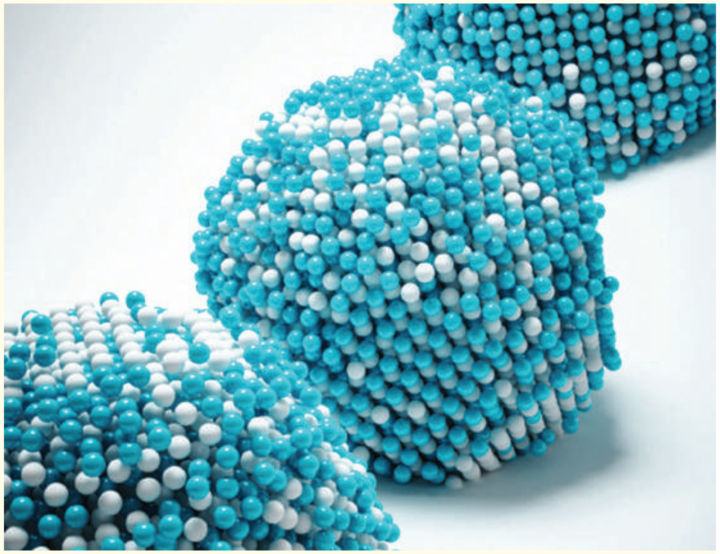
Capturing atomic motion in 4D for the first time

Prof. John Miao

NUCLEATION PLAYS A CRITICAL ROLE in many physical and biological phenomena ranging from crystallization, melting and evaporation to the formation of clouds and the initiation of neurodegenerative diseases. However, nucleation is a challenging process to study in experiments especially in the early stage when several atoms/molecules start to form a new phase from its parent phase.

Over the years, a number of experimental and computational methods have been used to investigate nucleation processes, but it remains unachievable to experimentally determine the 3D atomic structure and dynamics of early stage nuclei. Recently, Miao has led a team that developed 4D atomic electron tomography (AET) to study early stage nucleation at atomic resolution (J. Zhou et al., Nature 570, 500-503 (2019)).

Using FePt nanoparticles as a model system, they revealed that early stage nuclei are irregularly shaped, each has a core of one to a few atoms with the maximum order parameter, and the order parameter gradient points from the core to the boundary of the nucleus. They captured the structure and dynamics of the same nuclei undergoing growth, fluctuation, dissolution, merging and/or division, which are regulated by the order parameter distribution and its gradient.



This image shows atomic electron tomography captures 4D atomic motion in an iron-platinum nanoparticle at three different annealing times.

Miao has led a team that developed 4D atomic electron tomography (AET) to study early stage nucleation at atomic resolution.

These experimental observations were corroborated by molecular dynamics simulations of heterogeneous and homo-geneous nucleation in liquid-solid phase transitions of Pt. Their experimental and molecular dynamics results differ from classical nucleation theory (CNT), indicating a theory beyond CNT is needed to describe early stage nucleation at the atomic scale.

Looking forward, 4D AET is expected to open the door to study many fundamental problems in materials science, nano-science, condensed matter physics and chemistry such as phase transition, atomic diffusion, grain boundary dynamics, interface motion, defect dynamics and surface reconstruction with 4D atomic resolution.

Neurophysics Laboratory

Prof. Mayank R. Mehta

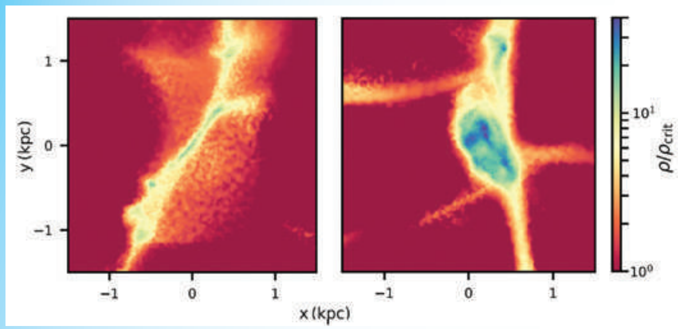
HOW DOES THE BRAIN CREATE abstract concepts from concrete, physical stimuli? This has been the focus of our research. In the past few years we discovered how the brain creates the perception of abstract space, time, distance and orientation, using virtual reality. During the last year we pushed this line of research further to measure how the brain makes memories of these perceptions as well as of events.

Our results provided surprising new insights about how vast networks of neurons make memories of abstract events. Even more exciting, these results are entirely consistent with a biophysical theory of memory formation that I developed twenty years ago. These insights would not be possible without a convergence between experiments and theory. The results resolve nearly half a century old quest about memory of abstract events.

Future research would reveal the fundamental mechanisms of how memories and abstractions are formed and how they get corrupted in a variety of diseases, ranging from autism to epilepsy and Alzheimer's, and pave the way for better artificial intelligence.

Our findings have challenged the prevailing hypotheses, and hence are met with considerable resistance. But, with mounting evidence, from our and other labs, our theories are rapidly gaining wider acceptance.

For example, the journal Nature made a documentary that focused on our body of research, a great honor: https://www.nature.com/articles/d41586-019-02154-x. For details, see my recent TEDx talk on "Space, Time and Imagination", that has gained considerable attention: https://youtu.be/o4Ey8JzTDBo.



Exotic Astrodynamics

Prof. Smadar Naoz

ALMOST EVERY GALAXY, our own Milky Way included, has a supermassive black hole (BH) in its heart, accompanied by a crowded place of stars and compact objects. This year, Naoz's group showed that this unique place dramatically influences the fate of stellar binaries (Stephan et al. 2019). For example, we showed that it could lead to type Ia supernova explosions, BH-Neutron star mergers (detectable by LIGO), as well as a high abundance of stellar-mass BH binaries. We then provided a unique technique aimed at disentangling the variety of mergers sources. Specifically, a supermassive BH induces a time-evolving imprint on the eccentricity the BH binaries, detectable by LISA (Hoang et al. 2019).

Most if not all of massive stars reside in binary or triple configurations. Since most observations focus on their midlife stage, little is known on their birth orbital distribution. Not any more! We showed that massive stars in triple configuration carry a signature of their birth orbital distribution (Rose et al. 2019). Focusing a well-studied massive star called V Hydrae, we found that its periodically violent material ejection may be a result of a binary companion pushing a planet into V Hydrae (Salas et al. 2019).

Finally, the oldest population of stars and compact objects are known to reside in dense star clusters called globular clusters that have little to no dark matter in them. What is the origin of these puzzling objects? We showed that these objects are linked to supersonically induced gas objects (with little to no dark matter) that are predicted to exist in the early Universe (Chiou et al. 2019).

