REFLECTIONS

REFLECTIONS: 2020 – 2021 YEAR IN REVIEW

UCLA DEPARTMENT OF PHYSICS & ASTRONOMY

UCLA College | Physical Sciences
Physics & Astronomy

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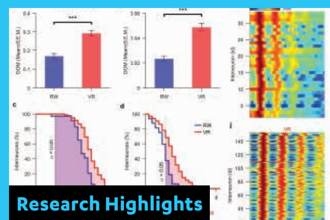

Cover: Photo by Annette Buhl.

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CHAIR'S MESSAGE

REFLECTING ON ACADEMIC YEAR 2020-21 is not a typical exercise. The year will be remembered as one with entirely remote instruction and social events. We can breathe some sigh of relief from the vantage point of today, with Fall 2021 being 80% in-person instruction. We are looking forward to being back 100% in the Winter Quarter of AY 21-22.

Despite being apart from one another, our research, learning, and social interactions continued—and even flourished in some respects. By the quantitative measure of this year's edition of Reflections, we even had to add four pages. I am beyond thrilled to have a feature article celebrating Andrea Ghez's 2020 Nobel Prize in Physics. While many campus publications have covered Prof. Ghez's and her collaborators' groundbreaking work, because this article is of and for the Physics & Astronomy Department, we are able to go into much more scientific and technical depth. It is with pride that I point out that this piece was written by a current Astronomy and Astrophysics graduate student, Briley Lewis.

I hope you enjoy this edition. In addition to the unprecedented feature article, we ask you to meet the Vice Chairs who help to sustain our department and its key activities. A cornucopia of research accomplishments are given to entertain and educate our current (and future) alumni. I also invite you to read how the undergraduate and graduate students' outreach activities rose to the challenge of remote life. To learn more, please visit our "Clubs" link on the top of the P&A homepage: https://www.pa.ucla.edu/.

Once again I want to thank all our supporters during this difficult time. The pandemic brought extra expenses ranging from audio-visual equipment to student financial support. Your generosity to the Chair's Discretionary Fund allowed us to be nimble and go beyond the limitations of our state and federal support. And I thank our dedicated departmental staff, whose behind-the-scenes work made this all possible.

I wish good health and a productive year to our entire P&A community and their loved ones.

Warm regards,
DAVID SALTZBERG
Chair, Department of Physics and Astronomy

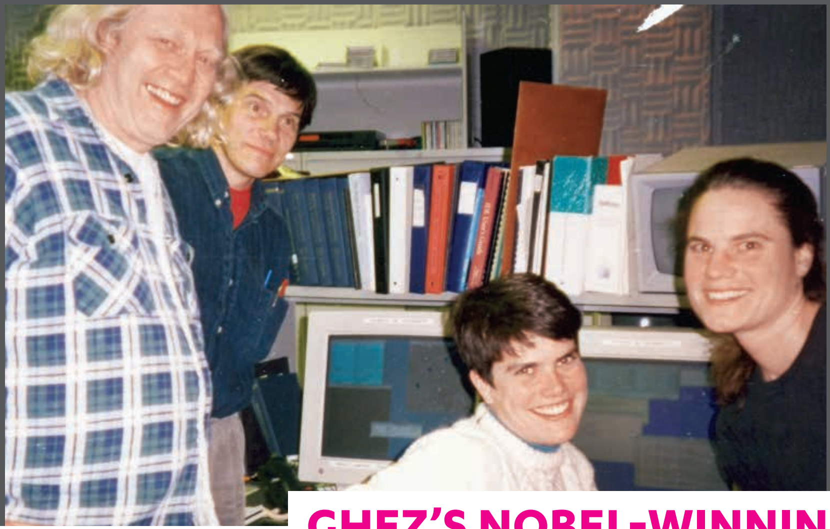
Photo by Annette Buhl

By Briley Lewis

ANDREA GHEZ
and the mysteries of the galactic center

At the center of our Milky Way, there is a black hole known as Sagittarius A* (Sgr A*). This fact seems commonplace to most current astronomy students yet the discovery of Sgr A* is relatively recent, only as old as most of those current students. Our very own Andrea Ghez, Lauren B. Leichtman and Arthur E. Levine Professor of Astrophysics, was awarded the 2020 Nobel Prize in Physics for this discovery, using observations from the Keck Telescopes to decisively show that there is, in fact, a black hole at the galactic center.

As Ghez, Director of UCLA's Galactic Center Group, explains, understanding our Galaxy is vital to understanding the universe as a whole. The galactic center is the only place we can observe a supermassive black hole (SMBH) and its surrounding environment with such detail, exploring how SMBHs shape galaxy evolution and how astrophysical processes work in such an extreme environment.



Ghez (second from right) in 1996, observing at W. M. Keck Observatory in Waimea (Kamuela). From left to right: Prof. Eric Becklin, Prof. Mark Morris, Ghez, and Beth Klein.

GHEZ'S NOBEL-WINNING RESEARCH

> "The Nobel is not 'You're done!' or time to rest on your laurels, but the opportunity to help your group continue," Ghez says.

This Nobel-winning work began as a simple question: Is there a supermassive black hole at the center of our galaxy? As a recent faculty hire in the 1990s, Ghez teamed up with Profs. Eric Becklin and Mark Morris to address this question by measuring the motions of stars around Sgr A*. They knew the Keck Observatory, which UC had a stake in, would be revolutionary, and Ghez knew she wanted to be a part of that. "I turned down faculty offers to get to UCLA," she remembers.

At that point, the Keck Observatory – two twin 10-meter telescopes atop Hawaii's Mauna Kea – was just about to come online. Astronomers were struggling with the idea of what was at the center of the Galaxy. Someone needed to show that the extreme mass at the galactic center was confined to a small enough volume that it had to be a black hole.

However, even with a facility like Keck, observing the galactic center was no easy task. Measuring the motion of galactic center stars from our vantage point on Earth is like standing in Los Angeles and seeing someone atop the Empire State Building wiggle their finger.

In order to make that measurement, the team used a technique pioneered by Ghez known as speckle imaging, which used multiple short exposure images to improve resolution. This idea was so outside of the box that it was originally rejected by the committee in charge of assigning telescope time. They claimed that speckle imaging would never work, and even if it did, stars at the galactic center wouldn't be moving fast enough to measure.

Their proposal was eventually accepted, and they did, in fact, see stellar motions corresponding to orbits around an extremely massive object, strong evidence for a supermassive black hole. Speckle imaging worked, with an unprecedented ability to resolve positions as small as 0.1 milliarcseconds – enough to see that wiggling finger in New York City.

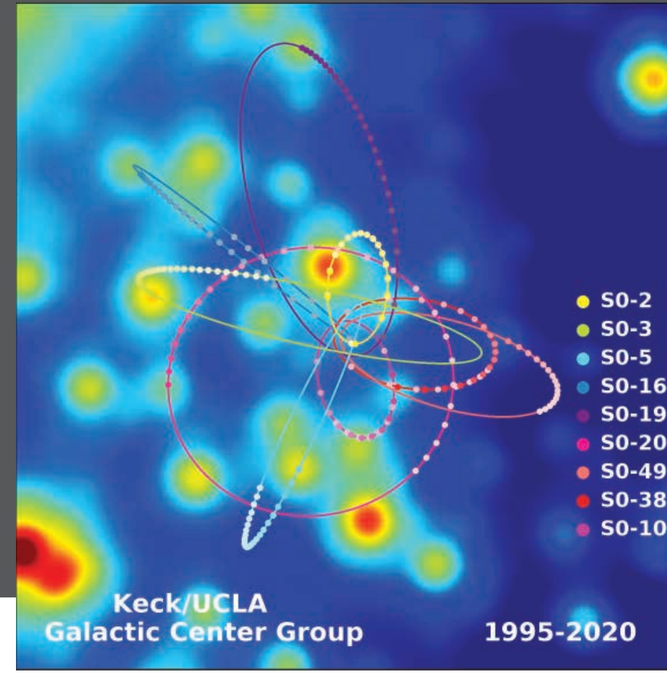
This success was only the beginning of the budding Galactic Center Group at UCLA. By 2000, they had measured accelerations for three stars in the galactic center, pushing back on theories claiming that there couldn't be a SMBH in our galaxy. Ghez says, "This [evidence] has made the galactic center the best case for a SMBH anywhere in the universe, demonstrating that these exotic objects really do exist...This is what the Nobel Prize was for." These observations also identified one star, known as S-02, with a period of 16 years – a reasonable timescale to observe an entire orbit.

In the early 2000s, adaptive optics (AO) was added to Keck, enabling even more precise observations of the galactic center and dramatically increasing the evidence for our central SMBH. Spectra revealed line-of-sight velocities, providing a 3D view of the galactic center. The first spectra of these stars also revealed a mystery known as the "paradox of youth", since the closest stars to the SMBH were unexpectedly young.

It's unusual to see such young stars near Sgr A* because the black hole's tidal forces should make star formation difficult (and the stars couldn't have migrated there quickly enough). Many solutions have been proposed to explain why the stars are there, from atmospheric stripping of old stars to dynamical migration, but the current hypothesis is that they actually formed in situ. This implies there may have been more gas around when these stars formed, and therefore past activity of the SMBH, similar to what we see in other galaxies as active galactic nuclei (AGN).

The group recently observed S-02 finish its orbit and make its closest passage to Sgr A*, allowing them to measure the relativistic redshift as a test of general relativity. As of 2020, the Galactic Center Group has been keeping an eye on Sgr A*

Left: Close up of KECK II single laser for the laser guide star system. Photo by Laurie Hatch Photography - http://www.lauriehatch.com/



Right: The orbits of stars within the central 1.0 X 1.0 arcseconds of our Galaxy. In the background, the central portion of a diffraction-limited image taken in 2015 is displayed. While every star in this image has been seen to move over the past 20 years, estimates of orbital parameters are best constrained for stars that have been observed through at least one turning point of their orbit. The annual average positions for these stars are plotted as colored dots, which have increasing color saturation with time. Also plotted are the best fitting simultaneous orbital solutions.

for 25 years, creating an incredibly rich decades-long data set that will enable science for years to come.

"Over the years, I thought it was conceivable that the work could have gone that far [to get a Nobel Prize], but I didn't think we'd get there yet," said Morris. "I've come to appreciate that Andrea and her group had really punched through the physics frontier in a more significant way than most astronomers can ever dream of."

A GREAT HONOR, A GREAT RESPONSIBILITY

This Nobel came as a pleasant surprise to everyone in the group – Ghez included. She expressed delight that this work has been recognized, understanding that it's a wonderful opportunity to spotlight the galactic center, her colleagues, and the amazing technical facilities they've had access to. However, she also considers it a tremendous responsibility.

"The Nobel is not 'You're done!' or time to rest on your laurels, but the opportunity to help your group continue," Ghez says.

As a scientific leader, she also wants to use this recognition to highlight UCLA, and what makes it a great place for this kind of scientific endeavor. In the 1990s, when Ghez joined the faculty, UCLA had a vision of becoming a leader in infrared astronomy for Keck. UCLA's involvement in Keck has been critical to her work – she calls it her "laboratory" and the "heart and soul" of this research.

Reflecting on her time at UCLA, Ghez describes how fortunate she feels to work at an institution that has been supportive of her research and ideas. She appreciates the risk they took to hire her only one year out of her Ph.D., and the strategy that our department has brought to hiring, finding colleagues with overlapping interests to collaborate. "The whole is greater than the sum of the parts in our department," Ghez says. "We can do things that are ambitious because of collaboration!"

Ghez also thanks UCLA for their role in helping the group gain outside support, allowing them to grow from a small collaboration to a full-scale research center. As postdoc Dr. Anna Ciurlo says, "There are only a handful of places around the world that study this region and UCLA is one of the best."

Ghez is only the fourth woman to receive the Nobel in Physics, and she takes this prize as an opportunity to highlight the contributions of women in science. "So few women are recognized in this way," she says. "It's an opportunity to encourage the next generation of women." Through personal experience, she recognized the importance of being a female role model, especially since there aren't many of them in physics. Ghez teaches first-year undergraduate classes to show students how a woman can succeed in STEM, and participates in documentaries and outreach efforts to reach a larger audience.

She also credits UCLA as a tremendous ally for her as a woman in the field, including in her role as a mother. "They've been amazing in supporting women and providing them with the key support that continues to enable them to be at the forefront…it sends the message that they believe in women having kids and doing great work."

THE FUTURE OF THE GALACTIC CENTER GROUP

The UCLA Galactic Center Group, started as a collaboration of three faculty members, has grown into a world-renowned research center with 24 core members, plus more collaborators across the globe. Ghez, reflecting on the growth of the group, excitedly noted how even when students graduate and move away, they continue to work together, bringing in new expertise from yet another new institution.

The sheer timescale of this project – 25 years monitoring a fraction of a parsec in our galaxy – is so unique, and the data set they have collected is invaluable. Even with the existing data, new science is constantly being done. "[Prof. Tuan Do] says this a lot, but every time you look at the galactic center in a new way, you find something that doesn't match up," says postdoc and recent UCLA grad Dr. Abhimat Gautam. "The Nobel science was just a part of this big thing; this data set can tell us so many other things."

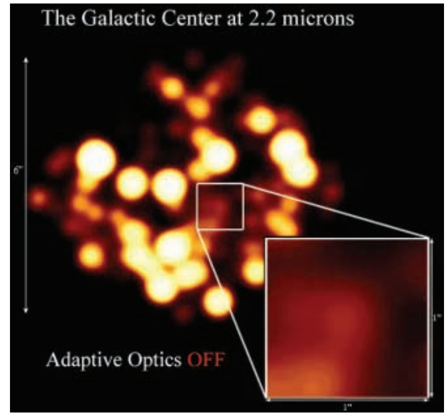
Understanding the galactic center is truly a team effort. Each group member is working on a piece of the puzzle, learning from each other to tease apart the story of this extreme region of space.

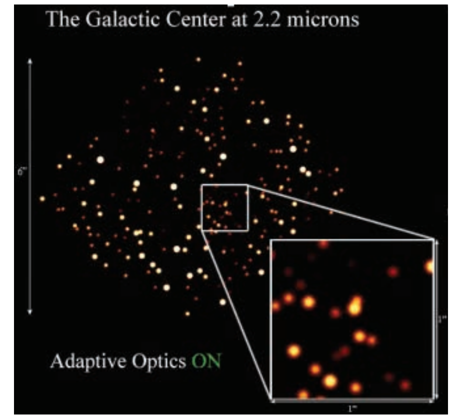
The group is far from done with unraveling the mysteries of the galactic center – Ghez calls it "the center of the galaxy that just keeps on giving." Ghez has built a thriving group here at UCLA, with many more discoveries on the horizon.

