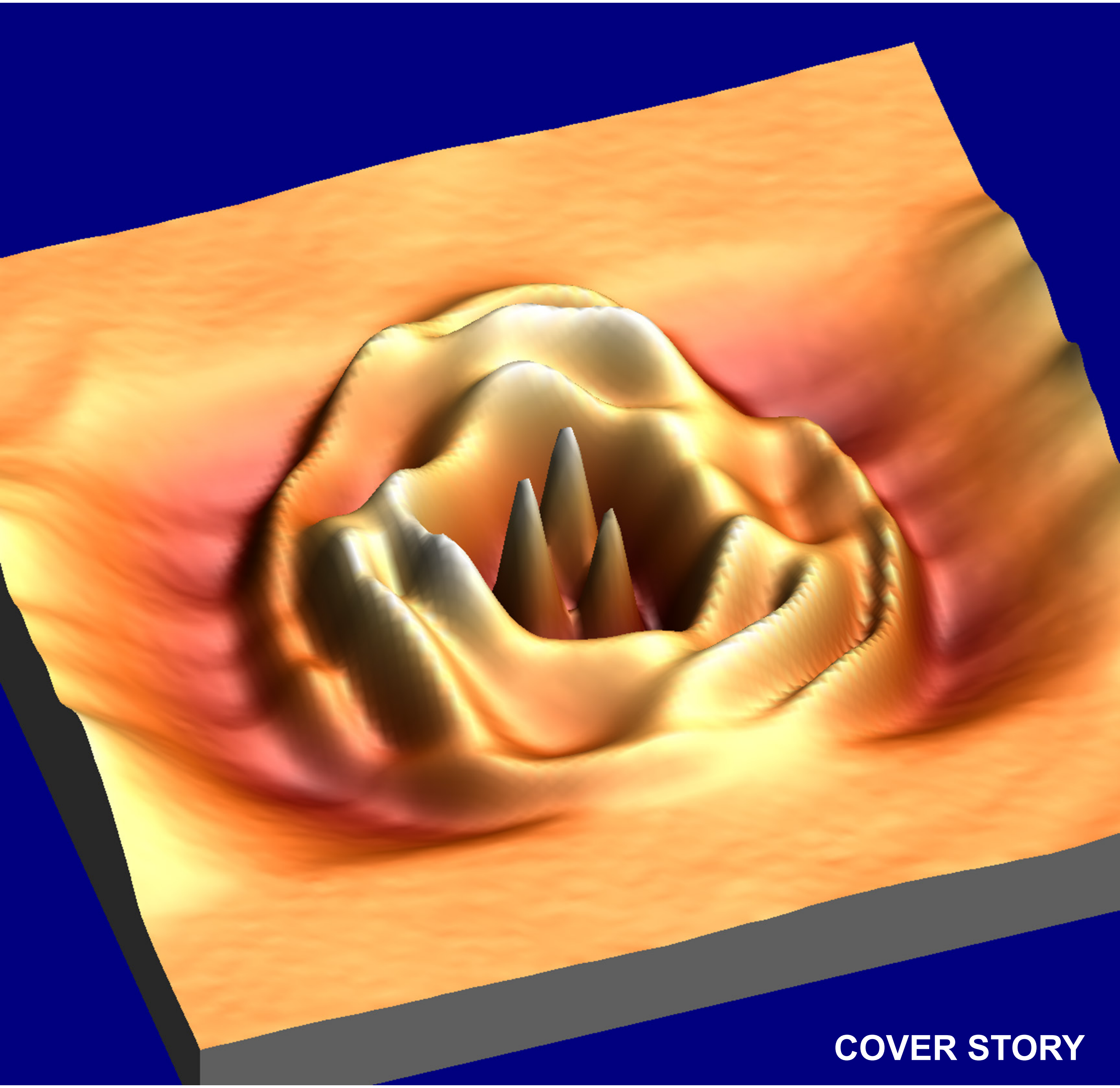
PHYSICS NEWSLETTER

University of California, Santa Cruz Physics Department

WINTER 2021

UNIVERSITY OF CALIFORNIA SANTA CRUZ



COVER STORY

Electron Waves In Graphene Dots

an important step toward quantum information technologies

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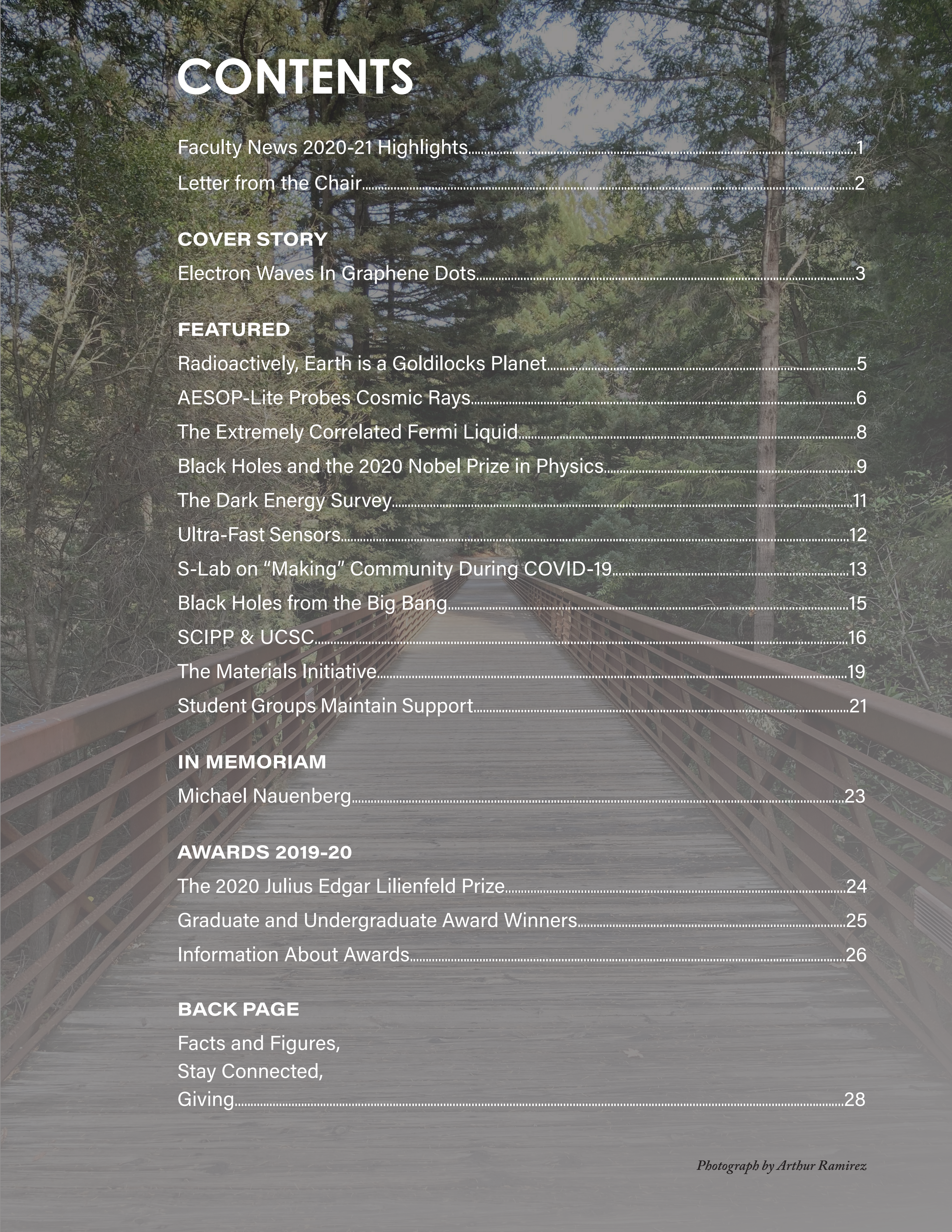


Photograph by Arthur Ramirez

FACULTY NEWS in PHYSICS

2020-21

Professor Emeritus **Joel Primack** was awarded the 2020 Julius Edgar Lilienfeld Prize by the American Physical Society. (See page 24 for more on this).

Professor Emeritus **Michael Dine** was elected to the National Academy of Sciences in recognition of his distinguished and continuing achievements in original research.

Professor **David M. Smith** was elected as President-Elect of the Atmospheric and Space Electricity Section of the American Geophysical Union.

Professor **Stefano Profumo** was elected Fellow of the American Physical Society for "Incisive contributions to the development of astroparticle physics. In particular, for work addressing many aspects of dark matter theory and detection, including direct and indirect detection, as well as collider searches."