Theoretical Plasma Physics

Prof. George Morales

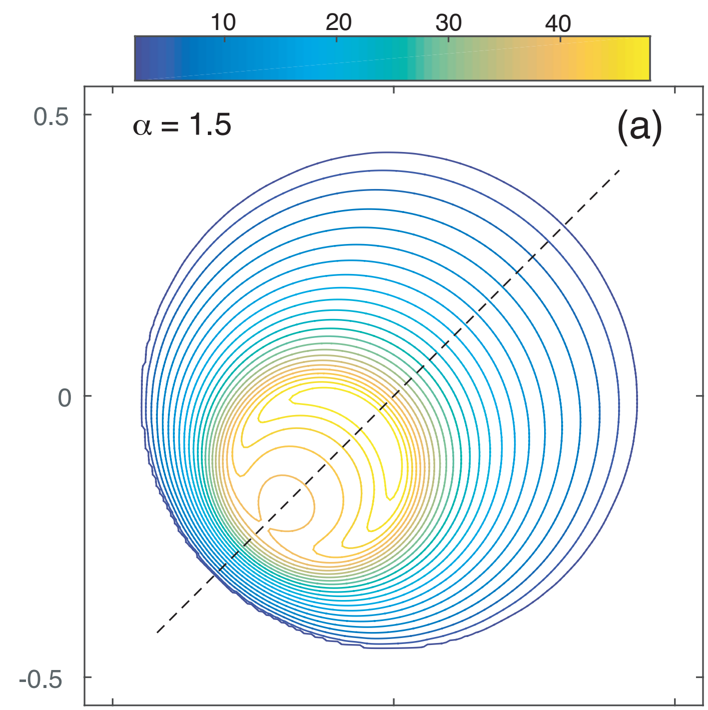
We study plasmas in regions beyond where the standard rules of statistical mechanics apply.

PROF. GEORGE MORALES, in collaboration with emeritus researcher J. Maggs, Dr. B. Van Compernolle, and graduate student Matthew Poulos, is pursuing the investigation of nonlocal transport. Although the problems are motivated by applications to plasmas made in the laboratory or naturally occurring in space, the techniques developed and the insight gained are applicable to a broader class of systems that are not in thermal equilibrium. Such conditions arise when the systems are subjected to intense heating or compression.

In those situations, the usual concepts of statistical mechanics are not adequate. The associated transport of heat and mass is nonlocal in the sense that the fluxes do not satisfy Fick's law; what occurs at one location can have global consequences. The underlying phenomena can take the form of intermittent avalanches, tornados, and catastrophic collapses of the density and temperature profiles. Instead of diffusion occurring through random stochastic processes, the behavior is determined by chaotic dynamics.

One significant advance made during the last year is the development of an iterative technique that allows the calculation of nonlocal transport in arbitrary geometries [J. E. Maggs and G. J. Morales, Phys. Rev. E 99, 013307 (2019)] (see figure). The technique has been used [J. E. Maggs and G. J. Morales, Phys. Plasmas 26, 052505 (2019)] to explain the unusual transport behavior observed in the LHD fusion device in Japan, whose geometry is extremely complicated.

Below: A nonconcentric heating source is applied inside a cylindrical system in which nonlocal transport takes place.



Very High-Energy Astrophysics

Profs. Rene Ong, Vladimir Vassiliev

THE GROUP LED BY RENE ONG AND VLADIMIR VASSILIEV works in the area of astroparticle physics and very high energy (VHE) astrophysics. The group consists of postdocs Ralph Bird, Sean Quinn and Ruo-yu Shang and graduate students Matt Buchovecky, Jamie Ryan, and Brandon Stevenson. A key focus is to explore highly non-thermal processes capable of producing VHE particles that are detected on Earth.

Sources able to produce such particles are typically powered by intense gravitational or electromagnetic potentials. Another focus of the group is the search for dark matter that is so far invisible and could constitute up to 90% of the material in the universe.

The Ong-Vassiliev group is pushing the frontiers of these areas through two primary experimental techniques. The first uses ground-based telescopes that detect VHE photons (gamma rays) using the atmospheric Cherenkov technique. The second involves balloon-borne detectors to search for unexpected components of antimatter.

UCLA is a major partner in the VERITAS Observatory in southern Arizona that consists of four 12m-diameter atmospheric Cherenkov telescopes. VERITAS has produced many significant discoveries during the last decade; it continues to operate well and is funded for continued operations. Within the last year, the UCLA group announced two exciting results: the discovery of a new VHE binary system called PSR J2032+4130 and the detection of a new diffuse component of VHE gamma rays near the Galactic Center.

The future gamma-ray observatory beyond VERITAS is the Cherenkov Telescope Array (CTA) that will consist of two large arrays of telescopes, one in the north (La Palma, Spain) and one in the south (Paranal, Chile). The project is being developed by a consortium of 1,400 scientists from 31 countries; UCLA has had major involvement in CTA since its inception.

Rene Ong serves as Co-Spokesperson of CTA and recently edited the book describing the CTA science case (*Science with the Cherenkov Telescope Array*[1]). Vladimir Vassiliev leads the development of an innovative two-mirror telescope for CTA called the Schwarzschild-Couder Telescope (SCT). A prototype version of the SCT has been built using funding from NSF and the University of California and was successfully inaugurated on January 17, 2019[2].

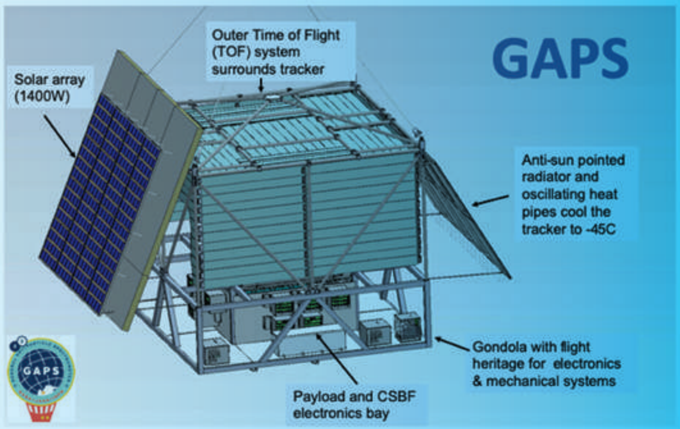
The techniques of experimental particle physics are allowing us to understand astro-physical objects and perhaps even dark matter.

A compelling dark matter candidate is the weakly interacting massive particle (WIMP), which could be detected through a unique signature of excess antimatter.

Astrophysical antideuterons (an antiproton and antineutron) have never been detected and so a clear signal for them would be an important result. A group led by Rene Ong is working with other institutions in the U.S., Japan and Italy to build the GAPS experiment that will search for antideuterons using a balloon-borne instrument in the Antarctic. GAPS is funded for a first scientific launch in late 2021.