"It's amazing the number of experiments that can come out of well done work, especially when you do it carefully like Andrea does – very organized, driven, smart, methodical, very pleasant to work with, very enthusiastic, and a great supporter of UCLA and women in science," says Becklin.

Morris emphasizes the importance of her leadership, saying "I'll stress the fact that Andrea's leadership has put a strong role in the success of our group...everyone who has worked with her and gone through the group as a student or postdoc has been really gratified to have been part of this experience. And that includes me, it's been the highlight of my career to have been a part of this group and worked with Andrea."

Congratulations again to Andrea Ghez and the Galactic Center Group for the 2020 Nobel Prize!





Keck, Adaptive Optics, and the UCLA Infrared Lab

As Ghez says, "If you have the best tools, you can do the best science."

UCLA's Infrared Lab, founded in 1989 by Profs. Ian McLean and Eric Becklin, was created with a goal of supporting science "in the era of the Keck 10-meter telescopes." They have delivered multiple science instruments to Keck and other infrared facilities such as the airborne observatory, SOFIA. These instruments, such as NIRSPEC and OSIRIS, have also been crucial to the success of galactic center observations.

In the last few decades, there has been a revolution in both infrared astronomy and diffraction-limited observation. New infrared detectors have allowed for longer-wavelength and higher resolution images, and adaptive optics (AO) entered into astronomy. Ghez has been a part of this revolution, working on the development of AO at Keck since 1995. She obtained the first ever diffraction-limited images from Keck with her speckle imaging methods, and her work in high resolution imaging has been an important complement to the IR Lab's work on instrumentation.

AO allows astronomers to reach the diffraction limit by sensing disturbances in a wavefront, due to atmospheric movement, and correcting them. Keck uses a laser guide star system, where a laser excites sodium atoms around 90 km off the ground. This creates an artificial star the system can lock onto to observe how a light wave is perturbed as it travels to the telescope. AO technology is critical for the high-resolution observations required by the galactic center group, as well as other science cases, such as exoplanet imaging. An upcoming upgrade to Keck's AO known as KAPA will add a fifth laser, enabling even more science. "More lasers are always better!" says Prof. Tuan Do.

The UCLA Infrared Lab, as well as Ghez and the Galactic Center Group, will be involved with the next big step in instrumentation: 30 meter class extremely large telescopes (ELTs). The UCLA IR Lab is building an instrument known as IRIS for the Thirty Meter Telescope, one of America's ELT projects.

New Science Cases for the Galactic Center Group

Morris calls these "'Who ordered that?!' objects."

A "Cusp" of Dark Matter

Morris predicted years ago that there should be a cusp around the SMBH, a concentration of objects that have settled into its deep gravitational potential well. However, we don't see a cusp of luminous old stars. This leads the group to think a collection of stellar mass black holes, neutron stars, or even dark matter particles are lingering unseen around the galactic center.

Stars orbiting Sgr A* will "feel" this invisible mass, causing their orbits to change. This change manifests itself as precession, where the orbit slowly rotates over time. Now that S-02 has completed multiple orbits around the SMBH, the group finally has the data needed to start observing precession and measuring the extended mass distribution in the galactic center. Spectroscopy of another star, S0-102, with an 11 year orbit will soon provide another data point for these detailed gravitational studies.

Testing Fundamental Physics

In an extreme gravitational environment, such as that near the central black hole, relativistic effects can also cause precession. Interestingly, this precession is in the opposite direction of that expected from the extended mass distribution, making the precession smaller and harder to measure. Graduate student Kelly O'Neil is currently working on precision orbital constraints to enable this tricky measurement.

Prof. Tuan Do is also using the extreme environment of the galactic center to test a big question in physics: why are constants the values that they are? Do is particularly interested in the fine structure constant, which governs electron transitions in atoms. By observing spectra of stars in the galactic center, he is searching for differences in the fine structure constant to see "which pieces of physics are broken, and what needs to be revised."

Stellar Populations

We know there's a rich and diverse stellar population near Sgr A* – and, we know there are too many young stars. A leading idea for how the young stars formed requires a past accretion disk. Upcoming work from the group will provide some observational signatures to test this idea, focusing on the stellar binary fraction in the galactic center.

Binary stars can tell us about how star formation may have happened. If the star-forming clouds cooled very quickly, we may expect a higher binary fraction. Any deviations of the binary fraction in the galactic center from that of our solar neighborhood may suggest that the way stars form in the galactic center is different. However, the binary fraction is complicated by dynamics, a problem Prof. Smadar Naoz (Howard and Astrid Preston Term Chair) is working on.

Gautam is thinking about the binary fraction from a different angle. Using the group's imaging data, he has been using photometry to measure the observed binary fraction. Along with Naoz, their goal is to hone in on the intrinsic binary fraction.

They also found an old binary star in the data – strange, because "old binaries shouldn't exist at the galactic center" as Gautam explained. Just by existing, this binary puts a limit on the maximum amount of mass around it, as shown in recent work by graduate student Sanaea Rose.

Mysterious "G" Objects

Old binaries aren't the only surprise in the galactic center. The team also found unusual objects with the emission properties of gas clouds but the orbital behaviors of stars. Morris calls these "'Who ordered that?!' objects," but they're more commonly referred to as "G objects." One of these objects, G2, was found when it was only two years away from its closest approach to the black hole, and scientists expected it to accrete onto Sgr A*. Surprisingly, G2 survived its passage, remaining compact instead of being stretched, ripped apart, or destroyed.

Naoz proposed that a massive object was inside the G objects, surrounded by a "fluffy" shell of gas – something that could be produced from the merger of two stars. This process is expected in the crowded galactic center because of dynamical effects like the eccentric Kozai-Lidov mechanism. Ciurlo is still studying these G objects, searching for more to add to the observed population and looking in different wavelengths to address various formation scenarios.

Feeding a Black Hole

G objects are also interesting because they could trigger accretion events. Unexplained increases in black hole activity have been observed before, and a particularly large event in 2019 took the group by surprise. Sgr A* was the brightest they've seen it in the last two decades by a factor of two. Ciurlo describes those observations, saying that "we don't know exactly what was the meal, but we think he [Sgr A*] had a meal!"

"People have been thinking about Sgr A* for a long time," says Do. Various theoretical models predict many different outcomes for the emission of the black hole as it feeds. Depending on the characteristics of the accreting plasma, there will be different ratios of emission processes, which changes the color of the material around the black hole. New work from Do is using machine learning to enable color measurements of the highly variable Sgr A*, providing new constraints on its accretion. The galactic center is the only place we can observe black hole feeding and accretion flows in such detail, working to understand how accretion depends on the environment around a black hole.

"

Each of these endowment gifts received Dean's Gift Matching Funds to enhance their impact within the department.

Dean's Gift Matching Funds

UCLA PHYSICAL SCIENCES Dean Miguel García-Garibay is dedicating resources to inspire gifts that will transform the division's future through endowed support. We are committed to increasing diversity within the Physical Sciences, knowing that a broader pool of talent fosters greater scientific accomplishments that significantly benefit our society. Thus, endowment gifts in support of diversity, equity and inclusion will be matched more significantly.

Diversity, Equity and Inclusion
Qualifying gifts of $100,000 to $1 million to any Physical Sciences endowment aimed at increasing diversity, equity and inclusion will be matched at 100%.

Other Endowments
Qualifying gifts of $100,000 to $1 million to all other Physical Sciences endowments will be matched at 50%.

Dean's Gift Matching funds are limited and available on a first-come, first-served basis. To learn how you can establish your legacy through an endowment to support the Department of Physics & Astronomy, please contact Amber Buggs at amberbuggs@support.ucla.edu or (310) 994-5782.

The Impact of Giving

Donors who generously gave $100,000+ to establish endowments in the Department of Physics & Astronomy between July 1, 2020 – June 30, 2021.

SUPPORT FOR graduate students continues to be a top priority of the Department of Physics & Astronomy; they are the future of the field, are critically important to the undergraduate student experience, and contribute significantly to important research. This year two currently existing funds were grown and converted into new funds that will benefit graduate students for generations to come: the **Michael A. Jura Graduate Research Fellowship fund** and the **Bernard M.K. Nefkens Endowed Graduate Fellowship fund**. We are touched and grateful that gifts to establish both of these funds were made in loving memory of highly respected and fondly remembered physics and astronomy faculty members.

The **Michael A. Jura Graduate Research Fellowship fund** was established by Dr. Martha Jura in memory of her husband, Dr. Michael A. Jura. Dr. Michael A. Jura joined UCLA's faculty in 1974 and taught through fall quarter 2015. He played a major role in advancing scholarship in his field and shaping UCLA's Division of Astronomy and Astrophysics over the course of four decades. Among his many contributions to UCLA astronomy and astrophysics, Jura was instrumental in developing the infrared focus of the division when he chaired the department of astronomy in the late 1980s, and he played a central role in hiring many of the astronomy faculty. We are honored that the Michael A. Jura Graduate Research fund will support fellowships for UCLA graduate students studying astronomy for generations to come.

Martha and Mike Jura

The **Bernard M.K. Nefkens Endowed Graduate Fellowship fund** was established through a generous family gift made in loving memory of Dr. Bernard M.K. Nefkens by his wife Helen and their children and spouses, Charles and Jill Nefkens, Karla, J.D. '90 and William, J.D. '90 MacCary III, and Julie and James Kirchberg. Dr. Nefkens was an internationally distinguished physicist who taught and made significant research contributions while serving on UCLA's faculty for 45 years. He taught both undergraduate and graduate physics and was involved in particle and nuclear research at numerous accelerators in the U.S., Canada, and Europe. He was committed to the academic and professional growth of his students, mentoring many excellent students throughout his career. We are grateful that the Bernard M.K. Nefkens Endowed Graduate Fellowship fund will support graduate students studying experimental particle physics in perpetuity.

Each of these gifts received Dean's Gift Matching Funds to enhance their impact within the department.

Nefkens Family

UCLA HAS ONE OF THE PREMIER OPTICAL and infrared programs in the world thanks in large part to the Remote Observing Space in Knudsen Hall, which allows UCLA's renowned astronomy research groups to remotely access and operate the Keck and Lick telescopes and, in the future, the Thirty Meter Telescope. To keep UCLA at the forefront of discovery, research and teaching, we are incredibly grateful to alumni and longtime supporters Astrid '67 and Howard Preston '65, Ph.D. '74 for their generous gift to establish the **Preston Remote Observing Endowed Fund**. This gift will support critical renovations and the expansion of the existing remote observing space. It will also establish an endowment to support computational analysis of the data gathered from the facility, future remote observing facility renovations and maintenance, technological advancements, necessary costs related to remote observing, and other needs determined by the Director of the UCLA Galactic Center Group. Once completed, this space will be named the Howard and Astrid Preston Remote Observing Facility.


Jeryl and Ronald Abelmann

UCLA'S CORE MISSION can be expressed in three words: education, research, and service. Alumni and steadfast supporters Jeryl '62 and Ronald Abelmann '59, M.S. '60 recognize that educating undergraduate students – tomorrow's innovators, researchers and leaders – is at the heart of this mission. To continuously encourage a culture of faculty and teaching assistants who strive to inspire students in meaningful and creative ways and encourage more mentorship opportunities, Ron and Jeryl have established the **Ronald and Jeryl Abelmann Award for Undergraduate Teaching Excellence**. This endowment empowers the department to publically recognize one faculty and one teaching assistant per year, awarding them each with a monetary and physical prize for their teaching excellence and inspiration of students at the undergraduate level.

Donors who generously donated $5,000+ to the Department of Physics & Astronomy between July 1, 2020 – June 30, 2021

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Heising-Simons Foundation
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UCLA Astrophysics Data Lab

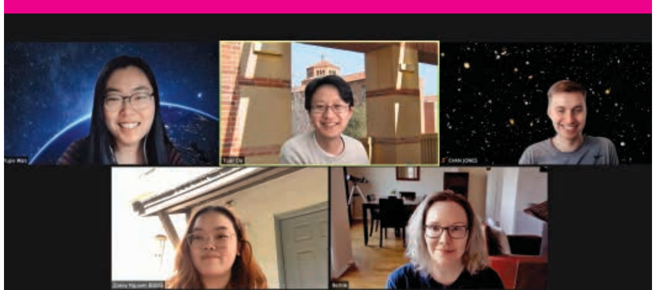
Prof. Tuan Do

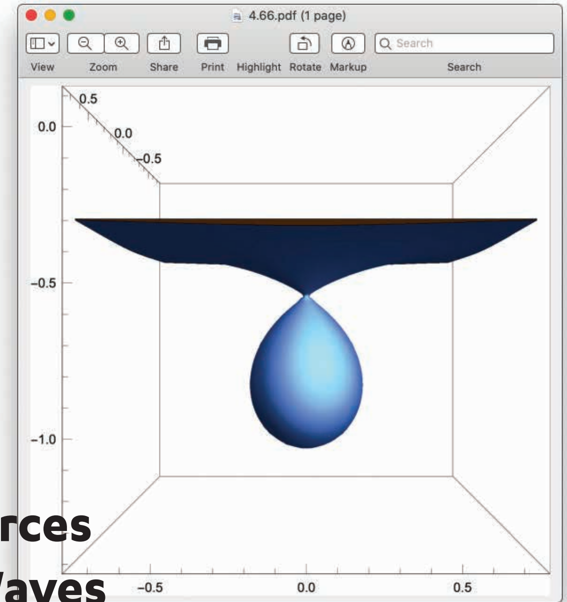
THE UCLA ASTROPHYSICS DATA LAB was created in 2020 to answer fundamental questions in astrophysics using large datasets that are available now and in the near future. These vast amounts of data offer new opportunities for transformative science, but requires new ways to think about data. The Lab is building the framework for translating machine learning to astrophysics and developing innovative ways of using data for astrophysics. They are also helping astronomers integrate new data-driven methods and practices into their work.

The UCLA Astrophysics Data Lab is led by Prof. Tuan Do and currently has four members: Postdoctoral fellow Dr. Bernadette (Bernie) Boscoe, graduate student Evan Jones, and undergraduates Zooey Nguyen and Yujie Wan.

Current projects include understanding the nature of Dark Energy by mapping the distances to millions of galaxies, revealing how supermassive black holes feed, and studying how and why astronomers use machine learning. ●

A meeting of the UCLA Astrophysics Data Lab.