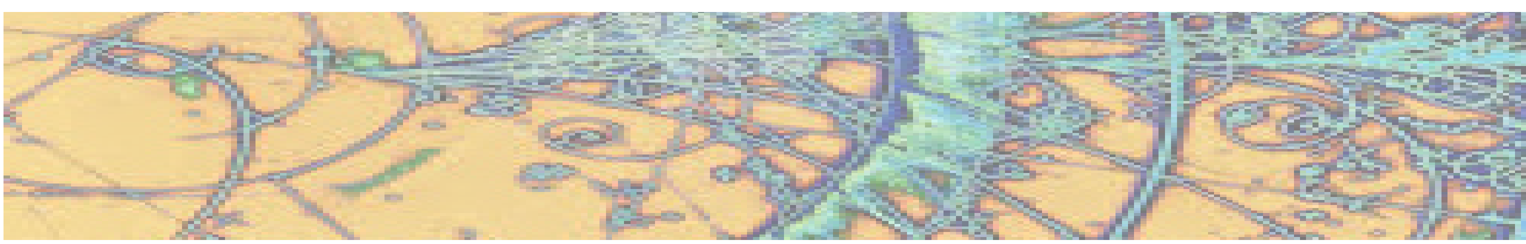
Professor **Onuttom Narayan** was elected Fellow of the American Physical Society for "Definitive work correcting the Fourier law of thermal transport below 2D, and for wide ranging contributions to statistical mechanics of granular systems."

Professor **Tesla Jeltema** was awarded the American Physical Society's Division of Particles and Fields 2020 Mentorship Award "For her dedication to mentoring young physicists through hands-on, heartfelt, and effective engagement with diverse students at all levels demonstrating how particle physics can be an inclusive and productive environment."

Professor **Steven Ritz** is this year's winner of the 2019-21 Outstanding PBSci Faculty Award for being "an extraordinary individual whose leadership, research, and devotion to teaching and service have made him an invaluable member of our campus and community."

Steven Ritz has stepped down from his position as Director of the Santa Cruz Institute for Particle Physics after ten years.
Professor **Jason Nielsen**, after serving as Associate Director of SCIPP for the past eight years, is the new Director as of 2021.

Note – The American Physical Society Fellowship recognizes members who have made advances in physics through original research, innovative application of physics to technology, or significant contributions to the teaching of physics or service to the Society. Each year the number of elected Fellows is less than 0.5% of the APS membership, which is presently about 55,000.



Graphic Image Credit: CERN

Letter from the Chair

Greetings to the UCSC Physics Community!

I hope you enjoy receiving and reading this – our first-ever Departmental newsletter directed towards the entire UCSC Physics community, most of whom are far away from campus, forging their own paths through life. We hope this finds you well and prospering. This newsletter will hopefully help in reestablishing ties to your department, while conveying a strong sense of excitement and purpose in these challenging times.

In terms of sheer numbers, our department is thriving. We are enjoying record popularity of our major tracks (physics, applied physics, and astrophysics) and graduate program, with about 500 declared and undeclared majors, and 73 graduate students currently enrolled. Of those receiving Bachelor's Degrees in Physics, at latest count we are currently 15th in the nation, with most of the institutions ahead of us in this measure having much larger overall student bodies.

As attested to by a number of recent awards, our faculty's research continues to influence and lead our field on the world-wide stage. We continue to secure major research funding, which helps to support our large body of graduate students. The ability to secure such funding rests on the excellence of our faculty, which we continue to rejuvenate with the hiring of remarkable new junior professors. The arrival of Stefania Gori and Wolfgang Altmannshofer has allowed us to maintain our strength in high-energy theory in the face of the recent retirements of Michael Dine and Howie Haber. Counterbalancing the retirement of David Belanger, Sergey Syzranov and Aiming Yan bring new strength in condensed matter theory and experiment respectively, and are central to our new interdisciplinary initiative in materials science (see the featured article on "The Materials Initiative," page 19).

In addition to these "regular" faculty, Emeriti faculty continue to play a major role in Physics Department research and student advising. An additional four faculty members who hold their positions within the closely-allied Santa Cruz Institute for Particle Physics (SCIPP) play significant roles in high-energy physics and astrophysics research. Taken as a whole, the research profile of the department is burgeoning, complete with opportunities abounding for student participation in, and even leadership of, research projects. You can read about a number of those initiatives in the pages that follow.

As you know, the global pandemic imposes numerous challenges to maintaining our traditional excellence in teaching, learning, and research. Essentially all of our instruction is remote and online at present, and our laboratories are accommodating significant restrictions to access the working environment. We deeply miss the community that arises from spontaneous interaction among the halls and labs of campus (and sometimes spills out into various venues downtown).

However, as Chair, I am gratified to report that all of us – students, staff and faculty – have risen to the occasion through a re-doubling of our efforts. Upon our full return to campus, I am confident that we will emerge from the trial stronger than ever. Enjoy your reading of the articles that follow, and the picture they paint of the deep and abiding strengths of the department, and of its bright, engaged, and beneficial future—and please stay in touch!

Best Wishes,

Bruce Schumm
Chair and Professor of Physics

Electron Waves In Graphene Dots

by Tim Stephens

"It's a missing piece of the puzzle, and taken together with the work of others, I think we're moving toward making this a useful system."-Jairo Velasco

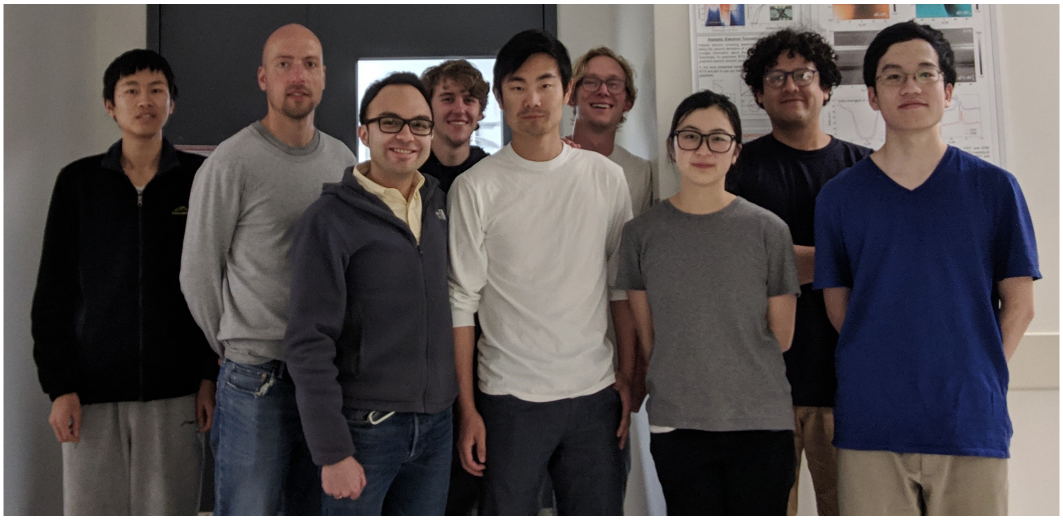
The 2010 Nobel Prize honored the discovery of graphene, a two-dimensional lattice of carbon in a honeycomb pattern, by Andre Geim and Konstantin Novoselov at the University of Manchester. Since their groundbreaking 2004 work, in which they showed how to image graphene, the exploration of its potential in different manifestations has become a major activity in condensed matter physics. Of particular interest is bilayer graphene, which is easier to produce and manipulate than single-layer graphene. Trapping and controlling electrons in bilayer graphene quantum dots yields a promising platform for quantum information technologies.

Physics professor Jairo Velasco and his students have now achieved the first direct visualization of quantum dots in bilayer graphene, revealing the shape of the quantum wave function of the trapped electrons. The results, published November 23 in Nano Letters, provide important fundamental knowledge needed to develop quantum information technologies based on bilayer graphene quantum dots.

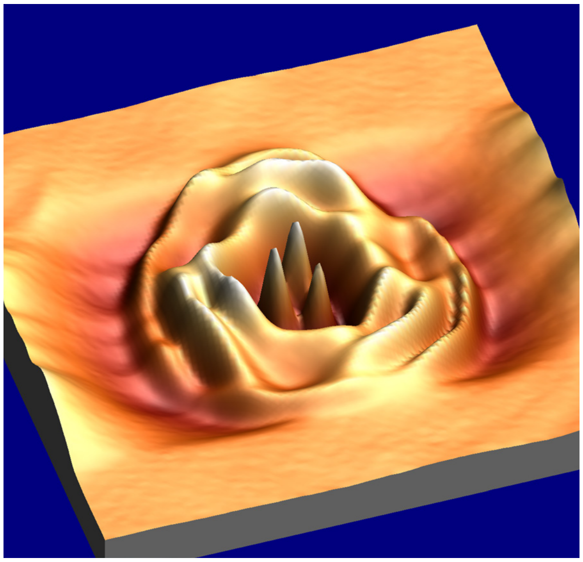
"There has been a lot of work to develop this system for quantum information science, but we've been missing an understanding of what the electrons look like in these quantum dots," said Jairo Velasco Jr., assistant professor of physics at UC Santa Cruz.

While conventional digital technologies encode information in classical bits represented as either 0 or 1, a quantum bit, or qubit, can encode a vastly large amount of information. When many qubits are coupled together in a single quantum mechanical wavefunction, they can be manipulated to perform calculations that are beyond the scope of even the largest supercomputer, the logic operations of which are based on classical bits. A variety of systems, based on materials ranging from diamond to gallium arsenide to graphene, are being explored as platforms for creating and manipulating qubits.

"These quantum dots are an emergent and promising platform for quantum information technology because of their potential for spin coherence, and the controllability of quantum degrees of freedom, with external control voltages," Velasco said. Understanding the nature of the quantum dot wave function in bilayer graphene is important because this basic property determines several relevant features for quantum information processing, such as the electron energy spectrum, the interactions between electrons, and the coupling of electrons to their environment.