[1]http://www.worldscientific.com/worldscibooks/10.1142/10986

[2]http://newsroom.ucla.edu/stories/ucla-leads-development-of-first-of-its-kind-telescope-for-gamma-ray-astronomy



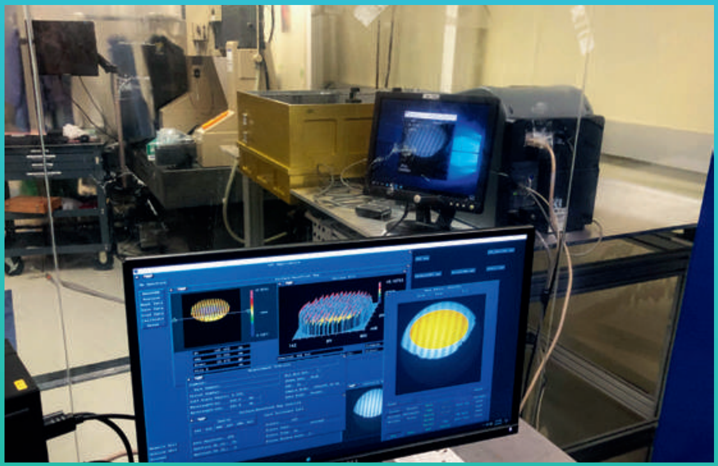
The figure shows a drawing of the full GAPS instrument.

Many-Body Physics

Prof. William I. Newman

LAST YEAR, Prof. Newman was a sabbatical member of the Institute for Advanced Study in Princeton and was named a fellow of the IBM Einstein Foundation. He focused primarily on solar system evolution issues. Using celestial mechanical methods pertaining to the three-body problem (Sun-Jupiter-planetesimal) as perturbed by Saturn, he and collaborators also performed large scale computer simulations answering the question of why Earth has undergone only a handful of major collisions.

In research relating to nearest-neighbor clustering, he extended his earlier closed-form analysis together with UCLA physics graduate student Philip Lu to dimensions 2 and above demonstrating that randomly distributed uncorrelated points form self-contained groups with an average of 3 points (in one dimension) up to many as 4. Nearest-neighbor interactions are pervasive in physics and this result has implications in arenas ranging from cosmology to small-world networks.



Above: A new isolated optical plate was built to hold our test cryostat (gold) and Zygo interferometer adjacent to our Coordinate Measuring Machine (CMM). This setup will be used to evaluate alignment procedures for the optical systems employed by IRIS.

Below: The NIRSPEC upgrade in progress. With the outer vacuum shell already removed, the internal cold shield is raised to provide access to the NIRSPEC optical bench, mechanisms and detectors. Two new detectors were installed.

Infrared Laboratory

Profs. Ian McLean, James Larkin and Michael Fitzgerald

Our state-of-the art infrared instruments are used by astronomers from around the globe at the world's most advanced telescopes.

THE UCLA INFRARED LABORATORY for Astrophysics (or IR Lab) was initiated in 1989 when Eric Becklin and Ian McLean joined the faculty. Since that time, the IR Lab has trained many students, and has delivered state-of-the-art infrared cameras and spectrometers to several different observatories. For example, of the four infrared instruments currently in use at the twin 10-m telescopes of the W. M. Keck Observatory (WMKO) in Hawaii, three were built under the leadership of UCLA faculty, and the IR Lab collaborated with Caltech to produce the fourth instrument. During the past year our group completed two major upgrades for WMKO; the OSIRIS Imager upgrade, and the NIRSPEC Detector upgrade. UCLA is also the lead institute in a multinational collaboration to build IRIS, a "first light" integral field spectrograph for the proposed Thirty Meter Telescope (TMT).

The Infrared Imaging Spectrograph (IRIS) is led by Professor James Larkin. Spanning the wavelength range from 0.84-2.4 microns, IRIS combines a wide-field diffraction limited camera, and an integral field spectrograph. A large international collaboration has been established to build IRIS, which has an estimated total budget of $45 million. Partners include UC San Diego, UC Santa Cruz, Caltech, NRC-Victoria, and the National Astronomical Institute of Japan (NAOJ). IRIS provides a base spectral resolving power of R~4,000 (8,000 in some modes), and can be used with four different image scales (0.004, 0.009, 0.025, 0.050 arcsec per sample). The associated imaging section of IRIS has a relatively large 34 arcsec field of view by using a 2 x 2 grid of 4K x 4K (H4RG) HgCdTe detectors from Teledyne Imaging Sensors. The plate scale for the imaging mode is a remarkable 0.004 arcsec per pixel.

During the past year Professor Michael Fitzgerald led the construction of a new OSIRIS Imager for Keck Observatory as part of the upgrade to this instrument that was first delivered in 2005 by Professor Larkin. The new imager improves sensitivity, and provides better and more stable imaging over a 20 x 20 field with the fine sampling required for precision astrometry. The upgrade was funded by the Gordon and Betty Moore Foundation, with cost matching from UC Observatories and UCLA.

Funded by a Major Research Instrumentation (MRI) grant from the National Science Foundation, UCLA contributed to the upgrade of yet another Keck instrument. Known as NIRSPEC, it was commissioned in 1999 by Professor McLean and was the first cross-dispersed, high-resolution 1-5 micron cryogenic echelle spectrometer on any 10-m class telescope. Led by Professor Fitzgerald, the first on-sky commissioning of the upgraded instrument happened in December 2019. The IR Lab team is also working with Caltech on a Fiber Extraction Unit that will reimage the output of a single-mode fiber bundle onto the NIRSPEC slit.

By leveraging on our IRIS and OSIRIS experience, we are developing the concept for a more advanced integral field spectrograph for Keck called Liger. With initial funding from the Heising-Simons foundation, this future project will be led by former UCLA student Professor Shelley Wright, now at UC San Diego, in collaboration with Professors Larkin and Fitzgerald. Finally, Professor Fitzgerald is acting as the point of contact for a potential second-generation instrument for TMT called PSI (Planetary System Imager).

The Universe on Grand Scales

Prof. Tommaso Treu

WE PROVIDED the most stringent limits on the free streaming length of dark matter to date, based on a phenomenon called flux ratio anomalies. Our measurement leaves very little room for warm dark matter as a solution to the small-scale problem of galaxy formation[3].

We provided a new determination of the timeline of cosmic reionization based on the opacity of Lyman-alpha during the epoch of formation of the first galaxies[4].

Our group received funding from NSF and NASA to support its research. Simon Birrer was awarded a Kavli Postdoctoral Fellowship at Stanford. Xin Wang completed his Ph.D., received the 2018 Chinese Government Award for Outstanding Graduate Students Abroad and started as a postdoctoral fellow at Caltech. Graduate student Anowar Shajib received a dissertation year fellowship.