Hydrodynamic Sources for Gravitational Waves

Prof. Christian Fronsdal

THE DISCOVERY OF GRAVITATIONAL WAVES has confirmed that gravitation is an integral part of particle physics, a canonical field theory that must eventually be quantized. A recently published paper by Prof. Fronsdal describes the coupling of gravitation to hydrodynamics, in a theory that includes vorticity and spin and provides continuous, hydrodynamical sources for the generation of gravitational waves. The theory incorporates the dual vector fields, phonons and rotons, of Landau's theory of superfluids. The roton has been identified with the massless and spinless Notoph of the 2-form gauge theory of Ogievetskij and Polubarinov.

The role of stress and thermodynamic rupture of metastable states in common fluids extends to astrophysics where it is the origin of the rupture that may characterize some supernovas. The emission of a gravitational waves of helicity 2 is accompanied by Notophs (helicity 0) that carries most or all of the recoil momentum. It is proposed to carry out another series of experiments, adapted to look for these massless waves with helicity 0.

This work provides realistic hydrodynamical sources for Einstein's equation of the General Theory of Relativity. The amplitude for graviton emission that accompanies a well-defined transition between two hydrodynamic states is calculated, to predict a signal with a characteristic time dependent polarization. It is accompanied by the emission of a signal with 0 polarization.

The illustration is computer generated, taken from an upcoming paper on Menisci and Capillary Action. It shows a hanging drop just before it lets go. It is the prediction of Prof. Fronsdal's new Hydrodynamics, using the same equations as were used for gravitational waves. It looks very much like an illustration by De Gennes. ●

The Julian Schwinger Lounge is the central gathering place for the Bhaumik Institute. Julian Schwinger is one of the giants of modern quantum field theory who was at UCLA for 20 years.

> **"Thanks to recent new gifts from Dr. Mani Bhaumik we have been able to make significant inroads into cutting-edge research into quantum entanglement, computing and sensing, as well as other topics.**

The Mani L. Bhaumik Institute for Theoretical Physics enters its fifth year

IT HAS BEEN A REMARKABLE and exciting five years since the inauguration of the Mani L. Bhaumik Institute for Theoretical Physics in July 2016. A primary mission of the Institute is to foster an environment where great theoretical physics can be carried out. While we like to think of theoretical physics as being pushed forward by a lone genius working in the mode of Einstein at the Swiss patent office, modern theoretical physics is a community effort driven by groups of people who not only define the important problems, but work together or compete to make the next breakthroughs. The Bhaumik Institute was designed around this concept.

In keeping with this ideal, the Institute runs a visitor program, and hosts workshops, conferences, and public lectures on the latest advances. In this spirit, our Julian Schwinger Lounge is our gathering place for carrying out discussions, journal clubs, and group meetings. To anchor the Institute, it has hired a group of postdocs who are at core of raising the intellectual level and excitement. On top of this, we have been able to provide substantial support to our graduate students, especially during the summer. In addition, we have had a remarkable set of distinguished speakers from around the world to help stimulate new ideas.

At its inception, the Institute began its focus on the central question in theoretical elementary particle physics on the unification of forces and matter, especially to unify gravity with the other forces. This has been the holy grail of elementary particle physics for more than a half century. Our Institute has worked hard on this question from multiple directions including string theory, the celebrated connection between gravity and gauge theories known as the AdS/CFT conjecture, and a remarkable link between gravity and the other forces known as the double copy. Thanks to recent new gifts from Dr. Mani Bhaumik, we have been able to make significant inroads into cutting-edge research into quantum entanglement, computing and sensing, as well as other topics. In light of Prof. Andrea Ghez's 2020 Nobel Prize in Physics for demonstrating the existence of black holes, our expansion into black hole and gravitational-wave physics could not be more timely. The Institute also helps support a diverse set of topics, described in the research highlights by Profs. Eric D'Hoker, Thomas Dumitrescu (Mani L. Bhaumik Presidential Endowed Term Chair in Theoretical Physics), Per Kraus, Michael Gutperle, Zhongbo Kang, Alexander Levine, Smadar Naoz, and Mikhail Solon, all of whom are members of the Institute.

A central role of the Institute is to help attract the best and brightest young faculty to UCLA who will be able to ensure our future. In this we have been quite successful, with the recent hiring of two new assistant professors, Thomas Dumitrescu and Mikhail Solon. Thomas and Mikhail are both young leaders in their respective fields. Thomas has made major contributions to the study of strongly interacting quantum field theory while Mikhail has done so by applying effective field theory to questions of experimental interest, most recently to problems in gravitational-wave physics. Further details of their recent work are given in subsequent research highlights. Their arrival here at the Bhaumik Institute has re-energized theoretical particle physics at UCLA.

Looking to the future, our primary goal is to carry out theoretical physics research that will not only stand out, but shake the physics world. While our ambitions are unbounded, we can look back with some satisfaction at the impressive research that has been carried in recent years. We would like to offer my sincere gratitude to Dr. Mani L. Bhaumik, whose vision and generosity has made the Institute possible. Our future has never been brighter!

UCLA-Industrial Cooperative to develop improved Computer Chip making Machines

Prof. Walter Gekelman and Dr. Patrick Pribyl

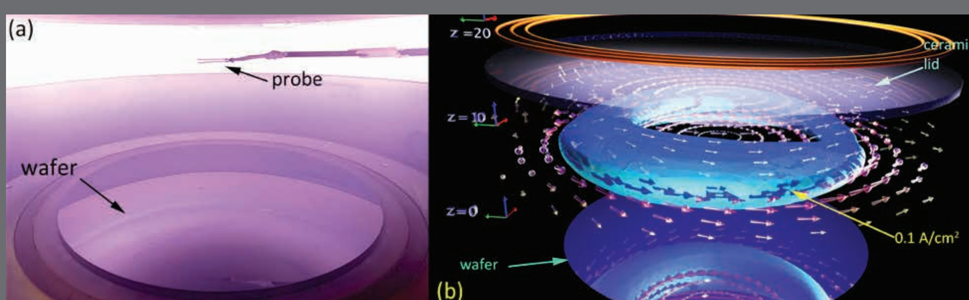
SMARTPHONES ARE UBIQUITOUS. Just about everyone on the planet has one. They all have one thing in common, astoundingly sophisticated computer chips. To make this possible everything in them has to be very, very small – features are just 0.3 billionth of an inch. Computer chips are also at the heart of all modern automobiles. Each car can have from several hundred to over a thousand small microprocessors which control key things such as engine timing to amenities such as remembering the optimum seat positions for the driver and occupants.

> **Dr. Gekelman has developed novel ways to study the plasma in an industrial tool donated by LAM.**

On April 23, 2021 the *New York Times* article "A Tiny Part's Big Ripple: Global Chip Shortage Hobbles the Auto Industry" reported that every major car manufacturer had to curtail car production because of the shortage. This is a national problem as our economy depends on them. The country's response to this disruption will probably be the construction of chip making foundries, or "fabs," in the U.S.

Plasma processing is used in the manufacturing tools in these foundries. The plasmas are a mixture of exotic gases, and electrons and ions (gas with one or more electrons stripped off). The plasma temperatures are about 100,000 degrees F and the gases cooler (about 1000 F). The ions in the plasma can be made into beams that precisely rain down on chips and etch three dimensional structures into it. Other plasma devices deposit materials atom by atom to build the electrical components. Two U.S. companies are the largest manufacturers in the world of the tools which make chips.

The National Science Foundation created the GOALI program (Grant Opportunities for Academic Liaison with Industry) to foster collaborations such as the one described here. The award "GOALI - Non-Equilibrium Processes, Stability, Design and Control of Pulsed Plasmas for Materials Processing" has sponsored a collaboration between one of the toolmaking giants, LAM Research Corp, and the UCLA group headed by Prof. Gekelman.



Dr. Gekelman has developed novel ways to study the plasma in an industrial tool donated by LAM. The researchers have published, for the first time, descriptions of the plasma evolution in full three dimensions and in time. The figure below left shows the plasma as viewed through a port of the tool as well as three dimensional measurement of plasma currents.

In the accompanying figure,

(a) Photograph looking into plasma etch tool. The single crystal wafer is 30 cm in diameter, located at the bottom. A hairpin probe used to measure plasma density is visible. The light emanates from the glowing plasma.

(b) Measurement of three dimensional currents in the same plasma etch tool. A 2 MHz radio frequency current is applied to a coil (shown to scale in the figure). The rf is switched on/off 10 times a second. Data is shown 3.3 ms after the coil is switched on. The blue shell is an isosurface of constant current density ($J = 0.1\ A/cm^2$). Computer chips and other circuits are assembled atom by atom on a silicon wafer shown on the bottom. Z is the height above the wafer in cm.

The NSF award resulted in the publication of two papers and a doctorate for Ms. Jia Han. It has led to a follow-on GOALI. The graduate student now working on the project is Ms. Yuchen Qian. Our theory partner is Prof. Mark Kushner and his group from the University of Michigan.

Research in the past decade has shown that the etch process can produce products of finer detail if the plasmas are pulsed on and off thousands of times a second. (Until recently all commercial products operated in the steady state.) The UCLA team constructed a novel pulsed power technology and studied the associated plasmas it produced under this award. The NSF-GOALI research helped convince LAM that improvements over existing pulse technology were possible, and has led to significant wafer processing benefits. Lam is releasing a new Etch product this fall, the first commercially available with this novel pulsing technology.

This is an example of how fruitful industrial collaborations with universities can be. This NSF-sponsored research at UCLA has contributed directly to the continued dominance of the U.S. industry in the chip making arena.

A big hand for science. The screen capture shows Malkan being 'virtually' sworn in along with another new board member to make it official. Former astronaut Ellen Ochoa, current NSB Chair, administers the Oath of office.

Prof. Matthew Malkan

IN JANUARY, Prof. Matthew Malkan was appointed to the National Science Board for a six-year term. The 24 members of the NSB are charged with directing the National Science Foundation and advising Congress and the White House on federal policies on STEM research and education.

Prof. Thomas Dumitrescu

(Mani L. Bhaumik Presidential Endowed Term Chair in Theoretical Physics)

OVER THE PAST YEAR, Thomas Dumitrescu has collaborated with Clay Cordova at the University of Chicago and Ken Intriligator at UC San Diego to demonstrate that the notion of symmetry in quantum field theory is much more expansive than previously thought, and must be extended to include modern mathematical structures such as higher groups and categories. They applied this understanding to explain many puzzling features of certain quantum field theories that have been constructed using string theory.

This work is one of the foundations anchoring the Simons Collaboration on Global Categorical Symmetries that Dumitrescu and fellow PIs founded over the past year, and which was recently funded at $8 million over four years by the Simons Foundation. Dumitrescu plans to organize some of the collaboration's events at UCLA, under the auspices of the Bhaumik Institute.

Together with UCLA collaborators Prof. Eric D'Hoker and Bhaumik Institute postdocs Dr. Efrat Gerchkovitz and Dr. Emily Nardoni, Dumitrescu has also studied confinement and chiral symmetry breaking in four-dimensional Yang-Mills gauge theories with quarks in the adjoint representation of the gauge group. (Real-world quarks are in the fundamental representation of the SU(3) color gauge group.) They were able to make progress on this problem by starting with a closely related, well understood supersymmetric gauge theory, and breaking supersymmetry in a controlled fashion. Based on this work, as well as her other achievements, Emily was awarded a prestigious Kavli postdoctoral fellowship at the IPMU in Japan.

Together with UCLA collaborators Prof. Eric D'Hoker and Bhaumik Institute postdocs Dr. Efrat Gerchkovitz and Dr. Emily Nardoni, Dumitrescu has also studied confinement and chiral symmetry breaking in four-dimensional Yang-Mills gauge theories with quarks in the adjoint representation of the gauge group.

Prof. Eric D'Hoker

OVER THE PAST YEAR, Eric D'Hoker and Oliver Schlotterer at the University of Uppsala, Sweden, produced a first principles derivation, in the Ramond-Neveu-Schwarz formulation, for the string amplitude with five external massless bosons. These results prove a conjectured form for the amplitude obtained last year by the authors in collaboration with Carlos Mafra and Boris Pioline.

D'Hoker and graduate student Nicholas Geiser succeeded in further elucidating the uniform transcendentality of one-loop string amplitudes, a study that was initiated with Michael Green in 2019. Nicholas was awarded a NSF AGEP-GRS for 2021-22 to help broaden impacts for under-represented minorities at UCLA, at the same time that he continues his scientific research on string theory.

Prof. Smadar Naoz

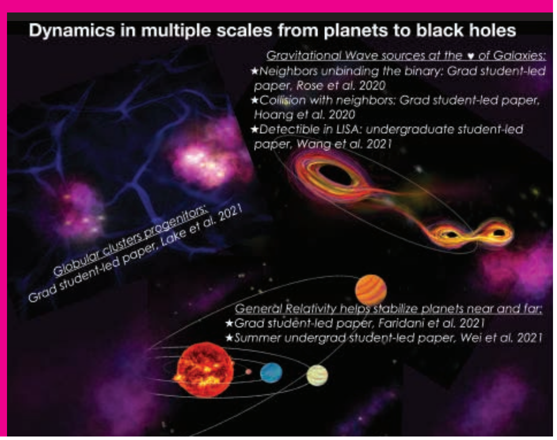
(Howard and Astrid Preston Term Chair)

THIS YEAR, the group welcomed Santiago Torres as a new postdoc to the group. Additionally, Jesus Salas completed his Ph.D., graduate students Bao-Minh Hoang received the dissertation year fellowship, and Sanaea Rose was awarded the Charles Young Graduate Student Fellowship and the Michael A. Jura award. Graduate student Denyz Melchor will start her NSF fellowship and Liz Holzknecht received the Bhaumik Institute summer scholarship.

The importance of General Relativity in Exoplanets: In recent years, space- and ground-based surveys found many multiplanet systems. Are there other planets that are beyond our detectability reach? In a series of papers, we highlighted that General Relativity helps to stabilize multiplanet systems, thus allowing to hide planets near and far from the host star.

As part of the Bhaumik Institute expansion toward black holes and gravitational-wave physics, **Gravitational waves at the heart of galaxies:** Almost every galaxy has a supermassive black hole residing at its heart, the Milky Way included. The supermassive black hole can induce collisions between binary members. In a series of studies, we showed that not only can this process naturally lead to gravitational waves mergers, but it can also result in an abundance of gravitational wave detections in the future LISA space probe. On the other hand, the frequent interactions with the neighbors in this dense environment can sometimes unbind the binary or merge them.