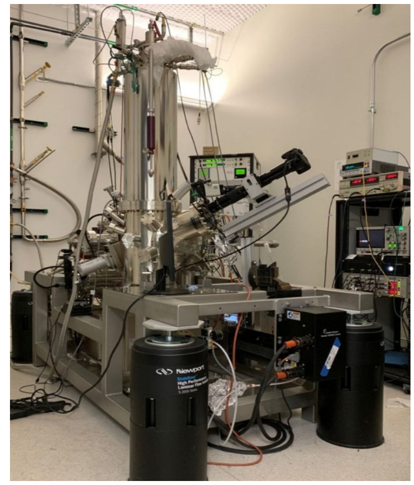
Professor Jairo Velasco and his student research group. From left to right: Zhehao Ge (Grad), Frederic Joucken (Postdoc), Jairo Velasco Jr. (Professor), Alex Stram (Undergrad), Bruce Ji (Undergrad), John Davenport (Grad), Belinda Zhen (Undergrad), Arturo Quezada (Grad), Albert Chen (Undergrad).

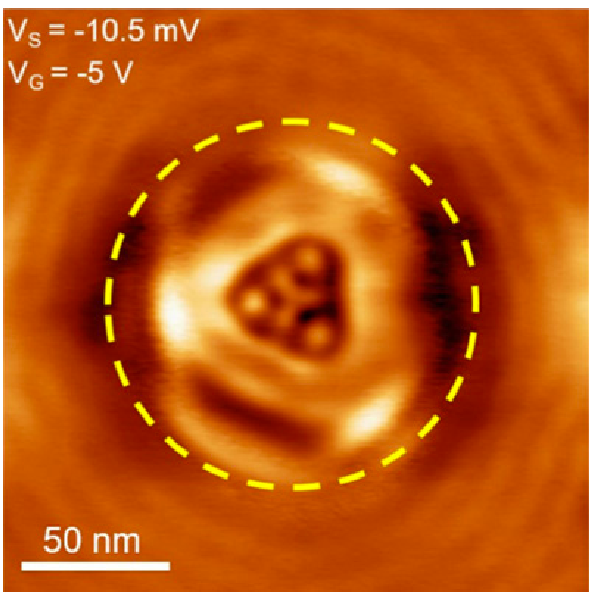


Visualization of quantum dots in bilayer graphene using scanning tunneling microscopy and spectroscopy reveals a three-fold symmetry. In this three-dimensional image, the peaks represent sites of high amplitude in the waveform of the trapped electrons. Image credit: Zhehao Ge, Frederic Joucken, and Jairo Velasco Jr. Caption credit: Tim Stephens and Jairo Velasco Jr.

Velasco's team used a method he had developed previously to create quantum dots in monolayer graphene using a scanning tunneling microscope (STM). With the graphene resting on an insulating hexagonal boron nitride crystal, a large voltage applied with the STM tip creates charges in the boron nitride that serve to electrostatically confine electrons in the bilayer graphene.

Right: The scanning tunneling microscope used to visualize quantum dots in bilayer graphene, as shown in the other 2 figures on this page.





The first direct visualization of quantum dots in bilayer graphene shows the shape of the quantum wave function of the trapped electrons. Image credit: Zhehao Ge, Frederic Joucken, and Jairo Velasco Jr. Caption Credit: Tim Stephens and Jairo Velasco Jr.

"The electric field creates a spatial region of lower potential energy, like a corral, that traps the electrons in the quantum dot," Velasco explained. The corral-like regions are about 100 nanometers across, or 1/1000 of the width of a human hair.

The researchers then used the scanning tunneling microscope to image the electronic states inside and outside of the corral. In contrast to theoretical predictions, the resulting images showed a broken rotational symmetry, with three peaks instead of the expected concentric rings.

"We see circularly symmetric rings in monolayer graphene, but in bilayer graphene the quantum dot states have a three-fold symmetry," Velasco said. "The peaks represent sites of high amplitude in the wave function. Electrons have a dual wave-particle nature, and we are visualizing the wave properties of the electron in the quantum dot."

This work provides crucial information, such as the energy spectrum of the electrons, needed to develop quantum devices based on this system. "It is advancing the fundamental understanding of the system and its potential for quantum information technologies," Velasco said. "It's a missing piece of the puzzle, and taken together with the work of others, I think we're moving toward making this a useful system."

In addition to Velasco, the authors of **the paper corresponding to this work** include co-first authors Zhehao Ge, Frederic Joucken, and Eberth Quezada-Lopez at UC Santa Cruz, along with coauthors at the Federal University of Ceara, Brazil, the National Institute for Materials Science in Japan, University of Minnesota, and UCSC's Baskin School of Engineering. This work was funded by the National Science Foundation and the Army Research Office.

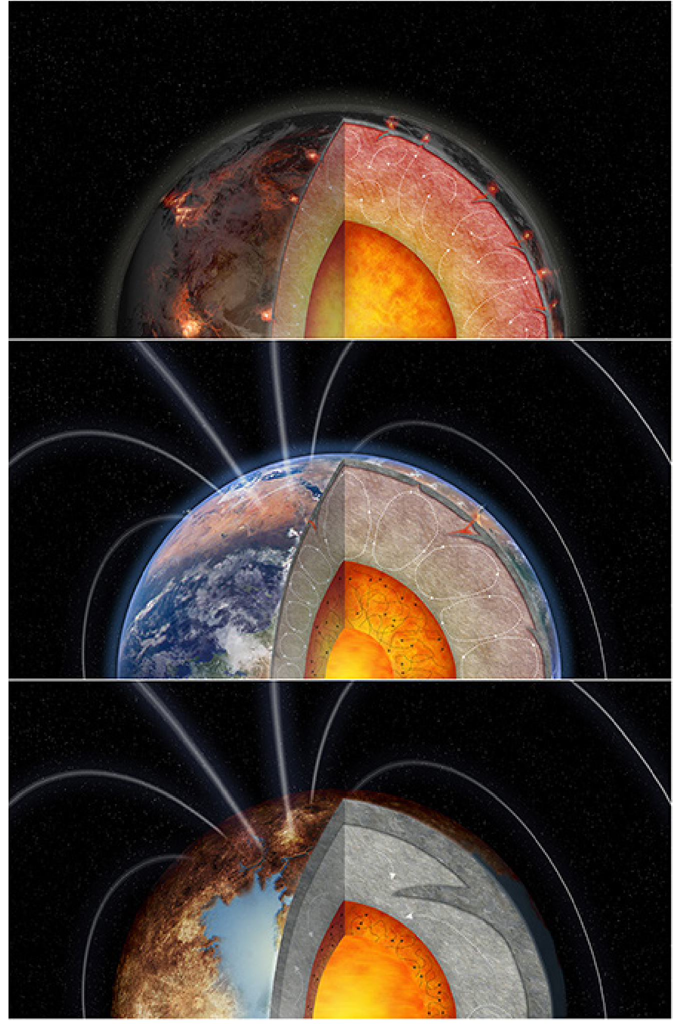
Radioactively, Earth is a Goldilocks Planet

by Joel Primack

Most of the gold in your jewelry, the rare earth elements in your cell phone, and the thorium and uranium whose radioactive decay provides much of the heat of the deep earth, all originated in mergers of neutron stars with other neutron stars or with black holes. We learned the source of these heavy elements when gravitational waves detected in April 2017 allowed astronomers to point powerful telescopes at a neutron-star merger for the first time. The resulting heavy elements detected added up to about 1/20th of the mass of the sun—including about ten times the mass of Earth just in gold!

At a recent meeting of UCSC scientists, gathering to organize a new Astrobiology institute, I pointed out that the neutron star merger discovery implied that the amount of the longest-lived radioactive elements thorium (Th) and uranium (U) was likely to vary quite a lot between different stars and their planets. Many astronomers had thought that the origin of such heavy elements, as with many of the lighter ones like oxygen and magnesium, was core-collapse supernovae—the giant explosions that end the lives of massive stars and leave behind neutron stars or black holes. But while core-collapse supernovae are relatively common, about one per hundred years in a big galaxy like our Milky Way, mergers of neutron stars and black holes are much rarer, only a few per million years. This rareness implies that stars that formed close to where such mergers had recently occurred would contain larger amounts of these heavy elements.

At the same meeting, UCSC Earth and Planetary Sciences Professor Francis Nimmo responded that he could calculate the effects of such variations using an Earth model he had created nearly twenty years ago. What he found was a delicate balance; if Earth had twice as much Th and U, for hundreds of millions of years it would have lacked a magnetic field, which protects the atmosphere and surface from destructive effects of cosmic radiation. Earth would also have had widespread volcanism that could have caused frequent mass extinctions. On the other hand, if Earth had half as much of these radioactive elements, this could have led to less or even no plate tectonics, the essential process that recycles the planet's carbon. Plate tectonics and a magnetic field may both be necessary for the evolution of complex life. Thus, as our recently published paper shows, Earth may be a Goldilocks planet in this sense, with neither too little nor too much Th and U.



Shown here are three versions of a rocky planet with different amounts of internal heating from radioactive elements. The middle planet is Earth-like, with plate tectonics and an internal dynamo generating a magnetic field. The top planet, with more radiogenic heating, has extreme volcanism but no dynamo or magnetic field. The bottom planet, with less radiogenic heating, is geologically "dead," with no volcanism. (Illustrations by Melissa Weiss).