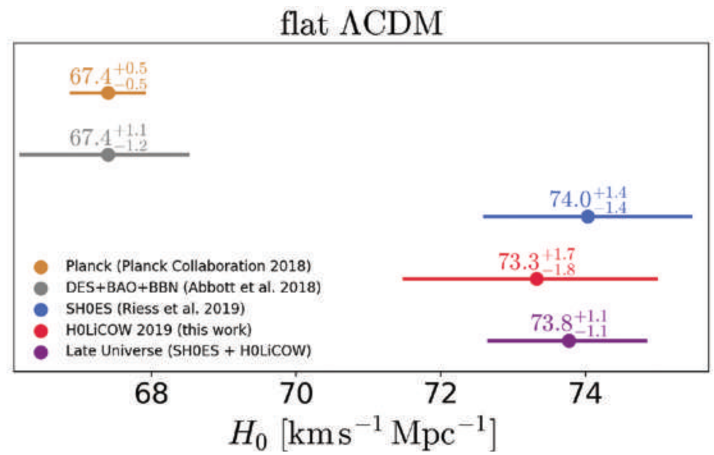


Figure. Our group [H0LiCOW] determined of the expansion rate of the universe H0 to 2.4% precision using multiply imaged quasars[1]. The purple point (combination of the blue and red points) is inconsistent with the points to the left at very high statistical significance. The tension between early and late universe probes could signal new physics beyond the standard model[2].

[1]Wong et al. 2019
[2]Verde, Treu & Riess 2019
[3]Nierenberg et al. 2019; Gilman et al. 2019
[4]Mason et al. 2019; Hoag et al. 2019

QCD and Nuclear Theory

Prof. Zhongbo Kang

THE RESEARCH GROUP led by Prof. Kang continues their study in Quantum Chromodynamics (QCD) and strong interactions. In the past year, they have made significant progress in understanding internal substructure of jets at the Large Hadron Collider (LHC), the highest energy collider in the world.

Jet physics are part of an exciting program at the LHC to measure fundamental parameters of QCD, map out internal landscape of the proton, search for physics beyond the standard model, and study quantum properties of emergent phenomena. Internal substructure of jets provides rich/novel information out of each collider event. In JHEP 1810 (2018) 137 and Phys. Lett. B 793 (2019) 41, we provide the most advanced theoretical computations for invariant mass distribution of a jet, which agree with the recent LHC data very well. This paves the way to precision study of jet substructure at the LHC.

Our team has received wide recognition in the community recently. Graduate student John Terry won a prestigious Graduate Research Fellowship from the National Science Foundation. Graduate student Jared Reiten received a prestigious fellowship from UC Office of the President: UC-National Lab Graduate Fellowship. With such a fellowship, Jared has the unique opportunity to conduct research at Los Alamos National Laboratory.

Our postdoctoral scholar Dingyu Shao won a joint fellowship from Center for Frontiers in Nuclear Science of Stony Brook/Brookhaven National Laboratory (BNL). Zhongbo also received a RHIC & AGS Merit Award from RHIC/AGS Users' Executive Committee at BNL. He was cited "for his unique and ground-breaking theoretical contributions to the field of transverse momentum dependent parton distribution functions and jet physics."

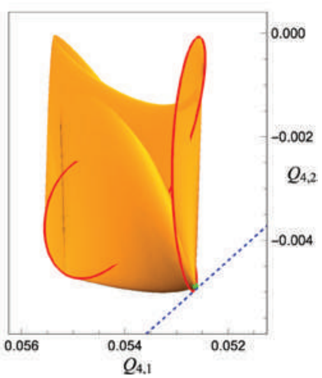
Physics of Viruses

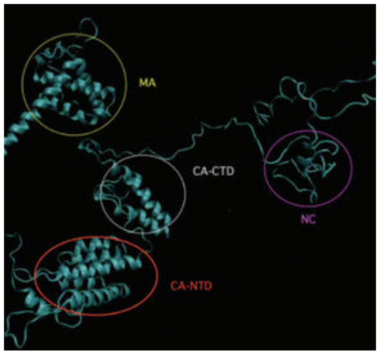
Prof. Robijn Bruinsma

OUR RESEARCH AIM IS TWOFOLD: First, to apply physics to understand how viruses work at a fundamental level when they are viewed as active "molecular machines." This can be compared to the development of thermodynamics as a basic science of macroscopic engines. To that purpose, we use a combination of statistical physics with all-atom molecular dynamics simulations and the investigation of coarse-grained models. Using these methods, Chen Lin – a graduate student in our group – discovered this year that the assembly of the HIV-1 virus is controlled by a molecular-level "phase transition" between an active and a passive state of the key GAG structural protein of HIV. The picture shows a snapshot of one of our simulations, which were done in collaboration with the group of Orlando Guzman at UAM, Mexico City.

For our second aim, we study viruses with the aim of identifying fundamental problems in statistical physics. We found that the statistical mechanics of the ordering of a viral shell during the assembly process cannot be understood within the framework of current Landau Theory, our most fundamental tool for understanding transitions of state.

This year, we resolved this problem by noting that a similar problem was encountered in the analysis of the Standard Model of high-energy physics. We employed the Kim geometrical method that was developed to address this problem for the Standard Model and constructed a complete phase diagram for the assembly of the smallest viruses. The picture shows an example of the geometrical method he developed.





Left: A "Kim Plot" where Q represents quartic terms in Landau Theory.
Right: A frame of a simulation of the GAG protein dynamics of the HIV virus.

SPECIAL UPDATE: Galactic Center Group

Faculty & Senior Members: Andrea Ghez (Director), Tuan Do (Deputy Director), Eric Becklin, Mark Morris, Shoko Sakai, Gunther Witzel, Greg Martinez, and Smadar Naoz

THE GALACTIC CENTER GROUP (GCG) works to transform our understanding of black holes and their role in the evolution of galaxies with high-resolution observations. Best known for its discovery of the supermassive black hole at the center of our galaxy, the GCG has been monitoring stellar orbits at the heart of the Milky Way for more than 25 years.

The most exciting result this year from the GCG was the first test of Einstein's General Theory of Relativity (GR) near a supermassive black hole. Published in the well-known journal Science, the key measurements captured the three essential observational events associated with the closest approach of the star S0-2 to the supermassive black hole in April, May, and September 2018.

By combining these data with over two decades of observations, the team was able to discover how gravity works near a supermassive black hole, an object that embodies the breakdown of our understanding of gravitational physics.