Gravitational wave sources are also expected to originate in globular clusters. We studied the large-scale distribution of the group's unique globular clusters' formation scenario. We then predicted the large-scale sky distribution, showing that our formation channels leave a clear anisotropic signature of the gravitational wave sky distribution. ●

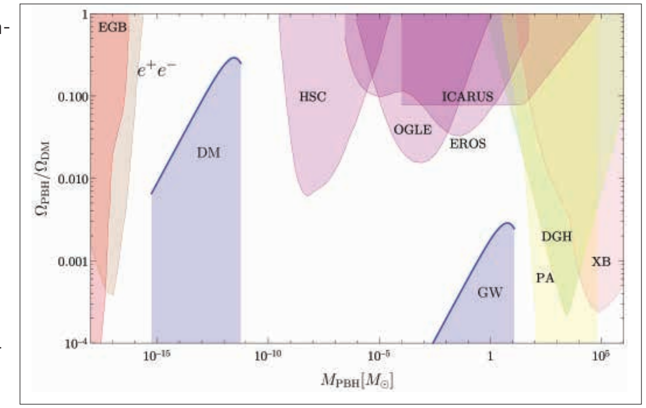


Theory of Elementary Particles, Astroparticle Physics, and Phenomenology (TEPAPP)

Prof. Alexander Kusenko

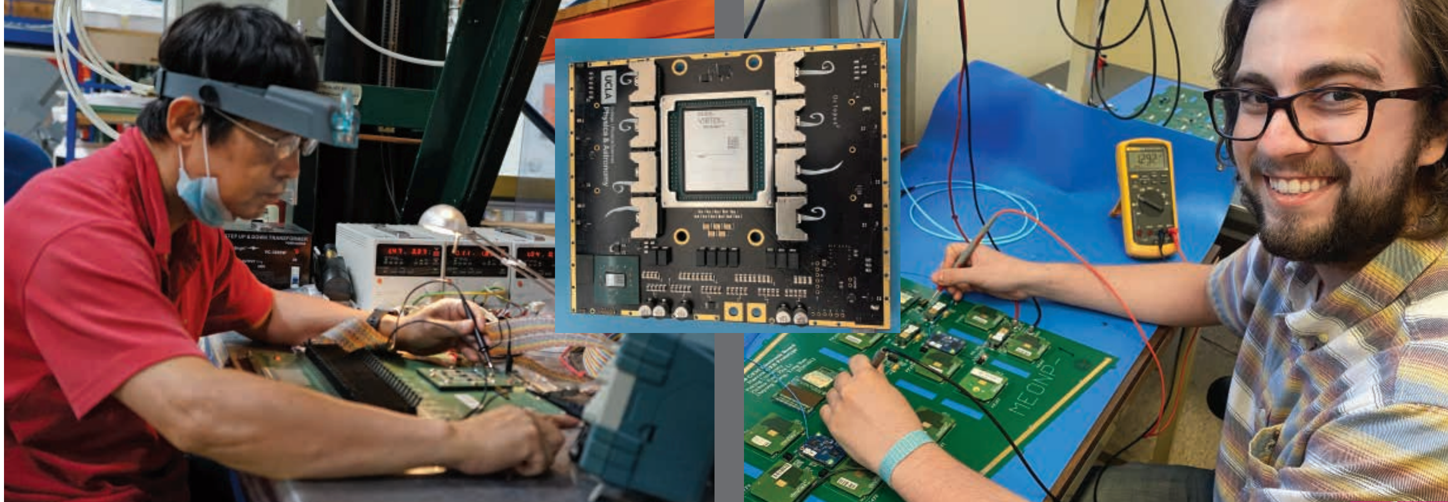
PROF. KUSENKO was awarded a Simons Foundation Fellowship in Theoretical Physics. He received one of five such awards made in 2021 across all fields of theoretical physics.

Prof. Kusenko and UCLA graduate student Marcos Flores have discovered a simple and generic way in which primordial black holes (PBHs) could have formed in the early universe in the amount that could account for all dark matter. The PBHs can also explain some of the gravitational waves events detected by LIGO experiment. In the early Universe, the scalar fields (such as the Higgs field, for example) mediate attractive forces that are relatively long-range compared to the Hubble size of the early universe. These forces create halos of heavy particles even during the radiation-dominated era. The same interactions result in the emission of scalar radiation from the motion and close encounters of particles in the halos. Radiative cooling due the scalar radiation allows the halos to collapse to black holes. The resulting black holes can be the long sought-after dark matter. This theory also offers an explanation of why the dark matter and the ordinary matter have similar mass densities.



The paper by Flores and Kusenko was published in *Physical Review Letters*. [M. M. Flores and A. Kusenko, Phys. Rev. Lett. 126 (2021) 4, 041101, DOI: 10.1103/PhysRevLett.126.041101]. Together with the Kavli IPMU astronomers, Kusenko has initiated a series of observations on the Subaru telescope to search for evidence of primordial black holes. The effects of PBHs can also be probed by a combination of stochastic gravitational waves and optical observations, as the UCLA and Kavli IPMU team of researchers showed in a recent paper published in *Physical Review Letters* [Sunao Sugiyama et al., Testing Stochastic Gravitational Wave Signals from Primordial Black Holes with Optical Telescopes, Phys.Lett.B 814 (2021) 136097, DOI: 10.1016/j.physletb.2021.136097].

Together with UCLA undergraduate student Alina Kochocki, UCLA postdoc Dr. Volodymyr Takhistov, and another faculty member, Prof. Nathan Whitehorn, Prof. Kusenko explored the implications of the puzzling neutrino data observed by the IceCube experiment at the South Pole. In 10 years of observations, the IceCube neutrino observatory has revealed a neutrino sky in tension with previous expectations for neutrino point-source emissions. The authors discussed a new physical explanation for neutrino production from populations of active galactic nuclei and starburst galaxies. Specifically, cosmic rays produced at such sources might interact with extragalactic background light and gas along the line of sight, generating a secondary neutrino flux. [A. Kochocki et al., *Contribution of Secondary Neutrinos from Line-of-sight Cosmic-Ray Interactions to the IceCube Diffuse Astrophysical Flux*, ApJ 914 91 (2021), DOI: 10.3847/1538-4357/abf830]. ●



Left: Xiaofeng Yang keeping thousands of UCLA custom-built muon detector electronics working at the CERN laboratory in Geneva Switzerland. Right: Joseph Carlson at work in the UCLA lab building the electronics that will detect GeV and TeV muons using gas electron multiplication.

R&D Engineers open the Energy Frontier at the CMS Experiment of the Large Hadron Collider

Profs. Michalis Bachtis, Robert Cousins, Jay Hauser, David Saltzberg

> **“The 14-layer Octopus board (center figure) designed and constructed at UCLA will perform 40 trillion operations per second in a 300 ampere field-programmable gate array.**

IN PREVIOUS ANNUAL REPORTS, our group has featured how the work of undergraduates, graduate students, postdocs, and assistant professors worked toward discoveries at the Large Hadron Collider (LHC), the highest energy particle accelerator in the world. The UCLA group contributed to the discovery of the Higgs Boson and now searches for new particles that would be even more exciting. UCLA has a large research group who have been building and using the LHC's Compact Muon Solenoid (CMS) Detector since its inception over 25 years ago.

This year we feature the work of our engineers. Professional engineers allow our group to build reliable, cutting-edge electronics that provide state-of-the-art data flows, the newest, largest integrated circuits, and radiation-hard electronics. They keep the institutional memory that keeps the electronics and detectors running, and upgraded, for decades.

R&D Engineer Joseph Carlson joined us recently after completing his bachelor's degree in physics at the University of Oregon. He and Prof. Saltzberg, postdoc Dr. Abhisek Datta, and grad student Antonett Prado are building electronics for a brand-new detector technology on CMS based on "gas electron multiplication" by passing muon particles. Historically, muons have been the harbinger of the decays of newly discovered particles. Working with former UCLA engineer and UCLA physics major Andrew Peck, their custom electronics combine fast copper readout with optical data links that will allow CMS to detect muons under high-radiation conditions, closer to the beamline than ever before, a zone where previously muons were just lost.

R&D Engineers John Jones and Maxx Tepper along with Prof. Bachtis are building electronics for the so-called "Trigger System." The LHC collides proton beams forty million times per second, but only about one thousand events per second can be saved for later analysis. Maxx was a UCLA physics major and John has a Ph.D. in physics and years of experience at the cutting-edge of electronics. Their latest electronics board processes 4 terabits per second of information from the trigger system with up to 56 Gb/s optical connections per fiber optic, and performs complex particle identification and measurement using one of the world's largest Field Programmable Gate Arrays (FPGAs). It will select the CMS events for further analysis in our next data run.

R&D Engineer Xiaofeng Yang works with Prof. Hauser and Researcher Dr. Mikhail Ignatenko to keep our existing muon detectors, based on cathode-strip technology, running. In previous experiments, detecting muons far away from the central region had only been done with mixed results. But for CMS the muon detection has worked wonderfully, in no small part due to Xiaofeng's efforts. Xiaofeng has been a member of the UCLA team for twenty years. By maintaining everything from the gas flow to electronics, Xiaofeng keeps muons on CMS detected efficiently. Recently, Xiaofeng has executed a major redesign of the gas systems to significantly reduce the use of greenhouse gases. ●

Braided Bundles of the Cell with a nod to Julian Schwinger

Prof. Alex Levine

TAKE A LOOK AROUND AT ROPES OR VARIOUS HAIR STYLES. You will see braids in abundance. The feature that makes a braid, weaving together impenetrable strings in a bundle of nearly aligned ones, is quite general and appears throughout nature from magnetic flux lines in superconductors to bundles of biopolymer filaments that pervade our cells and the spaces between them in tissues. Recently, the Levine group has been exploring the implications of braiding for understanding the mechanical properties of the biopolymer filament bundles.

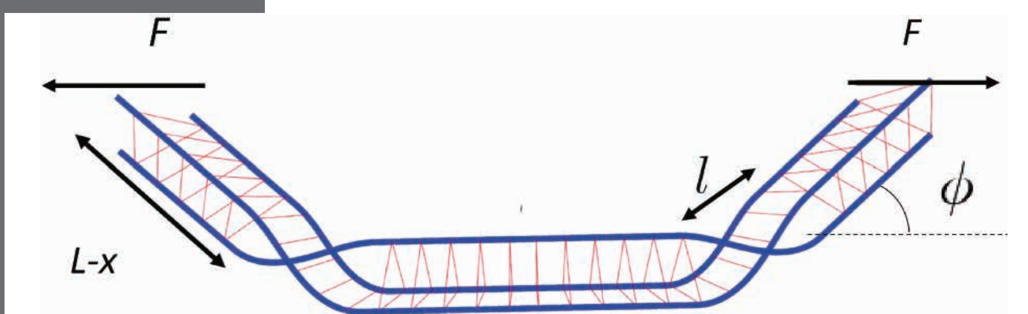
Biopolymer filaments in our cells form tightly bound bundles held together by small cross-linking proteins. When formed, these cross linkers can trap braids within the bundle. Levine and coworkers (both at UCLA and the Technical University in Munich) found that trapped braids create highly localized bends – kinks – in the bundles, even though the filaments strongly resist bending on their own[1]. These kinks have now been observed in recent experiments.

More interestingly, they showed that a bundle under compression will deform by producing braid/anti-braid pairs allowing the bundle to fold under compression. These topological braiding defects are akin to particle/anti-particle pairs (having equal and opposite braid-group charge). Braid pair production harkens back to a much earlier idea by the late Prof. Julian Schwinger of UCLA. He pointed out that a sufficiently strong electric field will pull apart electron positron pairs from quantum fluctuations of the vacuum[2]. Braid/anti-Braid production under large enough compression acts in the same way with thermal fluctuations replacing quantum ones.

> **The fact that current thinking in biological physics links up so nicely with work in high energy physics reminds us of the essential unity of theoretical physics.**

The fact that current thinking in biological physics links up so nicely with work in high energy physics reminds us of the essential unity of theoretical physics. It also emphasizes for me the pivotal role of the Bhaumik Institute for Theoretical Physics and the Center for Biological Physics in our department. By bringing together theorists from all of the far-flung areas of modern physics, we find new connections and with them, hopefully, new perspectives on both the fundamental structure of matter and the structures of the living world, including ourselves.

1. Valentin M. Slepukhin et al., Topological defects produce kinks in biopolymer filament bundles, *Proceedings of the National Academy USA* 118 (15) e2024362118 (2021); Braiding dynamics in semiflexible filament bundles under oscillatory forcing, *Polymers 13* (13), 2195 (2021); Thermal Schwinger Effect: Defect production in compressed filament bundles arXiv:2103.08832 (2021).
2. Julian Schwinger, On Gauge Invariance and Vacuum Polarization, *Physical Review 82* (5), 664 (1951).



Braid/anti-braid pair produced in a three-filament bundle and being pulled apart by force F.

UCLA Infrared Laboratory

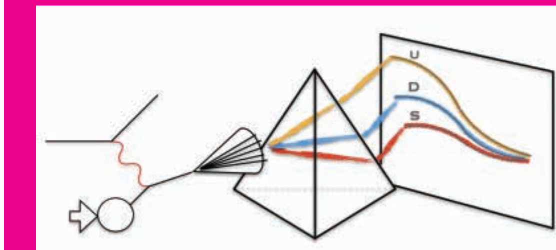
Rendering of the Liger integral field spectrograph being developed for the Keck Observatory. This cutaway drawing shows the cryogenic optical components which operate near 77 Kelvin to allow the instrument to make sensitive measurements in the near infrared. Liger rides the railway-like system at the observatory to store and dock with the telescope and adaptive optics system.

THE UCLA INFRARED LABORATORY celebrated its 31st year during the unprecedented lockdown. It was a year of significant transition with the retirement of its founder Prof. Ian McLean and the succession of Prof. Michael Fitzgerald as the new laboratory director and associate director of UC Observatories. The laboratory also saw the retirement of long-time staff members John Canfield and Theodore Aliado.

We also saw the completion of high-level final design reviews for the InfraRed Imaging Spectrograph (IRIS) planned for first light of the Thirty Meter Telescope (TMT). This 6.5-ton instrument is led by UCLA Prof. James Larkin and is an international project involving 10 institutions in four countries. IRIS works with TMT's advanced adaptive optics system to produce images several times sharper than the Hubble Space Telescope and with unprecedented sensitivity. The images can be broken into 128x128 pixels which are each dispersed into 512 spectral channels allowing an astrophysical object to be imaged at 512 wavelengths simultaneously. With applications ranging from monitoring rain on Titan, and volcanoes on Io, to much more detailed motions of the stars in the Galactic Center and even dynamics in galaxies in the early Universe, IRIS will open many new areas of astrophysical study and be used by hundreds of astronomers in the UC system and throughout the world.