In searching for life in the Universe, astronomers look for planets in the "habitable zone" around their stars, that is, at distances where liquid water could exist. The rare earth element europium forms with Th and U, but unlike them, it is relatively easy to measure in the spectra of stars. Therefore, europium can tell us how much of these radioactive elements are in rocky planets orbiting these stars, and thus whether such planets are also likely to have tectonics and magnetic fields. This could help narrow the search for planets with advanced forms of life.

This article has been adapted and edited with permission from the UCSC Newscenter and edited by Tim Stephens: https://news.ucsc.edu/2020/11/planet-dynamos.html.
Please see the piece on Joel Primack's recently won prize (page 24) for more content on his research.

AESOP-Lite Probes Cosmic Rays

by Robert Johnson

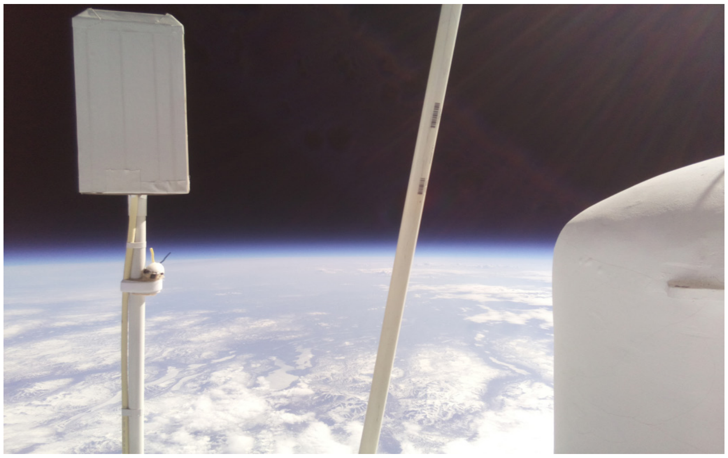
Above: The recovery of AESOP-Lite from the landing site atop a glacier on Ellesmere Island, Canada.

As physicists know, Earth is continually bombarded with cosmic rays that propagate through the heliosphere, traveling against the solar wind before they can reach us. While cosmic rays mainly comprise high energy protons and atomic nuclei, 1% of the particles are electrons. Despite this small contribution, the electronic component is thought to be essential for understanding the origin and propagation of cosmic rays, since their energy loss mechanisms are qualitatively different from those of heavier particles. At the low-energy end of the electronic spectrum, the effects of the so-called "solar modulation," or the Sun's contribution to the intensity of cosmic rays, are especially large. These effects can be measured by comparing the electron spectrum measured at Earth from high-altitude balloon flights to measurements made by the two Voyager spacecraft at the edge of the solar system. A thorough study of the variation in solar modulation with time through the 11-year solar cycle requires multiple flights. This is where the Low Energy Electrons (LEE) project comes in.

The LEE project originated in 1968 at the University of Chicago, before moving to the Bartol Research Institute at the University of Delaware in 1984. The LEE payload flew numerous times on high-altitude balloons since the early 1970s to map out the electron spectrum over several solar cycles. The payload consisted of scintillator detectors to trigger on the passage of charged particles, a Cherenkov detector to separate protons from electrons, and a lead-glass calorimeter to measure the electron energy.

In addition to heavy particles and electrons, cosmic rays contain the electron's antiparticle, the positron, the understanding of which will provide solutions to additional pieces of the cosmic ray puzzle. In the mid 2000s, John Clem, one of the LEE investigators at the University of Delaware, contacted me at UCSC about helping to build a magnetic spectrometer which could distinguish between electrons and positrons. I had recently finished leading the collaboration that designed and built the large silicon-strip tracking system of the NASA Fermi Large-Area Gamma-ray Telescope, which launched in 2008 and remains fully operational. Clem had realized that the same technology would be ideal for a balloon payload.

After the Italian PAMELA (Payload for AntiMatter Exploration and Light-nuclei Astrophysics) satellite discovered an unexpectedly large flux of high-energy cosmic-ray positrons (10 to 60 GeV) in 2008, interest in distinguishing between electrons and positrons in the cosmic ray flux increased. In 2014, NASA awarded the Delaware/UCSC collaboration a grant to replace the LEE electron calorimeter by a magnetic spectrometer and fly it in the arctic, where the tilt of the Earth's magnetic field lines allows low-energy cosmic rays to enter the atmosphere. The new instrument that came about from this effort is named AESOP-Lite, after the larger and older AESOP (Anti Electron Sub Orbital Payload), which was built around spark chambers for particle tracking (a long obsolete technology). AESOP-Lite uses the trigger scintillators, Cherenkov counter, pressure vessel, and much of the electronics from the original LEE payload. The goal of the experiment is to improve the knowledge of cosmic ray electron and positron fluxes below the energy range accessible to the PAMELA detector and its successor, the AMS cosmic-ray detector on the International Space Station.



AESOP-Lite at full float altitude over the Atlantic Ocean, taken by a camera Sarah attached to the payload. The creature strapped to the antenna mast is Roger, Sarah's mascot.

For the creation of AESOP-Lite, the Delaware group designed and procured a donut-shaped permanent magnet, while my graduate student researcher Sarah Mechbal and I set out to build the silicon-strip detector boards needed to instrument the spectrometer. With help from colleagues at the University of Pisa in Italy, I was able to repurpose silicon-strip sensors from the Fermi-LAT production to instrument AESOP-Lite. I also used custom-CMOS (complementary metal oxide semiconductor) readout chips previously designed for a proton computed tomography for medical imaging projects. Each of the seven detector boards includes 4 sensors, 12 readout chips, and a logic chip (field-programmable gate array) that operates on thousands of lines of firmware written by the UCSC group to do the triggering and data acquisition. These features make AESOP-Lite an especially sensitive piece of equipment, equipped for measuring the electron spectrum at high altitudes.

In January 2018, the collaboration gathered in Palestine, Texas to integrate the instrument with a gondola and prepare AESOP-Lite for flight. The assembly was then shipped to the Swedish Esrange Space Center, located north of the Arctic Circle (68° N) near the city of Kiruna, where Sarah spent several weeks preparing and testing the payload in anticipation of a launch opportunity. Finally, in mid May 2018, the weather conditions were perfect, and AESOP-Lite launched from the icy ground to begin a 5-day flight. With an average altitude of 135,000 feet (about 41 km), AESOP-Lite soared across the Atlantic Ocean and Greenland, landing by parachute on top of a glacier on Ellesmere Island, Canada (78°40' N).

In 2019, the collaboration was awarded another NASA grant to upgrade the payload and fly it again, hopefully in Antarctica and at a higher altitude. My colleagues and I are currently working to add an 8th tracking board and improved triggering, and are replacing most of the old 1980s vintage electronics by a single board with modern electronics, including a fast timing chip to distinguish between downward and upward going particles. The goal is to make dramatic improvements to the measurement with a longer flight and lower background, maximizing the accuracy of AESOP-Lite's future readings, thus bringing researchers closer to a full understanding of cosmic rays.

Project AESOP-Lite's collaboration, including Robert Johnson and graduate student Sara Mechbal to his right, plus faculty, students, and a postdoc from The University of Delaware, at the integration site in Texas.

The Extremely Correlated Fermi Liquid

by Sriram Shastry

I have been working together with students, postdocs and collaborators on developing a new theory for describing very strong interactions between electrons. These are of a type that arise in strongly correlated systems of quantum matter. We call this the theory of Extremely Correlated Fermi Liquids, or ECFL in short. Strongly correlated systems have been the focus of attention for several years now; these are systems such as copper oxide superconductors, metals in which electrons are "heavy" by virtue of their magnetic interactions, and so-called Kondo lattices of magnetic atoms in a sea of electrons. In all of these systems, the electron-electron interaction is very strong relative to their kinetic energy. This situation contrasts with the description of semiconductors and (elemental) metals aluminum, sodium, etc. In the latter, the electron-electron interaction is small enough to view these as weakly interacting gases of Fermions. Since liquids are understood to be weakly interacting gases, Landau called these systems as Fermi-Liquids. The phrase strongly correlated is used in current usage instead of strongly interacting—the latter term is more generic and is applied to other systems, such as nuclear matter and hadron physics.

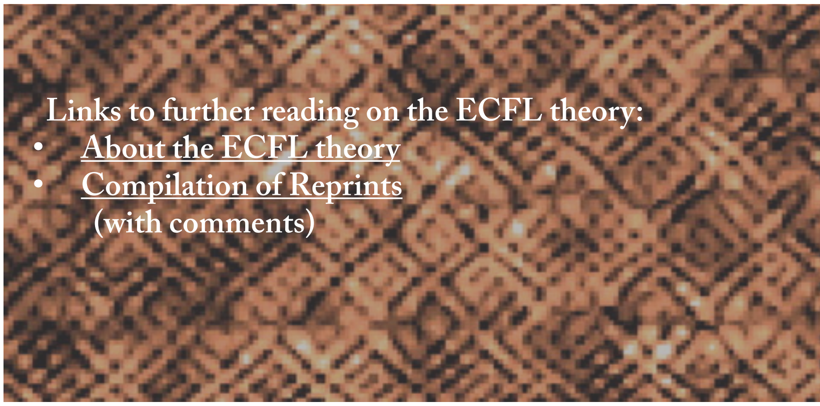
The prime motivation for developing the ECFL theory is to understand the copper oxide high Tc (transition temperature) superconductors. These were discovered by Bednorz and Mueller, and earned them the 1987 Nobel Prize for Physics, a mere year after the discovery! These materials became popular as the first superconductors with Tc above the boiling point of nitrogen (77 K). The highest achieved Tc is still rather low, we are thus far from the holy grail of room temperature ambient pressure superconductivity.