To enable the collaboration to work together more effectively on the analysis and paper writing for this project, the GCG hosted a 3-day writing retreat and provided recent GCG Alum and Core Collaborator Aurelien Hees, who is a specialist in Gravitational Physics, with a three-month visiting scholarship to return to UCLA to work full-time.

Careful analysis showed that our measurements absolutely rule out Newton's law of gravity and are consistent with GR and opened the next chapter for UCLA's Galactic Center Orbits Initiative (GCOI) – new tests of gravitational physics.

Along with the Science paper, a number of other papers were published this year associated with these results. More information on these results can be found in the press release http://newsroom.ucla.edu/releases/einstein-general-relativity-theory-questioned-ghez. Altmetrics shows that to date, the paper has generated 96 news articles from 88 outlets, and is in the top 5% of research scored.

GCOI's rich and long-term data set has been the basis of multiple generations of students' theses and postdoc projects, as well as collaboration projects, across a wide range of topics in astronomy & astrophysics well beyond tests of gravitational physics with stellar orbits, which drive its observational design, and this year was no exception.

One of the most exciting and unexpected benefits of having more than two decades of high angular resolution data on the Galactic Center is the ability to first discover and now study the infrared emission associated with SgrA*, which has given the GCG a window into exploring black hole accretion physics. In this domain, an exciting result emerged during a GCG Keck Observing run in May 2019 when Sgr A* became unexpectedly bright – the brightest it has ever been observed at infrared wavelengths.

Although black holes do not emit any light of their own, the matter that is falling into the black hole is heated up due to friction and constitutes the light we see. It is not known yet exactly what

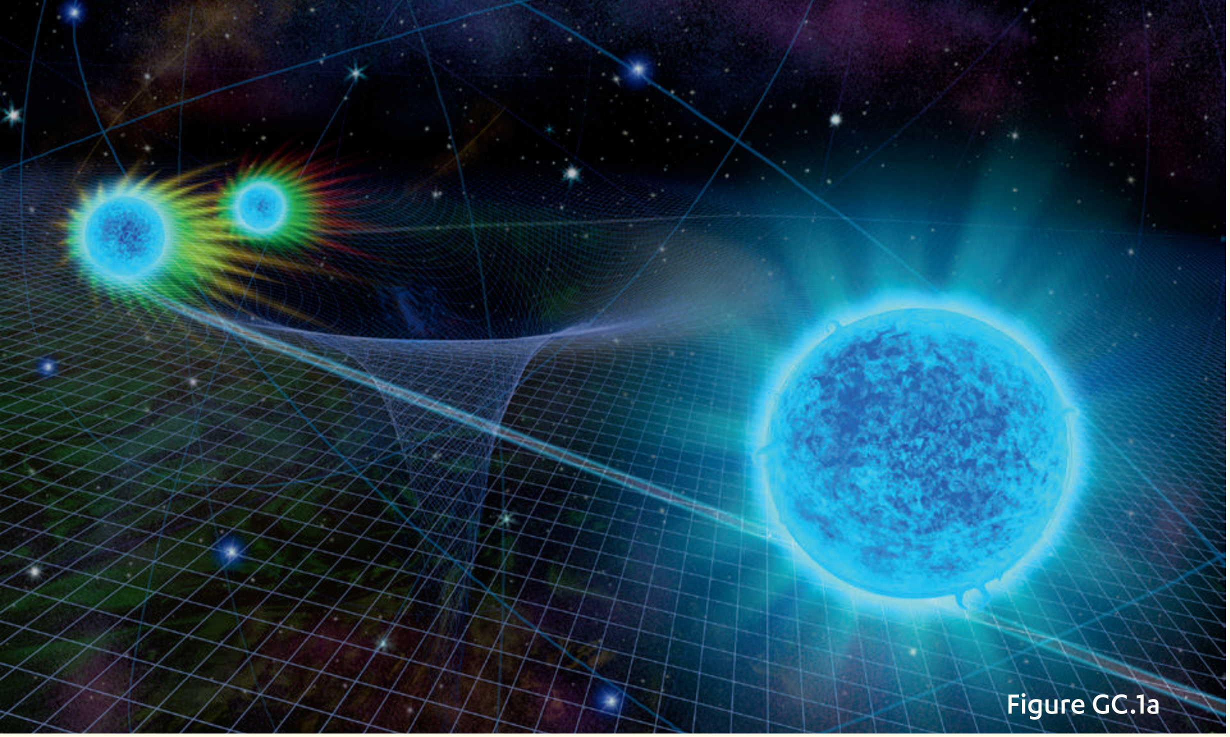


Figure GC.1a
A star known as S0-2 (the blue and green object in this artist's rendering) made its closest approach to the supermassive black hole at the center of the Milky Way in 2018, enabling the GCG to make the first test of Einstein's General Theory of Relativity near a supermassive black hole through measurement of the Gravitational Redshift. (Nicolle Fuller/National Science Foundation)

caused this flare but could have been the close passage of S0-2 last year or G2, a possible binary merger product, in 2014. Both ground- and space-based telescopes of multi-wavelengths have been targeting Sgr A* this summer to determine what is making it brighten.

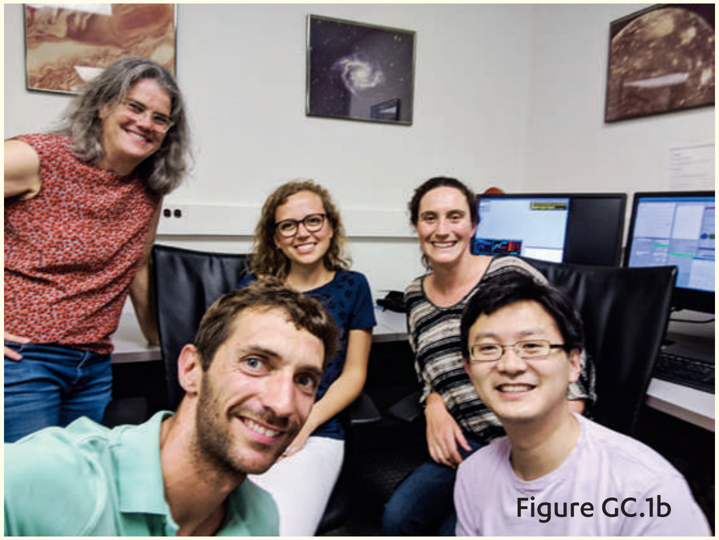
After many years of planning, funding for a next generation adaptive optics (AO) system at W. M. Keck Observatory (WMKO) has been approved from the National Science Foundation (NSF) ($7M) and the Moore Foundation ($4M). This project, known as KAPA (https://keckao.github.io/kapa/), is a partnership between the GCG and WMKO (Peter Wizinowich, KAPA PI, WMKO; Andrea Ghez, Head of KAPA Science Legacy Council and GCG Director), and Jessica Lu (KAPA Project Manager and GCG Associate Director for AO & Imaging). The KAPA acronym stands for the Keck All-Sky Precision Adaptive Optics project and is also a type of fabric made by native Hawaiians.