An important milestone this year has been the selection of the LIGER instrument being developed for the Keck Observatory for a full proposal to the NSF Mid-scale Research Infrastructure Program. Much of LIGER is a copy of the spectrograph within the IRIS instrument, and a private grant from the Heising-Simons foundation has been supporting the ongoing design work for the Keck-specific components. Profs. Larkin and Fitzgerald are in the leadership of the project, while former UCLA Infrared Lab graduate student Shelley Wright, now an associate professor at UC San Diego, is the overall Principal Investigator. LIGER will be another imaging spectrograph and the successor to the now 16-year-old OSIRIS instrument, also built and commissioned by Larkin and the Infrared Lab. The Galactic Center group, headed by Nobel Laureate Andrea Ghez, used OSIRIS to make important measurements of the three-dimensional motion of the stars orbiting the central black hole in our Galaxy.

The lab and staff are also developing several projects for directly detecting and characterizing planets around other stars. Prof. Fitzgerald is providing leadership for the HISPEC project at Keck Observatory, as well as its parallel effort MODHIS, a first-light instrument for the TMT. These fiber-fed infrared spectrometers are capable of characterizing the molecular content of exoplanet atmospheres, and use the exquisite high-resolution spectral information to characterize planet spins and map their cloud distributions. Prof. Fitzgerald is also leading the Planetary Systems Imager, a second-generation instrument concept for the TMT that aims to detect and characterize both gas giants and terrestrial planets around nearby stars. ●



Jet charge works as a prism for spin asymmetries.

Strong Interactions and Nuclear Theory

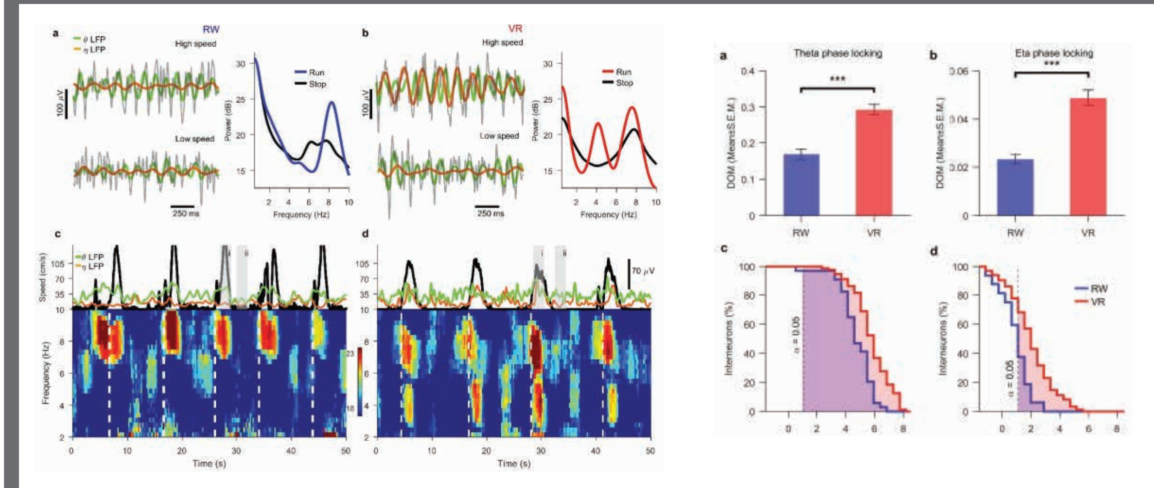
Prof. Zhongbo Kang

PROF. KANG'S research interests involve theoretical nuclear and particle physics. The fundamental theory that describes the strong interactions is called Quantum Chromodynamics (QCD). Understanding strong QCD interactions is crucial to interpreting collider searches for unexpected phenomena, as well as to understanding the structure and properties of cold and hot nuclear matter.

In a paper published in Physical Review Letters, the group and collaborators proposed that the electric charge of a jet is a natural flavor prism for spin asymmetries. Such information contained in a concept called "jet charge," was first introduced by Feynman. The idea roots in the fact that the u- and d-quark, to initiate a jet, have opposite charges. They demonstrated for the first time that the use of the jet charge observable can provide dramatically enhanced u- and d-quark flavor sensitivity in jet production.

Prof. Kang delivered a public lecture hosted by Norway about the strong force, which can be viewed on YouTube: https://www.youtube.com/watch?v=zVQ0Z0RLIIc

Prof. Kang was excited to attend the Bhaumik Institute Unveiling Celebration in November 2016, the same month when he arrived at the department in person. In the following years, he witnessed and personally experienced how the institute has helped and supported the career of junior theory faculty members. He has received kind support to host workshops and partial support of a postdoctoral scholar. Graduate student Fanyi Zhao received the very first Nina Byers Summer Fellowship in Theoretical Physics. He greatly appreciates all the support which boosted his career in this early stage. ●



Emergence of distinct ~4 Hz eta oscillation during running in VR. Enhanced theta rhythmicity, eta and theta modulation of interneurons in VR.

Neurophysics Laboratory: Virtual Reality (VR) boosts beneficial brain rhythms

Prof. Mayank Mehta

WHEN WE EXECUTE COGNITIVELY EFFORTFUL TASKS, such as problem solving, remembering an event, or run across space, a brain region called the hippocampus develops a representation of those mental spaces, a discovery that was awarded the Nobel in 2014. Our goal is to understand the process by which neurons turn concrete stimuli such as light and sound into abstract concepts such as events or space-time. To this end, we have developed a unique virtual reality system where nonspecific cues such as odors and textures can be eliminated and rats and humans have to rely solely on the visual (or auditory) virtual cues to define space and find rewards. This technique has yielded several surprising results in the past years. This year was no different.

A major mystery about this process is that during the above cognitive tasks, the hippocampus develops a prominent ~8Hz activity synchronized across millions of neurons, termed theta rhythm. This is so prominent that it is one of the oldest electrical signals measured in the brain (1938-54). Damage to hippocampus, e.g. during Alzheimer's, results in theta rhythm impairment and loss of theta rhythm induces cognitive impairment. Thus, theta rhythm is a major biomarker, with more than 70,000 publications. Yet, no reliable treatment exists to fix theta rhythm or cure Alzheimer's. Partly because we still don't understand exactly why the hippocampal activity becomes rhythmic during cognitively challenging tasks, and why that rhythm facilitates the performance in those tasks.

Based on our prior research we suspected that virtual reality may be able to change theta rhythm. To test this, we measured hippocampal electrical oscillations from thousands of electrodes while rats ran in VR or in visually similar real world (RW). We found that the frequency of theta rhythm was nearly the same in VR and RW, but the degree of rhythmicity of theta rhythm was greatly enhanced in VR. In addition, neurons deep within the hippocampus showed an entirely novel rhythm that was never seen by anyone in any condition. This rhythm had a frequency that is about half of theta rhythm, hence we termed it eta rhythm. These two effects are far greater than any pharmaceutical intervention. Several theories, including ours (Kumar & Mehta, 2012), and experiments show that the exact frequency of the rhythm will have a large impact on neuroplasticity and cognition, which we are now testing.

So, this has generated a lot of excitement. Besides, no new rhythm has been found in the hippocampus in the last 40 years. Hence, the manuscript was published in *Nature Neuroscience*: https://www.nature.com/articles/s41593-021-00871-z

It was covered extensively in new media (including the BBC Focus magazine) and ranked among the top 94-99% of all publications of similar age, anywhere or at Nature Neuroscience: https://nature.altmetric.com/details/108316423/news

"Several theories, including ours (Kumar & Mehta, 2012), and experiments show that the exact frequency of the rhythm will have a large impact on neuroplasticity and cognition, which we are now testing.

Planets and Exoplanets

Prof. Jean-Luc Margot

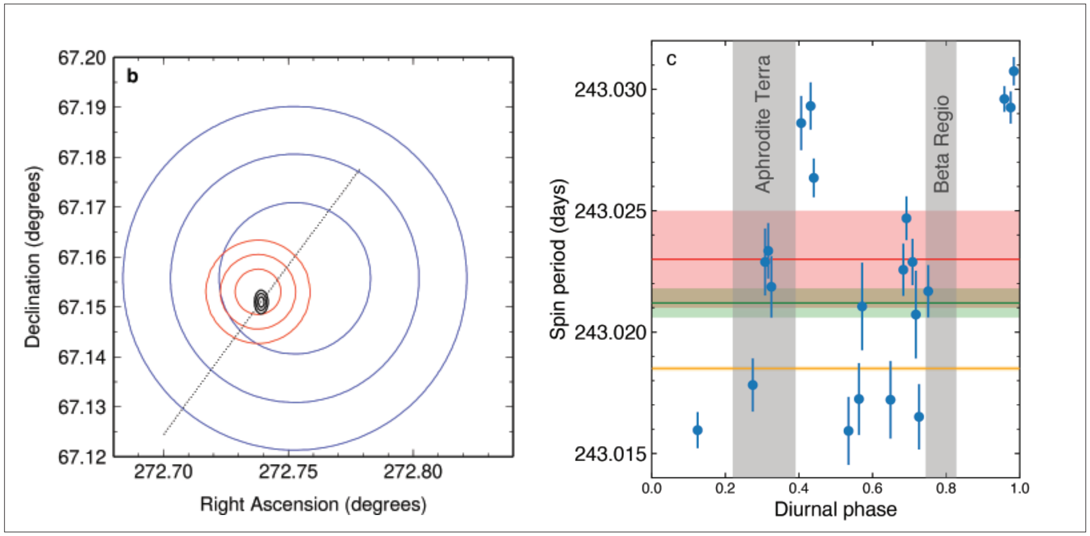
WE MEASURE THE SPIN STATES, gravity fields, and orbits of planetary bodies with a variety of telescopes and spacecraft. We also search for radio technosignatures.

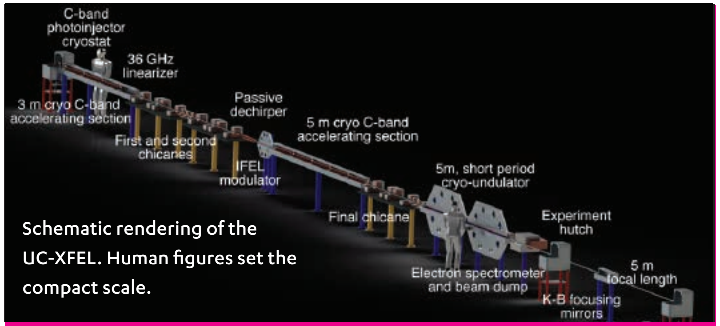
Radar speckle tracking observations with the Goldstone Solar System Radar and the Green Bank Telescope improved the knowledge of the spin axis orientation of Venus by a factor of ~10 in each dimension and enabled the first measurement of the spin precession rate and moment of inertia as well as an estimate of the size of the core (Margot et al., *Nature Astronomy* 5, 2021). The observations revealed that the spin period of Venus (~242.023 days) exhibits variations of ~20 minutes on diurnal timescales due to transfer of atmospheric angular momentum to the solid body. The diurnal forcing may be due in part to mountain torques.

UCLA physics graduate student Paul Pinchuk is scheduled to defend his Ph.D. dissertation in August 2021 and is expected to become part of a small group of approximately ten people who have completed Ph.D. work in the search for extraterrestrial intelligence (SETI). Paul contributed to our survey of solar-type stars in the plane of the galaxy (Margot et al., *AJ* 161, 2021) and developed an impressive machine learning tool for the identification of radio frequency interference (Pinchuk et al., *submitted*).

More than 100 undergraduate students and 10 graduate students have taken a full-length SETI course at UCLA to date. We will offer this course again in Spring 2022. Read about our progress at http://seti.ucla.edu. ●

Left: Improvements in the knowledge of the spin axis orientation of Venus. Uncertainty contours of estimates from Magellan radar observations (blue), Magellan radio science observations (red), and UCLA radar speckle tracking observations (black). Right: Variations in the spin period of Venus measured between 2006 and 2020. Horizontal lines and shaded areas show the average spin periods derived from Magellan radar images (1990–1992, orange), Magellan and Venus Express images (1991 and 2007, red), and Earth-based radar images (1988–2017, green).





Schematic rendering of the UC-XFEL. Human figures set the compact scale.

Prof. James Rosenzweig

THE UCLA PARTICLE BEAM PHYSICS LABORATORY (PBPL), directed by Prof. James Rosenzweig, is a world-leading group in probing the twin frontiers of ultra-high field acceleration processes and the development of new generation of coherent X-ray sources in the X-ray free-electron lasers (XFELs). This year, the PBPL has embarked on significant initiatives off-campus in the first thrust, in an ambitious suite of experiments in plasma and dielectric wakefield acceleration at the premier facility for such research, FACET-II at SLAC. On campus, the PBPL is now marrying high field acceleration to XFELs, in order to shrink them from kilometer-scale to a length below 40 meters, permitting their uniquely powerful capabilities in imaging ultra-fast (sub-femtosecond), ultra-small phenomena that are ubiquitous in atomic, molecular and solid state systems, in university labs.

A schematic of this revolutionary instrument, the ultra-compact X-ray free-electron laser (UC-XFEL) is shown in the figure. A description of the detailed physics of acceleration, femtosecond beam beam dynamics, advanced electromagnetic structures and micro-fabricated magnets, X-ray optics and the host of paradigm-shifting applications enabled by the UC-XFEL is found in a notably high-impact publication appearing last year in the New Journal of Physics (https://iopscience.iop.org/article/10.1088/1367-2630/abb16c).