In addition to their technological importance, the cuprates attracted enormous interest due to their unusual basic physics. It was recognized very soon after their discovery that these materials provide a physical realization of the much theorized doped "Mott-Hubbard" systems. These are described by the idealized Hubbard model and the closely related t-J model, where the electron kinetic energy is represented by hopping between nearby atoms and the interaction between electrons is taken to be short ranged. The simple looking mathematical statement of these models is matched only by the formidable difficulty of finding reliable solutions. Calculating reliably the physical consequences of these models is a classic many-body problem that has defied theorists for many decades.

The ECFL theory provides a controlled set of successive approximations to the t-J model. The theory overcomes a fundamental stumbling block for the use of perturbation theory (i.e. Feynman diagrams) methods, namely a large interaction energy scale. Instead, ECFL obtains an exact set of non-perturbative (Tomonaga-Schwinger functional) equations, and proceeds to solve these by a set of systematic successive approximations.

The initial results of the ECFL theory, applied to calculating properties of the cuprate superconductors above Tc are very promising. Previously our group has successfully calculated the observed highly unusual energy line shapes of electrons that are photo-emitted from the cuprates. In addition, we are excited by our recent success in one of the central problems in the field, namely the calculation of the temperature and electron density dependence of the resistivity. Further exciting problems involving the superconducting state and estimations of achievable Tc are in the offing.

Sriram Shastry, Professor of Physics.



Links to further reading on the ECFL theory:

- About the ECFL theory
- Compilation of Reprints (with comments)

Graphic Image Credit: Science Magazine

Black Holes and the 2020 Nobel Prize in Physics

by Anthony Aguirre

Black holes, some of the most interesting objects in physics (and the Universe) have been on a roll lately. In 2017, the physics Nobel prize was awarded for the discovery of gravitational waves from black hole mergers. Last year, the 2020 prize was awarded to Andrea Ghez, Reinhard Genzel, and Roger Penrose for pioneering observational and theoretical work to firmly establish that black holes are a concrete reality in the cosmos, as strange as they may be. More information on the prize can be found here.

Reinhard Genzel

Image Credit: MPG

Ghez and Genzel's work used novel and advanced techniques of adaptive optics and speckle imaging to resolve individual stars orbiting the central black hole in the Milky Way, leading to astonishing views of stars completing full orbits about a compact central source that could only be a black hole. Moreover, the precise shapes of these orbits directly probe Einstein's general relativity and the black-hole spacetime structure it predicts. This half of the prize is also an important indicator of increasing (but still too lacking) diversity in physics, as only the fourth physics Nobel prize awarded to a woman.

Andrea Ghez

Image Credit: UCLA

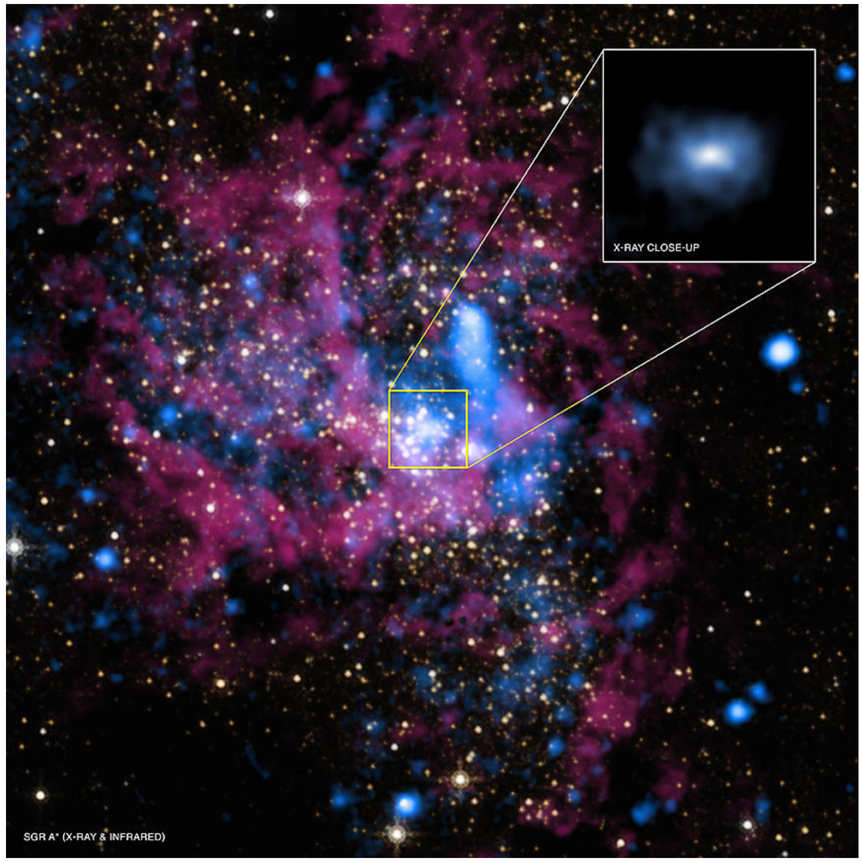
Roger Penrose's portion of the prize was awarded "for the discovery that black hole formation is a robust prediction of the general theory of relativity." Prior to his work in the 1960s with Stephen Hawking, many believed black hole solutions to Einstein's equations to be mathematical curiosities, likely irrelevant to the real world. Among his many achievements were Penrose's singularity theorems proving that under reasonable assumptions, very massive gravitationally collapsing objects inevitably form singularities of unbounded matter density and spacetime curvature. For more details, see this excellent article in Quanta Magazine.

Roger Penrose

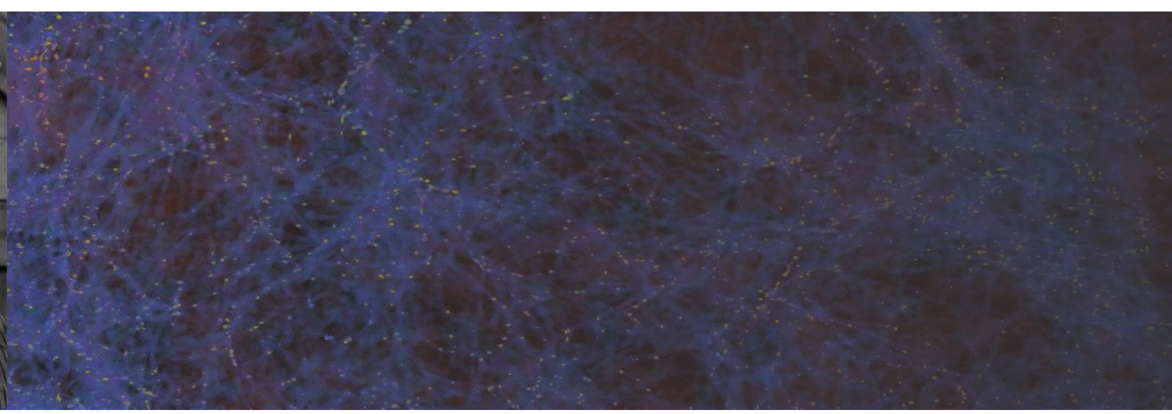
Image Credit: Oxford University

Research on black holes has in recent decades become a firmly established and very dynamic part of research in both physics and astrophysics, including exciting work being done here at UCSC. In astronomy, Enrico Ramirez-Ruiz and Piero Madau study the dynamics and evolution of both stellar-mass and supermassive black holes, and many observers pioneer observational techniques and instruments used in studying astrophysical black holes. In physics, observers and instrumentalists including Tesla Jeltema, Steve Ritz, David Williams, Robert Johnson, and Bill Atwood among others measure high-energy signals from black holes and other compact objects, largely with the Fermi Gamma-Ray Telescope (pictured on page 17). On the theory side, my own research group studies fundamental questions regarding the nature of black holes and their evolution, while Stefano Profumo's group investigates detection of primordial black holes, including as candidates for dark matter (see article on page 15 for more details on this).

Many mysteries regarding black holes remain, but it's amazing to see the progress in our understanding due to the winners of this year's Nobel prize, and so many others!



The center of the Milky Way Galaxy, with supermassive black hole Sagittarius A* (Sgr A*) located in the middle (Image and caption information credit to NASA). The image comprises both X-rays (blue) and infrared emission (red and yellow). The close-up shows Sgr A* in X-rays alone. For scale reference, the enclosed close-up region spans half a light year wide.



Anthony Aguirre, Professor of Physics.