GCG leadership spearheaded the writing of a paper on the galactic center for the National Academy of Science's 2020 Decadal survey, whose purpose is to identify key priorities in astronomy for the coming decade. The paper lays out a vision for the next ten years of Galactic center science and points out the technologies that the GCG hopes to support (such as improving Keck Adaptive Optics and TMT) that will enable transformative science and the need for research centers in Astronomy.

Several students passed critical exams along their way to their Ph.D. degrees with projects based on GCOI data. Graduate student Kelly O'Neil passed her 2nd year qualifying exam (covering both her first two years of course work and her master's thesis research project), in which she developed a new statistical approach for improving orbital solutions for stars whose orbital coverage is low. This method has been applied to the stellar orbits in the Galactic Center, as well as to the directly-imaged exoplanets and has led to a new collaboration with the exoplanet community.

Graduate students Abhimat Gautam and Devin Chu passed their advancement to candidacy exam, which is the final stage of approval for their Ph.D. projects. This pair of students, ironically, are both studying binary stars and their work is illuminating a nice connection to the gravitational wave detections being made by the LIGO/VIRGO collaboration.

GCG Postdoc Matt Hosek took part in the TMT Early Career Initiative's 2018 Workshop. The workshop is designed to support international collaboration among the TMT partners by engaging those in the early stages of their career in TMT.



Five new members joined the UCLA GCG this year: three UCLA undergraduate students (Rebecca Lewis, Ethan Cochran, Evan Jones, and Shizhe (Alex) Chen; one graduate student (Rory Bentley); and two postdocs (Dr. Matt Hosek and Dr. Michael Scroggins).

Saying good-bye to the UCLA GCG were Arezu Dehghanfar, Sam Chappell, Gunther Witzel, and Bernie Boscoe as they took their next step in their educational/ professional journey. Arezu has begun a Ph.D. program at the University of Paris. Sam entered the field of data analytics. Gunther moved on to a research scientist position at the Max Planck Institute of Radio Astronomy (Germany), Bernie Boscoe is now a postdoc in Information Science Department at the University of Washington.

This is the first test of Einstein's General Theory of Relativity near a supermassive black hole.

Acknowledgments: The GCG gratefully acknowledges external support from the National Science Foundation, the W. M. Keck Foundation, the Heising-Simons Foundation, the Gordon & Betty Moore Foundation, Arthur Levine & Lauren Leichtman, Howard & Astrid Preston and the Star Society, and the institutional support received from UCLA, UC Observatories, and W. M. Keck Observatory.

Figure GC.1b (Left)
GCG team members capturing data from S0-2's closest approach in the UCLA Remote Observing Room, where they control instrumentation at Keck Observatory. From left to right are Ghez, Hees, Ciurlo, O'Neil, and Do.

Fig GC.1c (Below)
The results from the closest approach of S0-2, which provided the first measurement of how gravity works near a supermassive blackhole. Key to this work was having complete orbital phase coverage for this star, which has an orbital period of 16 years, prior to this event. The fitted deviation from Newtonian prediction, overlain with the best-fitting orbit model (sold red line). The Redshift Parameter, Y, describes the gravitational model and has a value of 1 for a purely relativistic signal (dotted blue line) and 0 for a purely Newtonian model (dashed blue line) for an orbit with the same orbital parameters. The final value reported in *Science Magazine* is 0.88 ± 0.17, which is consistent with the GR model at the 1σ confidence level while the Newtonian model is excluded at > 5σ confidence.

Other Highlights:

GCG Director Andrea Ghez received an honorary degree from the University of Oxford, a Leadership & Communication Award from Toastmasters, and served as the UCLA College Marshall at graduation as well as a search committee member for UCLA's new Executive Vice Chancellor. She also joined Brian Greene at the World Science Festival for their "Darkness Visible: Shedding New Light on Black Holes" event, which now can be viewed online https://www.worldsciencefestival.com/programs/darkness-visible-shedding-new-light-black-holes/.

GCG Deputy Director Tuan Do was offered and accepted a UCLA faculty position, which will begin July 2020. He created a dynamic Machine Learning Reading Group that meets weekly and that has been attended by over 40 people from the departments of Physics & Astronomy, Information Sciences, and Computer Science.

GCG Board Members Arthur Levine and Howard Preston and their families, along with the Dean of Physical Sciences, generously provided a match for an offer from the Heising Simons Foundation to create the Andrea M. Ghez term chair in Astronomy & Astrophysics at UCLA.

Professor Smadar Naoz was appointed to be the inaugural holder of a new endowed term chair generously created by Howard & Astrid Preston.

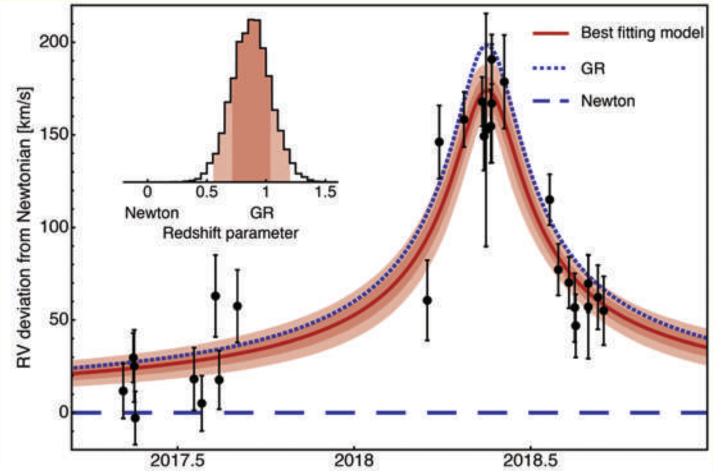


Figure GC.1c

We proudly welcomed two new faculty to the department in Fall 2019.

Professor Anshul Kogar

PROFESSOR ANSHUL KOGAR joined the Hard Condensed Matter Physics group in July 2019. Professor Kogar did his undergraduate studies at UCLA before getting his Ph.D. from the University of Illinois. There, he developed a new experimental method to probe condensed matter systems which now goes by the name of momentum-resolved electron energy loss spectroscopy or M-EELS. Using this method, he showed that the charge density wave transition in 1T-TiSe2 is driven by exciton condensation. Since then, he has pursued postdoctoral research studies at MIT using ultrafast electron diffraction studies on charge density wave systems.

"When I first moved to the U.S. about 14 years ago, UCLA was where I landed. I am so excited to give back to the community where I've felt most at home in the U.S."