A collaboration has been formed to create the first prototype of the UC-XFEL, with its members ranging from photon scientists, accelerator and FEL experts, engineers and industrial partners. The first collaboration meeting took place in July 2021 (https://conferences.pa.ucla.edu/free-electron-laser-2021/index.html), and discussed the direction of this research, much of which is centered on the new, large accelerator lab at UCLA, the PBPL SAMURAI Laboratory. ●

RESEARCH HIGHLIGHTS

Prof. Mikhail Solon

(David S. Saxon Presidential Term Chair in Physics)

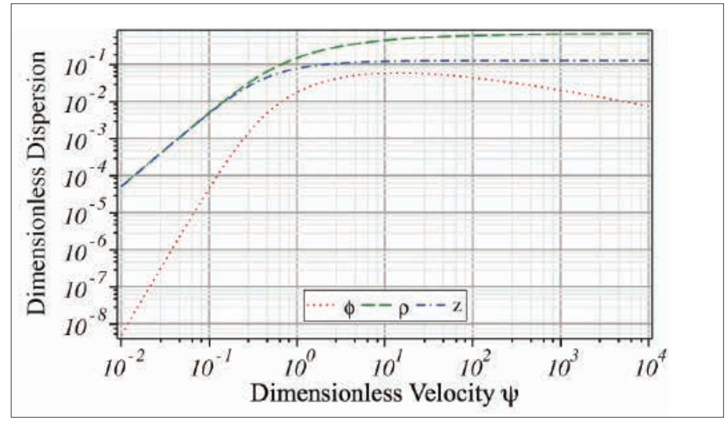
IF YOU HAD ASKED ME SEVERAL YEARS AGO what I would be working on in the next few years, I would have probably replied "dark matter" and "cosmology", two very important topics in theoretical physics. However, two things happened: (1) LIGO discovered gravitational waves in 2015 and (2) I moved to Los Angeles in 2017, within the sphere of influence of experts in the study of scattering amplitudes. This led me, an effective field theorist by training, to explore territory that lies within and across the boundaries of gravitational wave astronomy and scattering amplitudes. It has been exciting to bridge between these two domains and communities of theoretical physics, especially because it is through such cross-disciplinary inquiry that science is enriched with new insights and rapid progress.

Fast forward several years, and there is now a flurry of activity in applying ideas from quantum field theory to the study of gravitational wave emission from binary mergers. Also, I am now a father of two, a member of the Bhaumik Institute, and (so far) a survivor of a pandemic.

A few of the key papers in this venture were authored by members of the Institute – such as Zvi Bern and myself – and were highlighted as a new direction in theoretical high energy physics in last year's Snowmass Community Planning Meeting. Our work has greatly benefitted from the resources the Institute provides to pursue theoretical physics with intellectual freedom, especially new avenues of inquiry that require a great interchange of ideas across disciplines. In particular, several workshops hosted by the Bhaumik institute were responsible for accelerating the cross-pollination between general relativists and particle theorists.

In the next few years, I will continue to pursue this research direction, which has the hallmarks of a great problem in theoretical physics: it involves beautiful calculations in quantum field theory, it offers an opportunity to explore a new theoretical landscape (connecting classical gravitational physics and quantum scattering amplitudes), and it provides results that are directly useful for the exciting experimental program of precision gravitational wave astronomy. ●

Prof. William Newman



IN ARENAS RELEVANT to Physics and Astronomy, Prof. William Newman continues to work on Many-Body Physics, focusing on the response of charged particles in energetic astrophysical and space-physics environments and recently in applications to tokamaks where charged particles are injected aligned with toroidal magnetic field lines. An outstanding mystery in this area emerges from many computer simulations show as particles become more energetic that they become less collimated. Blending theoretical methods from statistical mechanics and classical mechanics with plasma physics, Prof. Newman employed "Hamiltonian integrability" and scaling theory to show why initially field-aligned particles lose memory of their initial direction as they become more energetic.

Without going into technical detail, the figure above demonstrates how particle behavior and motion dramatically changes as their initial speeds are increased. Prof. Newman extended many-body theory regarding the gravitational instability of massive toroidal distributions of circumstellar nebular, thereby explaining why they are not observed in extrasolar planetary systems nor influence in a significant way the evolution of our solar system.

As chair elect of the American Physical Society's Group on the Physics of Climate, Prof. Newman is organizing invited and focus sessions for the APS Annual Meeting in Chicago in March relating to the new Intergovernmental Panel on Climate Change Sixth Assessment Report as well as new physics-based insights that confirm the role played by human activity on our changing climate. ●

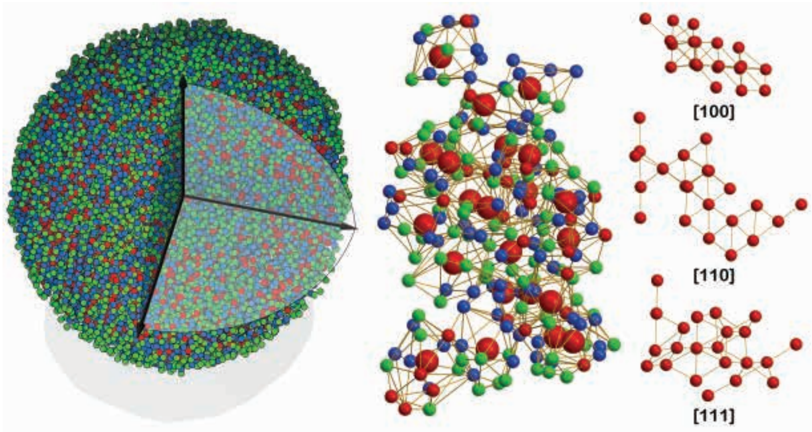
TEP and Bhaumik Institute

Prof. Per Kraus

DURING THE PAST YEAR, Per Kraus has continued his long standing interest in three-dimensional gravity, which provides a simplified model of quantum gravity that retains many of the conceptual and technical aspects of the more physically relevant four dimensional version.

With UCLA postdoc Ruben Monten and graduate student Richard Myers, Prof. Kraus initiated the canonical quantization of 3d gravity confined to a finite spacetime region. This setup is of intrinsic interest and also has relevance for a particular modification of the AdS/CFT correspondence known as the TTbar deformation, which defines a non-renormalizable, yet apparently meaningful, perturbation of a conformal field theory.

In work with former UCLA postdoc Shouvik Datta (now at CERN) and collaborators, Kraus developed a geometric understanding of this deformation involving coordinate transformations whose form depends on the quantum state of the system. ●



Direct observation of 3D atomic arrangement in an amorphous solid. (Left) Experimental 3D atomic model of a metallic glass nanoparticle. (Middle) 3D atomic packing of a representative medium-range order. (Right) The center atoms of the local clusters (dashed circles) form crystal-like medium-range order.

Century-old problem solved with first-ever 3D atomic imaging of an amorphous solid

Prof. John Miao

AMORPHOUS SOLIDS SUCH AS GLASS, plastics and amorphous thin films are ubiquitous in our daily life and have broad applications ranging from telecommunications to electronics and solar cells. However, due to the lack of long-range order, the three-dimensional (3D) atomic structure of amorphous solids has thus far defied direct experimental determination for more than a century. Using a multi-component metallic glass as a proof-of-principle, Miao and colleagues advanced atomic electron tomography to determine the 3D atomic positions in an amorphous solid for the first time (Y. Yang et al., *Nature* 592, 60–64 (2021)).

They quantitatively characterized the short-range order (SRO) and medium-range order (MRO) of the 3D atomic arrangement, also finding that although the 3D atomic packing of the SRO is geometrically disordered, some SROs connect with each other to form crystal-like superclusters and give rise to the MRO. In addition, the collaborators identified four crystal-like MROs face-centered cubic, hexagonal close-packed, body-centered cubic and simple cubic coexisting in the amorphous sample. These observations provide direct experimental evidence to support the general framework of the efficient cluster packing model.

Looking forward, they anticipate this experiment will open the door to determining the 3D atomic coordinates of various amorphous solids, whose impact on non-crystalline solids may be comparable to the first 3D crystal structure solved by x-ray crystallography over a century ago.

Capturing 3D atomic defects and phonon localization at the 2D heterostructure interface

The 3D local atomic structures and crystal defects at the interfaces of heterostructures control their electronic, magnetic, optical, catalytic and topological quantum properties, but have thus far eluded any direct experimental determination. Very recently, Miao and colleagues used atomic electron tomography to determine the 3D local atomic positions at the interface of a MoS_2-WSe_2 heterojunction with picometer precision and correlate 3D atomic defects with localized vibrational properties at the epitaxial interface. They observed point defects, bond distortion, atomic-scale ripples and measure the full 3D strain tensor at the heterointerface. By using the experimental 3D atomic coordinates as direct input to first-principles calculations, they revealed new phonon modes localized at the interface, which are corroborated by spatially resolved electron energy-loss spectroscopy. They expect that this work will pave the way for correlating structure-property relationships of a wide range of heterostructure interfaces at the single-atom level. This work has been accepted for publication in *Science Advances*.

> **By using the experimental 3D atomic coordinates as direct input to first-principles calculations, they revealed new phonon modes localized at the interface, which are corroborated by spatially resolved electron energy-loss spectroscopy.**

Exo-Planetary Science via the Study of Stars in the Initial and Final Stages of Their Lives

Prof. Ben Zuckerman and Dr. Beth Klein

OBSERVATIONS OF YOUNG STARS provide insight into formation of planetary systems. Two undergraduate students, Lou Baya Ould Rouis and Swetha Sankar, have been using photometric and spectroscopic methods to investigate planetary formation in the notable, nearby, youthful star cluster, Alpha Persei.

White dwarf (WD) stars are the last stage of evolution for most stars, including our Sun. From spectra obtained at Keck Observatory and the Hubble Space Telescope, we measure abundances of material accreted from their planetary systems. Through these studies – led in part by undergraduate students Ted Johnson and Kyle Davis – we address questions such as: is Earth "normal"? and do exoplanetary systems possess elements to support life? From a theoretical modeling perspective, graduate student Isabella Trierweiler (thesis advisor Ed Young in EPSS) is studying dynamical processes in WD planetary systems.

A remarkable discovery in 2020 from our interdisciplinary collaboration of Klein and Zuckerman with EPSS department researchers – recent Ph.D. Alexandra Doyle and Prof. Ed Young – is an extraordinary overabundance of the "light" element beryllium in two exoplanetary bodies. The abundances of Be measured relative to a suite of other elements in these objects is more than 200 times seen in any other astronomical objects. One interpretation led by Doyle is that the WDs ingested icy moons from their planetary systems.

Congratulations to Ms. Ould Rouis and Mr. Davis, who graduated with B.S. degrees this year, and are going on to Ph.D. programs in Astronomy at Boston University and UC Santa Cruz, respectively. Congratulations to Dr. Alexandra Doyle, who completed her Ph.D. in Winter 2021, and is currently a postdoc in EPSS. ●

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The abundances of Be measured relative to a suite of other elements in these objects is more than 200 times seen in any other astronomical objects.

Prof. Tommaso Treu

PROF. TREU PUBLISHED 28 REFEREED PAPERS. Highlights include: 1) the first determination of the mass of a supermassive black hole at cosmological distances (z=2.8) by studying the light echo of gas surrounding the black hole over a period of over 4 years; 2) a new framework to determine the expansion history of the universe using gravitational time delays.

Prof. Treu was awarded the 2020 Newcomb Cleveland Prize by the American Association for the Advancement of Science and the UCLA Division of Physical Sciences' Centennial Outstanding Discovery Award. The group received funding from NSF, NASA, and the Moore Foundation. Peter Williams completed his Ph.D. Visiting graduate student Lilan Yang received a prestigious JSPS postdoctoral fellowship from Japan. Former student Anowar Shajib was awarded a NASA Hubble/Einstein Fellowship. Postdoc Chih-Fan Chen and graduate students Shawn Knabel and Devon Williams joined the group. ●

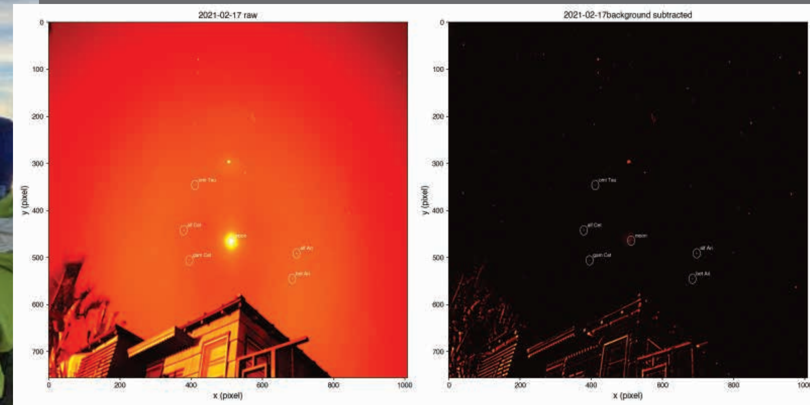
Prof. Jean Turner

PROF. TURNER, with postdoctoral researchers Daniel Cohen and Michelle Consiglio and students Nick Ferraro and Edwin Alexani, studies the formation of super star clusters in nearby galaxies. Consisting of millions of stars, these giant star clusters contain concentrations of the most massive stars in the universe. Winds from these stars are powerful enough to disperse the cluster gas, putting an end to star formation after only a few million years.

The group has recently found observational confirmation for the prediction that, in the most massive star clusters, rapid pollution of gas clouds in heavy elements created by these massive stars may stall the winds. Thus, above a critical mass there may not be a limit to how large a star cluster can grow.

The group uses the Keck Telescope for kinematic analysis of ionized gas, and has recently been awarded time on both the Atacama Large Millimeter-Submillimeter Array and the James Webb Space Telescope to observe the giant star cluster in the local dwarf galaxy NGC 5253. The group is also conducting a survey with the Very Large Array of 35 local galaxies showing spectral signatures of Wolf-Rayet stars in the search for other similar giant star clusters.

In addition, Prof. Turner has been serving on the Astro2020 Decadal Survey Steering Committee for the past two years. ●



Far Left: MacDougall, Angelo, and Petigura visit the summit of Maunakea.

Above: Triangulating the moon's position from background stars for the Astro-180 lab.

Left: Graduate students Mason MacDougall and Isabel Angelo and Prof. Erik Petigura observe at Keck Headquarters in Waimea, Hawaii.

Adapting to COVID and going beyond

Prof. Erik Petigura

LOOKING BACK ON THE 20-21 ACADEMIC YEAR, I'm filled with amazement for how resilient and flexible our department has been during the pandemic, as well as a longing to return to the rhythms of in-person teaching and research.

For me, teaching the advanced undergraduate astronomy lab (A180) was a difficult but rewarding experience. This class is key to our undergraduate major because students step away from the clean theory of their textbooks and get their hands dirty with real equipment and real data like our 14" telescope on top of the Math Sciences Building. My goal was to develop challenging but rewarding experiments that students could do at home without specialized equipment or facilities.

For their final project, students measured the orbit of the moon with their smartphones. Over the quarter, students imaged the moon and nearby reference stars and used astrometric techniques to triangulate the moon's position. They then wrote custom orbit-fitting code to measure properties like lunar eccentricity (ellipticity) and inclination (tilt). The lab was challenging, but the students really rose to meet it. Some even measured the orbit of the moon to a precision of 1 arcminute — the size of a penny at the length of one football field — all without use of a telescope.