Graphic Image Credit: Forbes Magazine

The Dark Energy Survey

by Tesla Jeltema

One of the greatest mysteries in modern cosmology is the origin of the observed acceleration in the expansion of the universe. This acceleration may stem from dark energy, an energy component of the universe that is thought to exist apart from the observed mass. Alternatively, it may indicate that the theory of general relativity is incomplete on cosmological scales. Dark energy and modified gravity models can be probed through observations that quantify the geometry of the universe and the formation of structure over time, which is the goal of the Dark Energy Survey (DES), an international collaborative effort involving over 400 scientists from 25 institutions in 7 countries. Using a dedicated wide-field camera on the 4-meter Blanco Telescope at the Cerro Telolo Inter-American Observatory in Chile, the DES has surveyed an eighth of the sky to a depth that allows researchers to look back roughly 8 billion years.

Graduate student Spencer Everett with the Blanco Telescope.

UCSC physicists are taking a leading role in several aspects of the DES survey. I myself serve on the DES Advisory Board and co-chair the DES Clusters Science Working Group, which addresses the evolution of the density of clusters of galaxies, the largest gravitationally bound structures in the universe. I am particularly focused on using external X-ray observations and spectroscopy to characterize the performance of the cluster finding algorithm used by DES, as well as constraining the intrinsic scatter of the DES cluster mass proxy called “richness.” These efforts have included many significant contributions from both Graduate and Undergraduate students in the group.

Graduate student Spencer Everett is a current member and former chair of the Early Career Scientist Committee which considers issues affecting DES scientists early in their careers, particularly onboarding, mentoring, and career advancement. In addition, he has led the development of a new, open source simulation suite called “Balrog,” which characterizes the selection effects and measurement biases of DES by injecting a realistic ensemble of stars and galaxies into the real survey images and then measuring the difference in their recovered vs. injected properties. These augmented images are analyzed in parallel with the original data to automatically inherit measurement systematics that are often too difficult to capture with traditional generative models. The resulting object catalog is a Monte Carlo sampling of the DES transfer function. It is used as a powerful diagnostic and calibration tool for a variety of DES science analyses, particularly for the calibration of the photometric redshifts of distant “source” galaxies and magnification biases of nearer “lens” galaxies. This effort is crucial for extracting accurate cosmological constraints from DES measurements.

Graduating students in the Jeltema research group at the 2019 Physics Department celebration. From left to right: Vernon Wetzell (B.S., Chancellor's Award), Lena Eiger (B.S., Dean's Award), Prof. Tesla Jeltema, Raziq Noorali (B.S., Dean's Award), Devon Hollowood (Ph.D.), Brynn Hegland (B.S.).

Undergraduate students are also making important contributions to the DES. Recent graduate Vernon Wetzell won the 2020 Chancellor’s Award for his senior thesis on using optical spectroscopy to study the dynamics of clusters and to understand cluster selection in DES. He is now the lead author of a DES collaboration paper on this work. Another recent graduate Lena Eiger has made significant contributions to the calibration of the DES cluster survey using X-ray observations. X-ray follow-up is critical to calibrating cluster masses which are needed to constrain cosmological parameters, like the dark energy equation of state. Lena won both the Dean’s Award for their senior thesis and the Transfer Scholar Activist Award, and they are now co-leading a DES collaboration “Essential” paper on the X-ray calibration work. In 2020-2021, four UCSC undergraduate students will complete senior theses on Dark Energy Survey research, including Jose Jobel (B.S. Summer 2020), Paige Kelly (B.S. Winter 2021), Verenise Martinez (B.S. Spring 2021), and Allison Swart (B.S. Spring 2021).

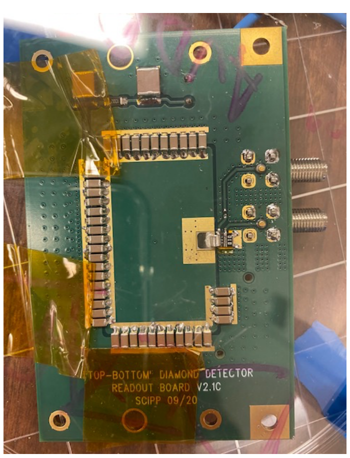
Ultra-Fast Sensors

by Bruce Schumm

UC Santa Cruz is well known as a center of innovation for particle physics instrumentation (see article on SCIPP, page 16). This ever-deepening expertise has positioned us for a new endeavor—pushing the limits of the speed of solid-state detectors. Over the past few years, a new group (including some old names) has formed: the Ultrafast Solid-State Detectors (UFSD) Group. I have joined Emeriti faculty Abe Seiden and Hartmut Sadrozinski to explore the following questions: how precisely can one measure the time of passage of a high-energy particle or the absorption of an X-Ray (timing resolution), and how quickly can one process the information and get ready for the next event (frame rate)?

In pursuit of these faster sensors, the UFSD group has played an instrumental role in the development of Low Gain Avalanche Detectors (LGADs), a class of silicon-diode sensors that make use of the internal "impact ionization" effect to multiply the number of conduction electrons released in the event, and boost the size of the sensor signal. As a result, the sensor can be made very thin—as thin as 20 µm—leading to collection of the signal charge in a few hundred picoseconds.

So far, LGADs have achieved a timing resolution as good as 17 psec, and a frame rate of 500 MHz. Sadrozinski, Seiden, and I, along with four other students and researchers, own intellectual property rights to two LGAD inventions: the "AC LGAD", which is finding prospective applications in detection systems requiring precise timing and position resolution while maintaining a rather sparse resolution, and the "Deep Junction (DJ) LGAD", designed to provide sensitive signal detection when high resolution is required. Such ultra-precise timing will result in greater precision in particle detection, leading to better tests of the Standard Model of strong-electro-weak interactions, and the possible discovery of new particles.



SCIPP's low-impedance signal board. The board is used to read out a monocrystalline diamond sensor (center) exposed to the full brunt of SLAC's Linac Coherent Light Source (LCLS) X-ray laser beam, measuring the individual pulses of the megaHertz beam.

Twenty-five channel microprobe card and design team, including (from left to right) SCIPP staff members Max Wilder and Zach Galloway, and graduate students Yuzhan Zhao and Carolyn Gee.

Branching out from the group's traditional focus on particle physics, I have led the development of a collaboration of UC institutions (including the Los Alamos and Lawrence Berkeley National Laboratories) working towards the development of advanced diagnostics for current and next-generation accelerator facilities. These efforts are especially focused on X-ray Free Electron Lasers (XFELs), with an eye towards applications across a broad array of fields, including physical chemistry and biochemistry, materials science, earth science, and computer engineering, to name a few.

For the accelerator diagnostics, diamond is a promising detection medium, as it collects charge more quickly than silicon sensors, and is very radiation tolerant. Consequently, the group is developing a new expertise in the design of diamond detection systems. As they transition to lasing, XFEL beam intensities grow by as much as six orders of magnitude, loading signal paths with short (as little as 100 psec) bursts of current that can exceed 1 kiloAmp. Developing high-bandwidth, low-impedance signal-path readout of diagnostic signals (from diamond or silicon) is one of the challenges that the group is beginning to address as the work of the collaboration gets underway.

Between the highly-recognized work on LGAD sensor and readout design, and the new effort in Advanced Accelerator Diagnostics, the Ultrafast Sensors group's funding level has increased to approximately \$1M per year, allowing for a significant increase in SCIPP's expert staffing and advances in its infrastructure. This includes the acquisition of a 13 GHz Keysight Technologies UXR digital storage oscilloscope, increasing the bandwidth of SCIPP's readout capability by over a factor of five—yet another way in which SCIPP infrastructure increasingly rivals that of US National Laboratories.