Professor Erik Petigura

PROFESSOR ERIK PETIGURA joined the Astronomy and Astrophysics Division in July 2019. Prior to his appointment at UCLA, Professor Petigura was a Hubble Postdoctoral Fellow at Caltech. His main research interests are the discovery and characterization of extrasolar planets, using ground- and space-based telescopes. Professor Petigura completed his undergraduate work in physics and astrophysics at UC Berkeley. For his thesis, also completed at Berkeley, he worked with the Kepler space telescope to measure prevalence of planets as small as Earth. This work was awarded the 2014 Cozzarelli Prize from the National Academy of Sciences.

"Teaching at UCLA has been a dream of mine for years. The department is lovely, and everyone is so collegial and supportive. I'm also a product of California public schools from grade school up to my Ph.D. I'm a firm believer in the mission of the University of California, and I'm thrilled to contribute to it."

In Memoriam: Elihu Abrahams

ELIHU ABRAHAMS, 91, a towering figure in theoretical physics, died on October 18, 2018. In 2009 he moved to UCLA as a Distinguished Adjunct Professor where he continued cutting-edge research to his last day. Abrahams was a Fellow of numerous prestigious societies. He was unfortunately unable to collect his 2019 Oliver E. Buckley Prize from the American Physical Society. A blackboard was dedicated (2019) in his name at the Aspen Center for Physics. It will remind us of his deep respect for good science.

"He was very encouraging to students and younger colleagues and showed up diligently at my group meetings. I will miss him and his words of wisdom immensely, as will everyone else."

– Sudip Chakravarty

Teaching Innovations in the Department

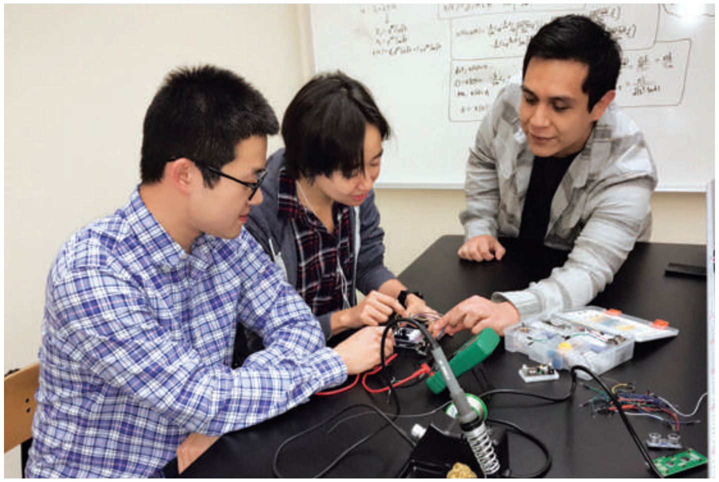
THE DEPARTMENT teaches well over 10,000 students per year. More and more of our faculty members use active learning and other modern teaching techniques. Active learning has been proven more effective than the more passive "chalk and talk" education. While all the students benefit from this approach, underrepresented minorities show particularly dramatic improvements in their learning outcomes.

Professors Michael Gutperle, Paul Hamilton, Jay Hauser, Alexander Kusenko, Matthew Malkan, Ian McLean, Christoph Niemann, Tommaso Treu, Jean Turner, and Nathan Whitehorn engage the students with the use of modern teaching tools, such as pre-lecture videos and in-class polling in Astronomy 3, Physics 1, Physics 5, and other courses.

Digital learning materials developed by UCLA faculty members and available on kudu.com are used in other universities as well. This work improves the students' educational experience, helps the students save money on textbooks and clickers, and has also generated some funding for a student fellowship and for several scientific conferences.

The introductory physics lab classes for scientists and engineers have been completely revamped. As before, the focus is on comparing measured outcomes to physics predictions. Students now purchase their own inexpensive data acquisition systems that include numerous sensors and Arduino processors that plug into laptops. Students use the open source Python computer language to analyze their data and make plots. Armed with these powerful, modern, and easy-to-use measurement tools, students carry out and present creative group projects. As a result of the changes, the students now greatly enjoy these classes, and enrollment has nearly doubled.

Stay tuned: Next year we will report on recently introduced teaching laboratory innovations.



Javier Carmona (right), Tiema Qian (left) and Pauline Arriaga (middle) prepare the new Arduino-based laboratory controller and its sensors for the 4A/B-L introductory laboratory class.

Galactic Center Group Outreach

EVERY YEAR, GCG members enjoy sharing black hole science with the general public through a wide variety of forums including talks, documentaries, textbook contributions, interviews, and press releases. One of the group's favorites is Exploring Your Universe (EYU), which was launched by Astronomy & Astrophysics graduate students a decade ago (including GCG Alumna Breann Sitarski) and which has become the largest STEM (Science, Technology, Engineering & Math) event at UCLA, attracting thousands of families to campus the first Sunday of November each year.

At the GCG booth this year, the team shared their exciting results on the closest approach of S0-2 to the supermassive black hole and had demonstrations on how infrared (IR) light behaves and how some telescopes use IR cameras to study the universe.

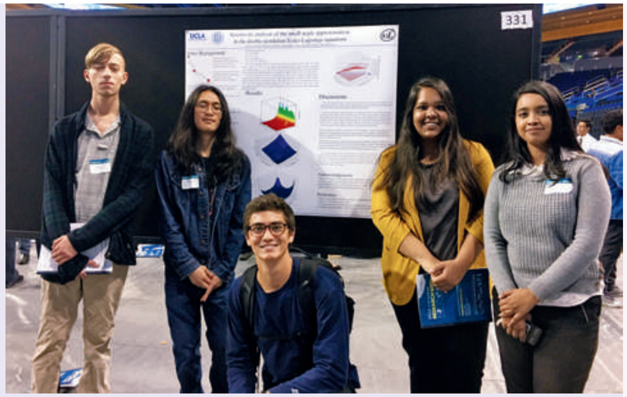
You can also join the GCG through the UCLA Alumni Travel program. They will host trips to Iceland in July 2020 and Antarctica in Jan 2021: https://travel.alumni.ucla.edu/tours/2020-07-circumnavigation-of-iceland/.

As members of the Keck Observatory and the TMT community, the GCG actively works to reach students and the general public on the Big Island of Hawai'i. The GCG has a particularly good and long-term engagement with two programs: Journey Through the Universe's Family Science Day and Astronomy Educators in the Classroom, which brings science and career advice to students on the Hawaiian Island (https://www.gemini.edu/node/1181) and the Akamai Workforce Initiative internship program, which is a program designed to help students from Hawai'i with career development in STEM fields (https://akamaihawaii.org). GCG Graduate student Devin Chu is an alum of the Akamai program and is now developing new projects within this program.