On the research front, my group has been using the Keck telescope to study the properties of extrasolar planets detected by NASA's TESS mission. Observing at the telescope is key to this work, and while we've been making do with "pajama mode" observing at home, nothing beats being at Keck headquarters. As pandemic restrictions lessened, my group was fortunate to make a trip to Hawai'i island for an intensive observing training session and also managed to visit the summit to learn about the astronomical, cultural, and geographic significance of Maunakea. ●

"Observing at the telescope is key to this work, and while we've been making do with "pajama mode" observing at home, nothing beats being at Keck headquarters.

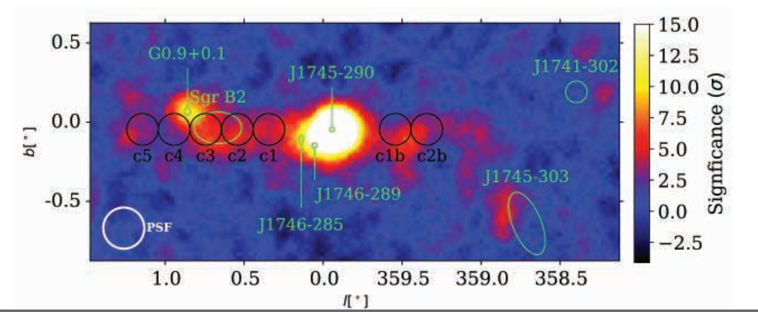
Astroparticle Physics

Prof. Rene Ong

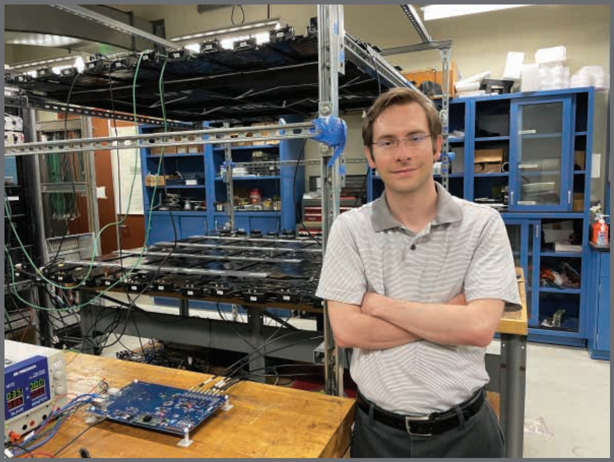
The Ong group has constructed a prototype detector that uses as much of the flight instrumentation as possible, including long scintillation counters and high speed electronics.

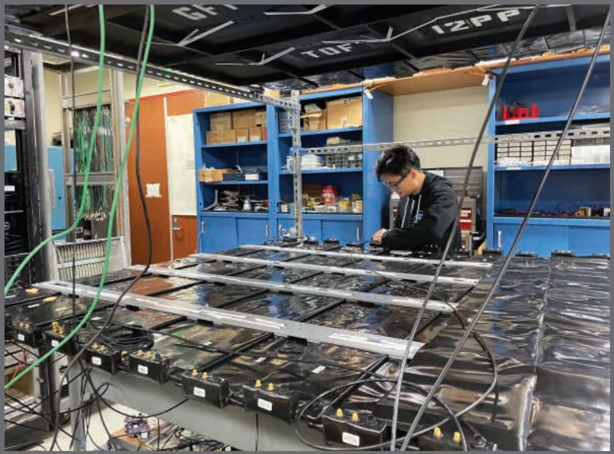
THE ONG GROUP works in the area of experimental astroparticle physics with an emphasis on high-energy gamma-ray astronomy and the search for astrophysical signatures of new physics. An important result, recently published in the Astrophysical Journal, is the mapping of the Galactic center region in high energy gamma rays using the VERITAS telescope (see figure). This work, carried out by graduate students Matt Buchovecky and Jamie Ryan, measured the energetic emission from the Galactic center to higher energies than previous instruments and detected a component of diffuse emission from the Galactic ridge at energies up to 40 teraelectron-volts (TeV). The latter detection provides strong evidence for the existence of a "PeVatron", an accelerator of cosmic rays up to 1 petaelectron volts (1 PeV).

The study of antimatter in space has been a highly fruitful pursuit over the last few decades. Ong has assembled a team of researchers to build an experiment called GAPS that will study antiprotons and antideuterons that would provide strong evidence for new physics such as dark matter annihilation. Funded by NASA, GAPS is in the final design phase and preparing for a first flight in the Antarctic in late 2022. The Ong group has constructed a prototype detector that uses as much of the flight instrumentation as possible, including long scintillation counters and high speed electronics. The prototype is being assembled in an A-level laboratory in the Physics and Astronomy Building and will be operational by September 2021.



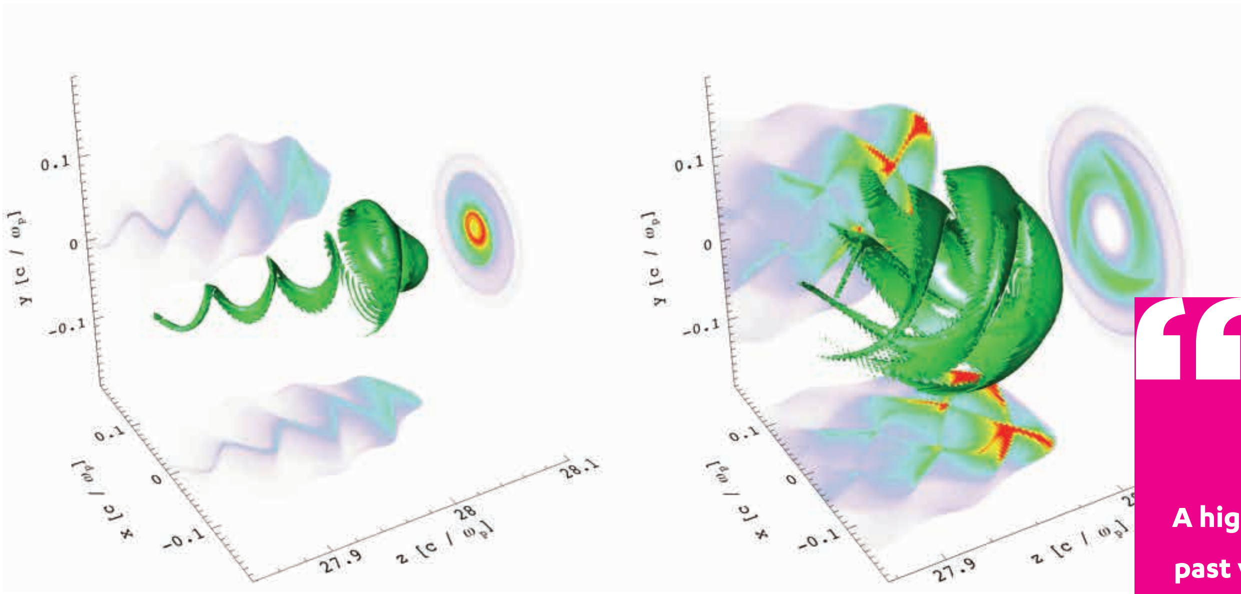
Map of the Galactic Center region in high-energy gamma rays as seen by the VERITAS telescope. The color map shows the statistical significance of detection as a function of Galactic latitude (b) and longitude (l). The central bright source is associated with the Galactic center. The black rings correspond to regions of diffuse emission associated with the Galactic ridge.





Top: Postdoctoral researcher Sean Quinn standing in front of the prototype detector for the GAPS balloon experiment. The two black horizontal layers are layers of long scintillation counters for the detection of charged particles. On the table is a custom-made high-speed digitization board developed by Quinn and colleagues.

Bottom: Engineer Takeru Hayashi working on the prototype detector for the GAPS balloon experiment. The two black horizontal layers are two layers of long scintillation counters for the detection of charged particles.



Generation of twisted ultra-bright electron beams in plasma wave wakefields through lasers with combinations of spin and orbital angular momentum.

A highlight from this past year was Paulo Alves becoming a faculty member of the department and a member of the simulation of plasmas group.

Computer Simulations of Plasma Group

Profs. Warren Mori and Paulo Alves

THE COMPUTER SIMULATIONS OF PLASMA GROUP under the leadership of Profs. Warren B. Mori and Paulo Alves conducts pioneering work in high-performance computing of complex plasma phenomena. The group is home to the particle-in-cell and kinetic simulation software center (PICKSC) and it also includes research faculty members Viktor K. Decyk (emeritus) and Frank S. Tsung as well as researcher Ben J. Winjum, a post-doc (Dr. Fei Li) and 10 graduate students. The group is supported primarily by the U.S. Department of Energy (DOE) and the National Science Foundation (NSF).

The group continues to be focused on developing state-of-the-art plasma physics simulation software and to increase the use of this software to accelerate the rate of scientific discovery, particularly in the areas of laser and beam plasma interactions, plasma based accelerator and light sources, space and astrophysical plasmas, inertial fusion energy, and high-energy density plasmas.

A highlight from this past year was Paulo Alves becoming a faculty member of the department and a member of the simulation of plasmas group. The group has also made significant breakthroughs in science discovery and in software development. It has developed new methods for synchronous injection and acceleration of ultra-bright electron beams [1, 2, 3] including examining how lasers with spin and orbital angular momentum can imprint their structure into injected electrons and a method for pre-bunching the beams on nanometer scales. These are important steps towards the development of compact XFELs.

The group is also investigating efficient particle based simulations methods for studying plasma based acceleration [4].

The group has also recently been awarded an NSF-DOE grant to start an exciting new project that will explore the use of machine learning algorithms to bridge the gap between kinetic (small scale) and fluid (large scale) modeling of magnetic reconnection — a fundamental plasma process responsible for the conversion of magnetic energy into plasma kinetic energy. The ultimate goal of this project is to develop accurate and computationally efficient simulation algorithms to model the multi-scale dynamics of magnetic reconnection.

1. F. Li et al. (2021). Ultra-bright Electron Bunch Injection in a Plasma Wakefield Driven by a Superluminal Flying Focus Electron Beam. https://arxiv.org/abs/2108.00030v1
2. T. N. Dalichaouch et al. (2020). Generating high quality ultrarelativistic electron beams using an evolving electron beam driver. *Physical Review Accelerators and Beams*, 23(2), 21304.
3. Xinlu Xu et al., *"Generation and acceleration of high brightness electrons beams bunched at X-ray wavelengths using plasma-based acceleration"*, arXiv:2010.16081
4. Li, F. Et al. (2021). A quasi-static particle-in-cell algorithm based on an azimuthal Fourier decomposition for highly efficient simulations of plasma-based acceleration: QPAD. *Computer Physics Communications*, 261, 107784

Get to Know the Department Vice Chairs

Our department, with its nearly 600 members and over $40M per year of activity, relies on its vice chairs to keep things running smoothly and bring about important improvements as times change.

Prof. Alice Shapley

PROF. ALICE SHAPLEY is the Vice Chair for Astronomy and Astrophysics (A&A). In many ways, A&A runs like a department-within-a-department with its own undergraduate major, its own graduate program, its own colloquium, its own floors of the buildings, and about one-quarter of our faculty. Such operations are kept moving along and are constantly improved by Alice. Recently, she led the way to modernize our graduate admissions, no longer requiring the Physics GRE exam, thereby allowing A&A a deeper and broader Ph.D. applicant pool. She keeps her research thriving with the collection and analysis of the world's leading dataset of spectra from early galaxies, all while teaching many large general-education astronomy classes. ●

Prof. Jay Hauser

PROF. JAY HAUSER is the Vice Chair for Academic Affairs. Somehow he finds the faculty to teach all of our many undergraduate and graduate courses during this time of skyrocketing enrollment. Jay stays on top of modern teaching techniques which he shares with us and has led groups modernizing our lecture and laboratory curricula. He collected and shared "lessons-learned" about remote teaching which benefited our students during the pandemic. Jay is an experimental particle physicist, co-discoverer of the Higgs boson, using the thousands of custom electronics boards he built and keeps running at CERN. He's now searching in Large Hadron Collider data for exotic phenomena known as sphalerons and for production of microscopic black-holes. ●

Prof. Wes Campbell

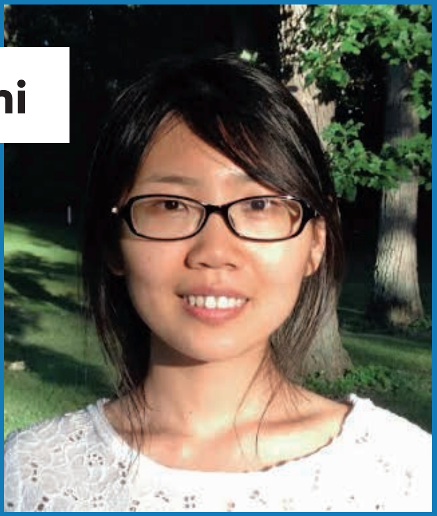
PROF. WES CAMPBELL is the Vice Chair for Resources. He keeps the department infrastructure running smoothly in collaboration with our fantastic department Facilities Group. He is responsible for the critical mechanical and electronics shops, used by the entire Physical Science Division. And every new faculty member that needs a lab, sees him to secure and modernize the space to allow them to thrive. For COVID, Wes kept us informed of C.D.C., L.A. County, and university guidance while helping our essential researchers find their way back into their laboratories. Other times, you'll find him in his basement Atomic-Molecular-Optical (AMO) physics laboratories with his lasers and the world's best qubit. ●

We proudly welcomed two new faculty to the department!

Prof. Alvine Kamaha

ALVINE KAMAHA will join the department's faculty in November 2021. She was recently a postdoctoral research fellow in the physics department of the University at Albany, State University of New York, where she worked on the LUX-ZEPLIN (LZ) experiment, the flagship direct-detection dark matter project in the U.S. On LZ, Dr. Kamaha served as coordinator for calibrations and operations. Dr. Kamaha earned her Ph.D. at Queen's University in Canada and stayed there for her first post-doc before moving to Albany, SUNY. Dr. Kamaha has a versatile background in physics, earning Masters degrees in theoretical atomic physics and neutrino physics before switching to experimental astroparticle physics for her Ph.D. and postdoctoral work. Her research interests currently are in astroparticle physics, with an emphasis on dark matter and neutrino physics. She will continue in her leading role on the LZ project and has plans for the development of future dark matter experiments using novel detection techniques.