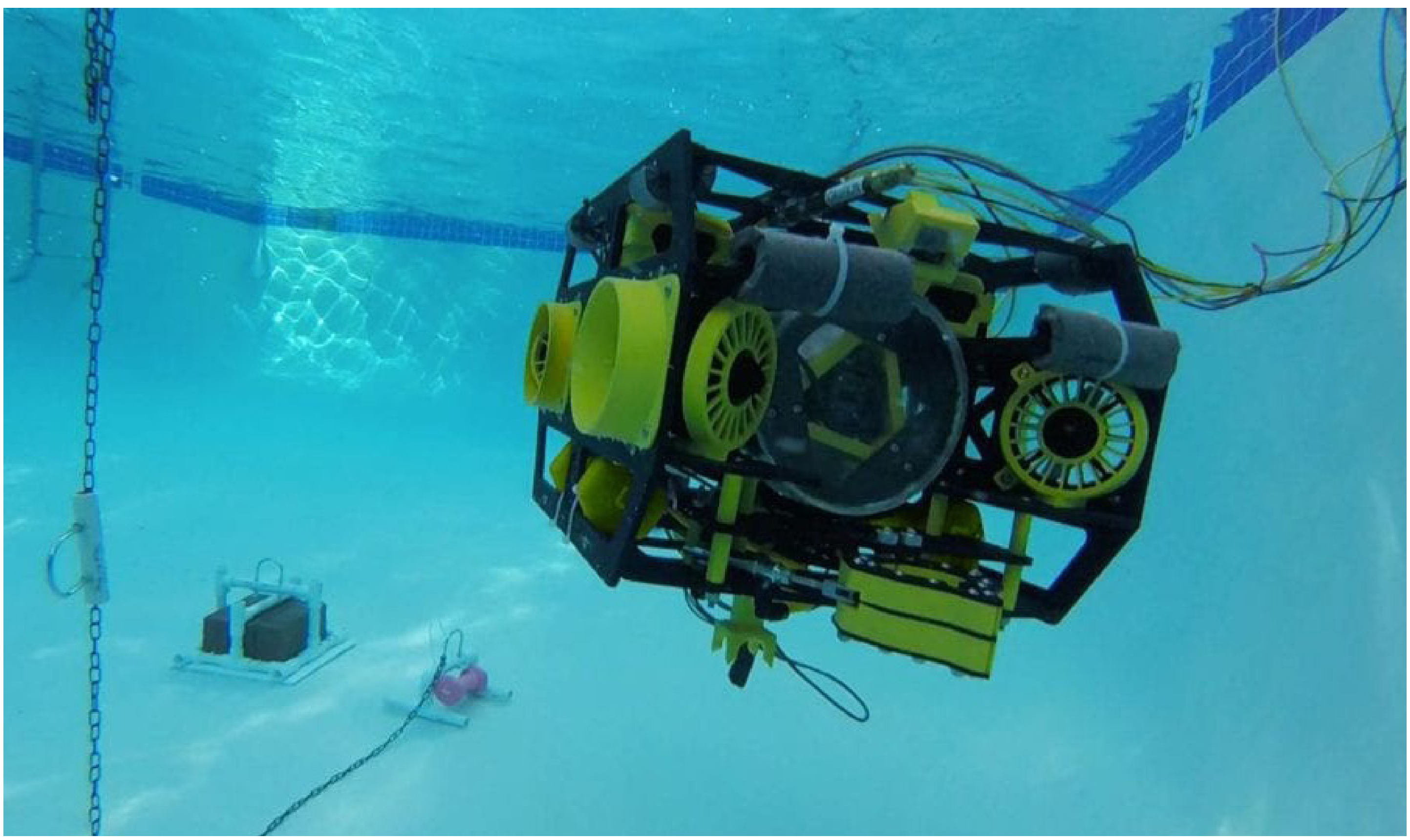
“Making” Community During COVID-19

by Tela Favaloro

The students of the Sustainability Lab, a multidisciplinary makerspace for UCSC’s undergraduates, have been finding creative ways to maintain a sense of community during COVID-19 restrictions.

The S-lab supports student innovation across campus by providing a multidisciplinary space where students have access to the resources, equipment, and training needed to forge their solutions to today’s challenges to sustainability. Established in 2016 by Physics Professor Sue Carter, myself (an Electrical & Computer Engineering scientist), and 12 dedicated students, the S-lab has developed into a thriving community with 150 members across 15 majors, serving student clubs, capstone projects, individual research, and entrepreneurial endeavors. Its laboratory facilities include computer, electronics, rapid prototyping, and wet labs, as well as a machine shop and team workspace in Thimann Labs. These have all been made possible due to support from PBSci, CITRIS-UCSC, and the Campus Sustainability Council.

Prior to Covid, the S-lab was poised for its most active year to date. For example, the Plastics Recovery Team won a CITRIS SEED Grant to support their ongoing multidivisional collaboration for their project: “Diversion and Recovery of PLA Plastic from the UCSC Waste Stream.” UCSC’s Rocket Team competed in NASA’s 2019 Student Launch Initiative, placing 22nd out of 45 national universities that qualified—the first UCSC team to compete in a national STEM competition. Slugbotics competed in the international 2019 Marine Advanced Technology Education Competition, placing well for their first year—15th out of 25. The teams even found time to give back to their community, teaching basic physics through rocket and model building to the children at the Boys & Girls Club of Scott’s Valley.



Final testing of the Slugbotics underwater ROV before the international Marine Advanced Technology Education Competition in 2019.

Unfortunately, alongside so many campus groups, the S-lab closed its facilities in early March of 2020, as its activities curtailed due to COVID-19. The S-lab students and staff have found nevertheless creative ways to persist and maintain this vibrant community. Thanks to the dedicated work of the S-Lab student-board over summer, selected training modules were adapted to be offered remotely, including Computer Aided Design & 3D Printing, Graphical Application Design, Electronic Circuit Design & Automation, and Sustainable Power in Portable Devices.

With student-mentors taking the lead to teach these topics, incoming students are engaged and able to learn necessary skills to work on their projects while maintaining a sense of community. These training modules have even been formalized into a course for credit as part of the Sustainability Minor.

UCSC's Rocket Team building rockets and teaching physics to the youth of the Scott's Valley Boy's and Girl's Club in late 2019.

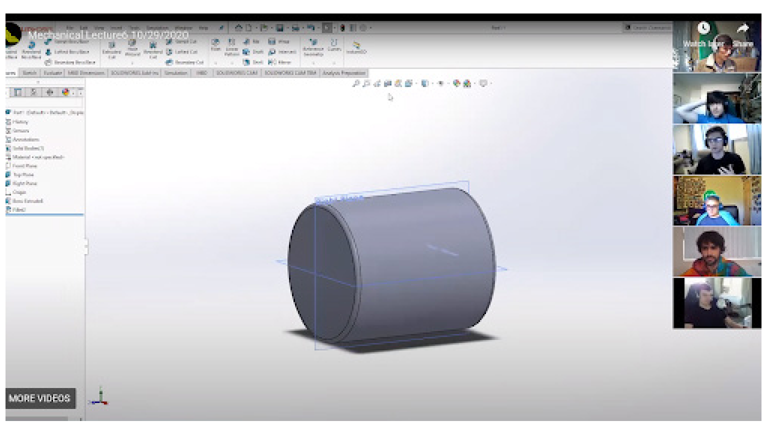
UCSC's Rocket Team preparing for launch at NASA's 2019 Student Launch competition.

Thus, fall quarter onboarding proceeded as usual with a virtual twist, and proved successful in generating student participation, especially among new students looking to make connections in an otherwise isolating context. More than 100 students are participating in this course, with over half enrolled for credit. For many of the students, joining the virtual S-lab is the their first laboratory experience and indeed many of these students are in their first quarter at UCSC. Through the creative use of Zoom breakout rooms, design challenges, and mail-out kits, student-participants not only learn and explore through design, they also get to know their fellow remote colleagues. After-class discussions have expanded from homework topics to discussions about gardening, trains, mountain biking, and even virtual game nights.

Thus, through ingenuity and interaction, the S-lab continues to grow. The present adversity has solidified both the essential academic role of the S-lab as well as its importance for fostering community.

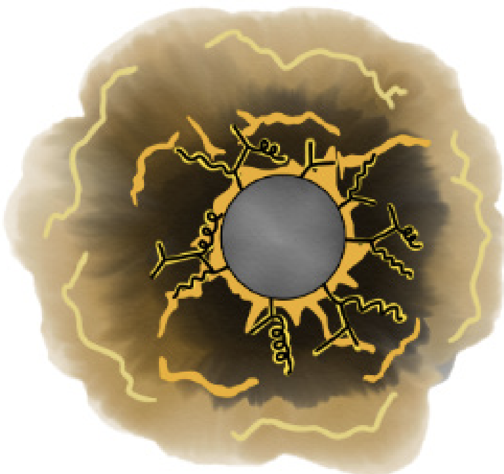
Find out more at https://slab.sites.ucsc.edu/

Right: A lecture via Zoom on advanced tools in Solidworks, led by Physics major Spencer Jaseph and Robotics Engineering major Wren Sakai as part of CRNS 151C: Computer Aided Design.



Black Holes from the Big Bang

by Benjamin V. Lehmann



Artist's impression of a microscopic primordial black hole, magnified by a factor of 10^{32}. Such small black holes are thought to emit a storm of super-hot radiation in a process called Hawking evaporation, a feature that may one day enable their detection. This feature is represented above through markings surrounding the black hole, as a bath of particles radiating outward. If this diagram were life-size, the black hole would have a mass comparable to Earth's. (Illustration by Natalie Telis).

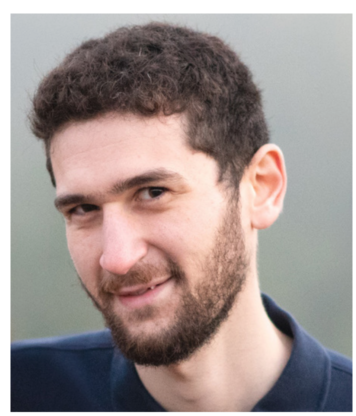
Modern cosmology is rapidly advancing in precision. By studying the leftover debris of the big bang, cosmologists can test the present model of cosmic history all the way back to the first second after the birth of the Universe. Using ever more advanced Earth and space-based telescopes, researchers are now able to measure the densities of matter, radiation, and other forms of energy in the universe at large. However, these precise observations leave some weighty questions unanswered. What happened in the very first moments after the big bang? What is the origin of matter and cosmic structure? And what is the invisible dark matter that accounts for 85% of all matter in the Universe?

The nature of dark matter is central among these questions because it points to new physics, accessible in the late Universe. Dark matter surrounds us even now, and so it offers a glimpse into physics beyond the current state-of-the-art picture: if researchers can reveal the particle physics of dark matter, its underlying nature will almost certainly hold new clues to other cosmic puzzles. In fact, this remains so even if dark matter proves not to be a new particle at all. An intriguing alternative, dating back fifty years, is that dark matter is made up of primordial black holes. Several groups on campus are actively engaged in this quest, including my own, but there is no single method that can detect primordial black holes of all kinds. To make progress, we need to come up with new signatures—subtle imprints that they might leave in observational data. Students, postdocs, and faculty in UCSC's own physics department are developing new ideas for observational probes that may one day lead to the discovery of primordial black holes. This is a theoretical puzzle that spans whole fields of physics, from early Universe cosmology, to quantum gravity, to the dynamics of neutron stars.