The Galactic Center Group was delighted to be awarded its first grant to formally pursue its mission to inspire and support the next generation of women and minority leaders in science. Funded by the Heising-Simons Foundation, the new "Empowering Transformational Leadership" program provided support for women visiting scholars, for community-building activities for the eight women faculty (out of 60 total) in the department of Physics and Astronomy, and for teaching support for Astronomy & Astrophysics Vice Chair Alice Shapley, as she stepped into this leadership role.

Young guests at Exploring Your Universe discovered how they look in an infrared camera at the demonstration booth presented by the Galactic Center Group.

The Upsilon Lab



Undergraduate students present their research.

UPSILON LAB AIMS TO PROVIDE its members with training and knowledge that reaches beyond their classes and equips them to enter professor-sponsored or lab-based research. With that as its goal, it undertakes a number of projects throughout the year to provide that training and experience. Each project is led by an undergraduate student manager and generally consists of six to eight students.

During the 2018-2019 school year, Upsilon Lab ran nine projects:

The pilot waves project (manager, Alexander Tolstov; sponsored by Prof. Putterman) worked to replicate the hydrodynamic pilot waves shown in the John Bush paper, Pilot-Wave Hydrodynamics.

The PID w/ microcontroller project (manager Helena Huang) created a car using an Arduino development board that could sense objects in front of it and stop before hitting the object.

The elementary particle detection project (manager PJ Smigliani; sponsored by Prof. Whitehorn) sought to build a cloud chamber to detect muons reaching the Earth's surface.

The cyclotron motion simulation project (manager Jared Rivera) used Python to simulate the movement of charged particle in a magnetic field.

The efficient electricity generation project (manager Mercedeh Khazaieli) used Python to simulate various energy-generation methods (e.g. photovoltaics, wave power, and thermelectronics) and optimize their efficiency.

The solar team project (manager Emma Peavler) created an interactive graphical program in Python that calculated various properties of a solar cell depending on user-entered values for different parameters.

The modeling quantum systems project (manager Joshua Wong) uses Python to create a neural network that can be trained to guess the ground state wavefunction of an electron given any potential function.

The solid-state simulations project (manager Ahmad Bosset Ali) built a 3D-printer and explored ways to print complex structures.

Lastly, the course in introductory programming for physics (manager Suyash Kumar) taught programming skills and dove further into topics covered in Physics 1A such as pendulums and satellites in orbit.

Science Lab Teaching Club

THE SCIENCE LAB TEACHING CLUB is a group of students who give demonstrations about science topics at local elementary schools using equipment borrowed from the physics department's Demo Lab. The club aims to provide teaching experience for undergraduates and spark kids' interest in science by engaging them in it from a young age. Our members meet weekly during the school year to prepare lessons and practice lab demonstrations. The club has presented on topics such as energy, forces, gravity, electromagnetism, and waves, and is expanding to include other disciplines of science.

This year, the club engaged in many outreach activities at local schools.

MAY 10 • 2019

Fairburn Avenue Elementary School

MAGNETISM DEMONSTRATION: A magnetic needle array is used to demonstrate the magnetic field around a bar magnet. Kids are prompted to think about what would happen if a magnet is broken in half in different ways. They are told magnetic monopoles (explained) have not been experimentally discovered so far. They are then introduced to the idea of magnetic domains, which are demonstrated again with the magnetic needle array. Kids are asked to line up in the classroom and face in one direction, showing the magnetization of the bar magnet. The line is broken in half, and kids are told that since they are still facing the same direction, the two sub-lines also possess magnetization. We then demonstrate how paperclips, usually not appearing to be magnetic, can be magnetized by a magnetic field and attract other paperclips just like a magnet. Presenters: Erika Hoffman and David Su.

APRIL 27 • 2019

Grant Elementary School for their Science Expo Day

GRAVITY DEMONSTRATION: The fabric of spacetime “trampoline” is brought to the school with a few marble balls to demonstrate how the gravity cause the curved orbits of the planets.

MOMENTUM DEMONSTRATION: A dynamics track with carts is used to demonstrate the conservation of momentum. Presenters: Ken Li, Joshua Tavares, Alexander Tolstov, and David Su.

APRIL 23 • 2019

Wilson Plaza MLK Remembrance Day at UCLA

STRUCTURE OF THE ATOM DEMONSTRATION: A molecular-modeling kit is used to demonstrate how a molecule is made up from even tinier particles such as the atom. Kids are asked to throw ping-pong balls (alpha particles) at a basketball (gold nucleus), so kids get an idea of how Rutherford studied such microscopic objects as the atom. Colored ping-pong balls, labelled electron, proton, and neutron, are used to demonstrate the parts of an atom. Each kid is given one particle, and is asked to pair up with other kids so their particles would make up the atom as we know it. Presenters: Erika Hoffman, Alexander Tolstov, Ken Li, Joshua Tavares, Myank Singhal, and David Su.

FEBRUARY 28 • 2019

Pluralistic School One

POTENTIAL AND KINETIC ENERGY DEMONSTRATION: A dynamics track with various accessories such as weights, carts, springs are used to help kids practice using energy concepts to describe the phenomena they see. By physically moving cups from one stack to another, we help kids visualize how energy is converted from one form to another but never created or destroyed. Presenters: Myank Singhal, Alexander Tolstov, and David Su.

JAN 31 • 2019

Fairburn Avenue Elementary School

ELECTRICITY DEMONSTRATION: Kids are introduced to charges and how positive charges and negative charges interact with each other. Many demonstrations are brought to the classroom to demonstrate static electricity, including the Van De Graaff generator, Franklin’s Bell, the classic comb and plastic pieces, etc. Kids are also introduced to currents, the movement of charges. Simple series and parallel circuits were shown to the kids. Presenters: Scarlett Yu, Alexander Tolstov, and David Su.

Undergraduate majors travel to local elementary schools and share their passion for physics and astronomy.

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Exploring Your Universe

The Department's Astronomy Live! program has been engaging with K-12 students throughout Los Angeles for years, connecting future scientists with hands-on demonstrations and exciting learning opportunities at their schools or here at UCLA. Astronomy Live! was one of the founding partners behind Exploring Your Universe (EYU), a free, day-long public science festival on the UCLA campus, organized entirely by UCLA graduate students.

Photo above left: Helping to celebrate the 11th year of EYU was Mayim Bialik, UCLA alumna, author and star of the hit TV series "The Big Bang Theory" (pictured center). EYU student organizers from the Physics & Astronomy Department included Jordan Runco (far left) and Jon Zink (second from right). Fellow graduate students from the departments of Chemistry and Biochemistry and Earth, Planetary, and Space Sciences rounded out the organizing committee, which welcomed more than 10,000 attendees to campus on Nov. 3, 2019.