Prof. Qianhui Shi



QIANHUI SHI will also join the department's faculty in November 2021. Just prior to that she was a postdoctoral researcher at Columbia University. Her research efforts have focused on electronic properties in low dimension systems, with her Ph.D. studies on conventional 2D systems realized in quantum wells, and postdoc work on van der Waals 2D materials. Examples of her past research subjects includes exotic quantum Hall states, exciton condensates, stripe phases, and non-equilibrium transport phenomena. Dr. Shi is interested in realizing and probing exotic quantum phases of matter exploiting van der Waals material as building blocks. Dr. Shi earned her Ph.D. in physics at the University of Minnesota in 2017.

Richard Ross, director of the new Master of Quantum Science and Technology program

> **The Master of Quantum Science and Technology will prepare students for research and development in the burgeoning quantum technology fields.**

Quantum Master Program takes flight

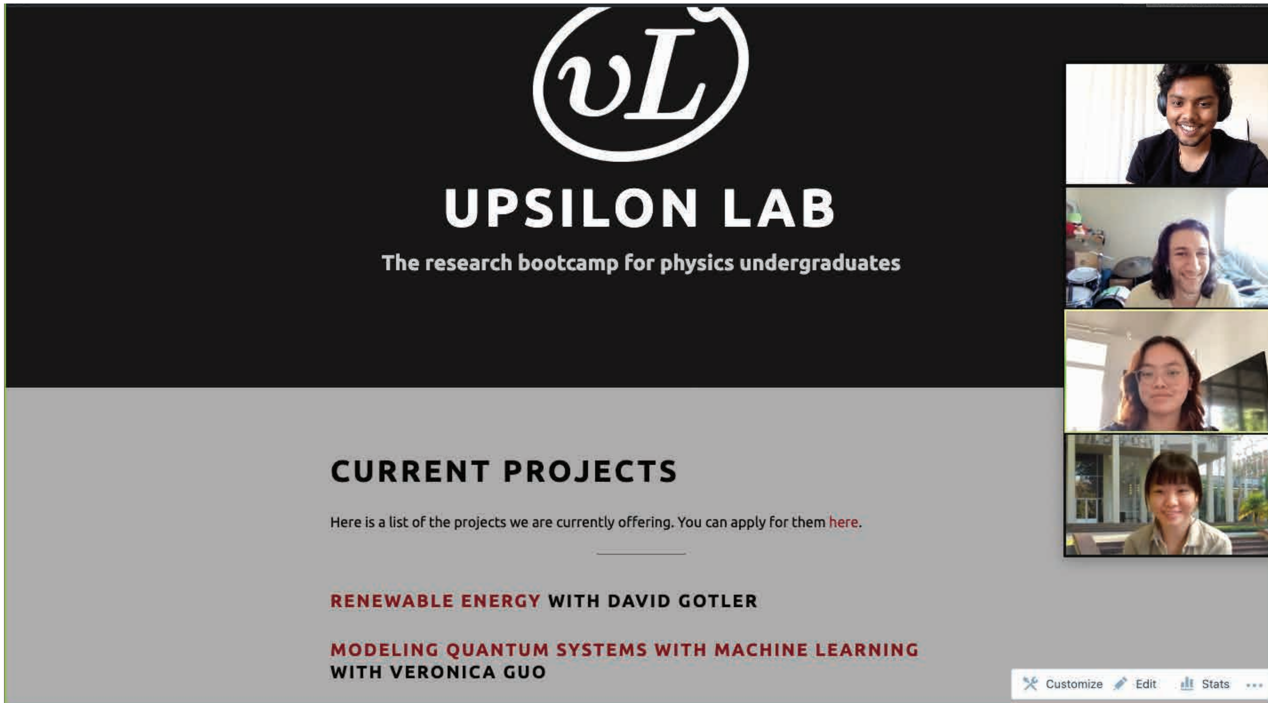
IN MAY the department received approval from the Office of the President for the establishment of a new Master professional degree program in Quantum Information Science. Led by Prof. Eric Hudson, the conception and creation of this program has been two years in the making with significant help from Prof. Stuart Brown, Prof. Paul Hamilton, Prof. Jay Hauser, and Prof. Yaroslav Tserkovnyak, Si Un Cha, and Kathleen Micham, as well as support from the UCLA Center for Quantum Science and Engineering (CQSE) and the NSF Challenge Institute for Quantum Computation (CIQC). The program will be directed by Dr. Richard Ross, who will join the department in September 2021, following a long career at HRL Laboratories (formally Hughes Research Laboratories) in Malibu, CA.

The Master of Quantum Science and Technology will prepare students for research and development in the burgeoning quantum technology fields. Students will learn the foundations of quantum mechanics, quantum computing, quantum information, and quantum devices; they will learn how to work in the laboratory with quantum optics, quantum sensing and materials, and quantum devices; and they will learn the algorithms, languages, and tools of quantum computing. In short, the program will expose the students to the breadth of topics that make up quantum science, engineering, and technology, and prepare them for these cross-disciplinary technical careers.

This program represents an early response to the growing need for a workforce pipeline in quantum science and technology, and takes advantage of UCLA's privileged location in Southern California where a number of small and large companies alike, including Google, Amazon and Microsoft, have chosen to locate their quantum technology development groups. The program anticipates significant interest from local engineers and recent graduates with physical science degrees for a one-year continuing education program to prepare them in modern technology development and research methods. Graduates are expected to fill laboratory-and computing-oriented roles as Quantum Device Fabrication Scientists, Quantum Device Test Engineers, Quantum Chemists, Quantum Computing Scientists, Quantum Control Engineers, and Quantum Data Scientists.

Designed as a one-year full-time academic program, the first cohort of approximately 16 students will begin in Fall 2022. Among the first of its kind in the world, ours is the first Quantum Master program in the UC system, and will serve as a model for future programs in quantum science and related interdisciplinary fields. Consistent with the goals of the Department of Physics and Astronomy, this Master program aims to provide the highest quality graduate education, build a diverse student population, and to promote equity, diversity, and inclusion both within our department and the industry this program is designed to serve.

UNDERGRADUATE WORK



Upsilon Lab 2020-21

> **Upsilon Lab is a research-oriented lab run by undergraduate students.**

IN THE ACADEMIC YEAR OF 2020-21, Upsilon Lab adapted to a completely virtual format due to the onset of the COVID-19 pandemic. Over the year, Upsilon Lab hosted four projects — modeling classical mechanics with neural networks (led by William Zhu), modeling quantum systems with machine learning (led by Joshua Wang and Zooey Nguyen), developing a laser-box software (led by Keqin Yan), and building machine-learning powered renewable energy devices (led by David Gotler and Suyash Kumar). All these projects were developed using Python and its various libraries. A significant achievement this year was the practice of interdisciplinary research, particularly with the integration of state-of-the-art machine learning methods like neural networks that are easily implemented using Python's libraries TensorFlow and PyTorch. The co-presidents Suyash Kumar and Alexander Tolstov also organized educational workshops where programming in Python was taught from a beginner's perspective. While the remote nature presented several obstacles in terms of encouraging participation from students because of "Zoom fatigue," Upsilon Lab is proud to have continued its traditions of providing undergraduates introductory research experience to provide them skills for working with professors. The new presidents for the academic year 2021-22, Zooey Nguyen and Suyash Kumar, plan to extend the lessons learned this year to encourage flexible instruction (with operational in-person and virtual components) in imparting research experience to undergraduates.

IN MEMORIAM

Bob Finkelstein (3rd from left) listening to J. Robert Oppenheimer at the Institute for Advanced Study in 1946. Credit: Alfred Eisenstadt, *The Family of Man*.

Prof. Robert Finkelstein

OUR MOST SENIOR AND BELOVED COLLEAGUE, Prof. Robert Finkelstein passed away on August 27, 2020. Having arrived in 1948, Bob was a familiar face in the department, where we always appreciated his kind demeanor. During WW2, he served as a scientific liaison to Albert Einstein and during his career worked with George Gamow, Robert Oppenheimer, and Julian Schwinger. Bob performed original work on a broad range of topics in particle physics, most recently using knot theory. His record of nearly eighty years of scientific publications continued into this academic year. We are grateful that many of our theory graduate students were sponsored by the Finkelstein Fellowships, which were created and augmented over the years by Bob and his wife Norma. In 2016, our department hosted a 100th birthday celebration of Bob's career, with memories of the invited talks and presentations at: https://conferences.pa.ucla.edu/finkelstein-centennial/index.html. ●

Prof. George Igo

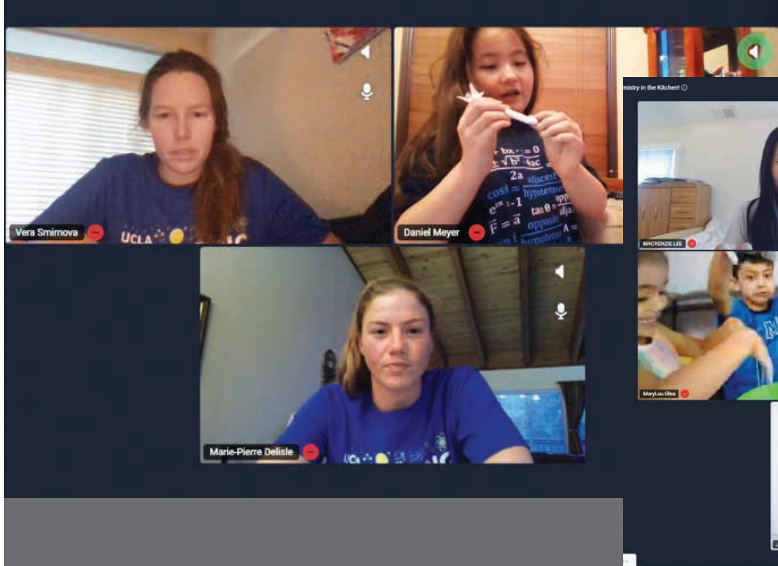
George Igo with his wife Nancy and daughter Saffron. *Courtesy of the Igo Family.*

PROF. GEORGE IGO passed away December 11, 2020. A native of Colorado, George served in the Army during WW2 and was en route to Japan when the war ended. This was followed by study at Harvard then Berkeley, where his thesis advisor was Nobel laureate Luis Alvarez. He continued research at Brookhaven, Stanford, Heidelberg, Lawrence-Berkeley Lab, and Los Alamos, but spent most of his career at UCLA, where he was a leading figure in experimental nuclear and intermediate-energy physics. George served as department chair in 1976-79, a time of rebuilding physics after the end of the Apollo program. George and Prof. Chuck Whitten founded the UCLA nuclear and intermediate energy group. They were leading members in CERN's "Spin-Muon Collaboration" which forced re-evaluation of the elementary structure of nucleons. We always enjoyed his energy, good-naturedness, frank assessments of physics, and good humor. He was also an avid motorcycle rider. ●

Steve Moszkowski, second from right. (1962) *Courtesy of the Emilio Segrè Visual Archives.*

Prof. Steven Moszkowski

OUR COLLEAGUE AND FRIEND, Prof. Steven Moszkowski, passed away December 11, 2020. Steve joined our faculty in 1953 and was a highly accomplished figure nuclear theory. He studied the elementary forces of nature and fundamental issues in the bound states of quarks and nucleons. We fondly recall how Steve was our link to history, having observed and participated in many events first-hand. Albert Einstein was a family friend and Steve even sat on Einstein's lap as a boy. Steve's thesis advisor was Nobel laureate Maria Goeppert-Mayer and he co-authored a famous book on beta decay with Chien-Shiung Wu. In recent years, Steve regaled us with wonderful stories of Einstein from the 1930s and also sad stories from the dark days leading up to WW2. Steve was a very important person in the history of our department. Our hearts go out to his wife, Esther, and his loved ones. ●



Far Left: An aspiring young astronaut builds straw rockets in *Launching into STEM*.

Left: Getting hands dirty making oobleck in *Chemistry in the Kitchen*.

Exploring Your Universe 2020 – A Successful Virtual Experience

> **Exploring Your Universe was founded within the Department of Physics & Astronomy, so our students were proud to continue the tradition in a very non-traditional year.**

HOW COULD WE TAKE the largest on-campus science outreach event at UCLA and turn it virtual? With hundreds of hands-on activities and science experiments, a planetarium, special science talks and an award ceremony, it seemed like it would be impossible to convert the bustling day of events at Exploring Your Universe (EYU) to a virtual format.

But a group of graduate students from various UCLA departments came together to tackle the challenges of continuing EYU's tradition of providing free hands-on, accessible science education for all ages. EYU was founded within the Department of Physics & Astronomy, so our students were proud to continue the tradition in a very nontraditional year.

At 12:00 p.m. on Sunday, November 1, our all-virtual EYU kicked off with a welcome by UCLA Chancellor Gene Block. Dean of Physical Sciences Miguel García-Garibay presented the fourth annual Science and Education Pioneer Award to Dr. Andrea Ghez, recipient of the 2020 Nobel Prize in Physics, who then delivered a keynote presentation about her work on black holes.

Live science talks for all ages continued on the main stage, such as "Why is Antarctica melting?" (Jordyn Moscoso, EPSS, and Ken Zhao, AOS) and "Unrolling the History of the Earth" (Andrew Parisi, EPSS) followed by questions from the audience continued until 5pm. Hundreds of volunteers helped out in the 43 virtual science booths that were divided into virtual demos, DIY science experiments, and a virtual planetarium. Dr. Ghez showed up again to volunteer in the Galactic Center's virtual demo booth, while other demo booths such as "The Wonder of Minerals" displayed various minerals and the growth of rock candy.

Before the event, organizers posted a list of basic home supplies for participants to gather for the interactive booths. But no one was certain how many people would actually show up prepared with the items ahead of time. We were thrilled when hundreds of children and families showed up with cornstarch, food coloring, and other supplies to follow along with the volunteers and conduct science experiments in their own homes.

As a surprise addition to the event made possible by the virtual platform, we added Q&A rooms where expert scientists answered live questions about everything from Earth's Interior to COVID in English, Spanish, Italian, and German.

The hands-on engagement and live interaction throughout the event captured the attention of even those who had been experiencing Zoom fatigue throughout the week.

In fact, data after the event showed that the average user time spent at the event was over two hours!

While nobody knew what to expect for the virtual version of Exploring Your Universe, a turnout of thousands of engaged participants from all over the world surpassed our expectations of what would be possible for this year's event.

While we remain optimistic for an in-person experience for 2021, we hope to incorporate some of the lessons learned from this year's event into future years of EYU. Thank you to the hardworking graduate student organizing committee, our volunteers and speakers, and generous donors who made this event possible.

Recordings of the talks, Q&As, and experiments can be found at www.ExploringYourUniverse.org.

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The 2020 Exploring Your Universe Student Organizing Committee

Learn more about EYU, including details about next year's event, at https://www.physicalsciences.ucla.edu/eyu/.