Black holes are unique objects, falling somewhere between stars and particles, and although they can be very massive, they are completely described by only a few numbers. This poses a challenge for primordial black hole hunters, since a primordial black hole looks exactly like any other black hole. Still, there is hope for an unambiguous observational signature: any sufficiently "light" black hole cannot come from a dying star. Stellar black holes cannot be formed any lighter than roughly the mass of the Sun, but primordial black holes can span a huge range of masses, from under a milligram at the Planck scale, up to millions of solar masses.

Many researchers have speculated that some massive black holes today have a primordial origin, but it is challenging to test this hypothesis. On the other hand, black holes below one solar mass would clearly have a non-stellar origin. These light black holes could show up in gravitational wave detectors if some are large enough to be near the mass of the Sun, or could make pulsars "wobble" if they are much lighter than that, as light as about 10^{20} kg. It is indeed possible that primordial black holes are microscopic, and even have the potential to show up in laboratory experiments on Earth. If all dark matter is composed of the smallest class of primordial black holes, then there are about 10 million such black holes passing through Earth at any moment.

Finding even one primordial black hole would make for an Earth-shaking discovery, and could shed light on many of today's biggest cosmic puzzles. The study of black holes in Earth's galactic neighborhood has only just begun. With a little luck, we may soon discover that we are surrounded by black holes from the big bang.



Benjamin V. Lehmann, Physics Ph.D. candidate.

Above: SCIPP postdoc Sofia Chouridou hosts a virtual visit to CERN in the ATLAS experiment control room.

SCIPP & UCSC

by Jason Nielsen

The Santa Cruz Institute for Particle Physics (SCIPP) is the home of research in particle physics and related areas, including particle astrophysics, theoretical physics, cosmology, and particle detector instrumentation. As one of three interdisciplinary Organized Research Units on the UC Santa Cruz campus, SCIPP draws its membership from several academic departments, with the majority having ties to the Physics Department. There are more than 100 Ph.D. researchers, technical staff, graduate students, and undergraduates currently affiliated with SCIPP.

SCIPP was established through the direct approval of the UC Regents in 1980, and physics professor Abe Seiden served as Director during the first thirty years of its existence. Abe and Assistant Director Georgia Hamel were instrumental in setting the tone for collaboration at SCIPP, while many researchers shuttled back and forth between Santa Cruz and the Stanford Linear Accelerator Center (SLAC) National Laboratory in Menlo Park. Over the years, SCIPP experimentalists became leaders in the development of particle tracking detectors, first wire chambers and ultimately silicon-based detectors. By the time physics professor Steve Ritz became Director in 2010, SCIPP had expanded into research projects in particle astrophysics, cosmology, and medical physics. An especially important feature of SCIPP is the close connection between theorists and experimentalists. Over the years, through analytic theory, large-scale cosmological simulations on supercomputers, satellite-mounted and balloon-borne experiments, and terrestrial telescopes, local researchers have studied a wide variety of problems. Most of these problems address fundamental questions such as the large-scale structure formation in the universe, the hypothesized new physics of dark matter and dark energy, and the origin of high-energy gamma rays and cosmic rays in a wide variety of settings, from terrestrial lightning to supermassive black holes to huge galaxy clusters.

From left to right: Stanford professor Peter Michelson and SCIPPers Bill Atwood and Steve Ritz pose next to the Fermi Gamma-ray Space Telescope during assembly. Bill was awarded the 2012 Panofsky Prize in Experimental Particle Physics for his work on the design and construction of the Large Area Telescope (the silvery box on top). Steve was the Deputy Principal Investigator for the mission, and Robert Johnson designed the LAT electronics and managed the LAT construction project. Fermi continues to collect data in low Earth orbit.

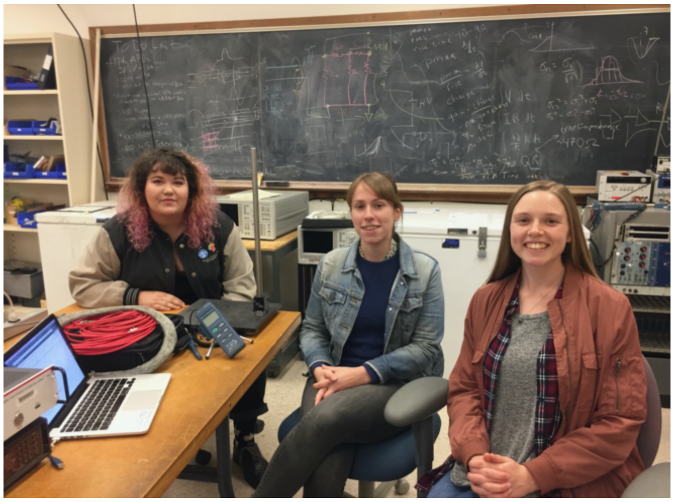
In addition to physics research, particle detectors have been adapted for medical imaging and recording electrical activity in neural systems. Theorists and experimentalists cheered together in 2012 for the discovery of the Higgs boson with the Large Hadron Collider at the European Organization for Nuclear Research (CERN) in which SCIPPers played a variety of important roles. In all these activities, undergraduate and graduate students have been directly involved and have enjoyed international visibility.

Today, SCIPP continues to reinvent itself to address new research challenges. An expanded laboratory cleanroom in the Natural Sciences 2 building is filling up with equipment to build and test more than 3000 new silicon strip and pixel detector modules for upgrades to the ATLAS experiment, one of the two general purpose detectors at CERN. The silicon sensor lab next door focuses on prototypes of Ultra-Fast Timing Detectors that combine position resolution better than 10 microns with timing resolution of 30 picoseconds. SCIPP researchers have also played key roles recently in building, commissioning, and analyzing data from a group of new experiments and survey telescopes, including AESOP-Lite (see page 6), the Dark Energy Survey/Dark Energy Camera, the Dark Energy Spectroscopic Instrument, and the Vera C. Rubin Observatory.

These experiments have inspired new directions in theoretical physics and demonstrate the research synergies that arise at the boundaries between particle physics and cosmology.

Another class of synergies is found at the boundaries of high-energy physics and information technology. One of the best examples of this synergy is the World Wide Web, which was first developed as a means to organize large-scale physics collaborations. Today, a common thread in data analysis for nearly all high-energy experiments is the rise of high performance computing and machine learning. The challenge of integrating state-of-the-art computational techniques into experiments has proven to be particularly attractive to student researchers at SCIPP, many of whom continue their information technology research in Silicon Valley industries after graduation. The big-data/physics interplay is also the basis for several SCIPP outreach and inclusion programs, which give high school students and teachers a chance to learn what particle physics is all about and what particle physicists do. In this way, SCIPP carries on a proud tradition of impacting the world at large while doing great physics research!

More photos related to this article are shown on the next page.



Undergraduate students (from left to right) Jane Gunnell, Katie Dunne, and Dena Giovinazzo gaining hands-on electronics experience in the SCIPP particle detector laboratories before interning at the CERN and DESY laboratories in Europe.

SCIPP theory group members (from left to right) Akshay Ghalsasi, Stefano Profumo, and Hiren Patel discuss dark matter in a research meeting.

Abe Seiden (right) and Hartmut Sadrozinski (left) cut the cake at SCIPP to celebrate the 25th birthday of the ATLAS Collaboration at CERN.

The Materials Initiative

by David Lederman

New materials lie at the core of many modern technologies. An exciting future technology is quantum information control, and it is safe to say that Materials Physics is at the forefront of the search for new forms of quantum matter. This research, in addition to work on energy-harvesting, biological, and two-dimensional systems, form the basis of the campus's new initiative to create a Materials Science and Engineering program. The Materials Science and Engineering Initiative was started in 2015 by the Physical and Biological Sciences Division as an interdisciplinary effort to accelerate materials research, enhance graduate programs, and provide additional research opportunities for undergraduate students at UC Santa Cruz. This new academic program is a response to the demand by students for instruction and research in this area of great intellectual and technological promise. The theme of the initiative is the development of new materials for environmentally sustainable technologies, especially energy efficient electronics. The interdisciplinary research involves more than 25 faculty members in the departments of Physics, Chemistry, Earth & Planetary Sciences, and Electrical & Computer Engineering, with a mix of experimentalists and theorists. The synthesis and properties of quantum materials, photoelectronic materials, magnetic materials, and hybrid biomolecular/solid state interfaces are being studied for applications in quantum computing, photovoltaics, data storage, and human-computer electronic interfacing, among others.

Perhaps fittingly, new lab facilities for materials physics were built in a former Texas Instruments fabrication facility located at 2300 Delaware Ave., just across the street from Natural Bridges State Park. The labs include clean rooms for thin film growth and device fabrication, ultra-low temperature (< 1 degree Kelvin) measurements, and nanoscale imaging of electronic structure (Jairo Velasco, Aiming Yan, Arthur Ramirez, and myself). Projects being pursued in these labs include the study of spin injection into insulators, with possible applications as novel "bits" of information and ultra-fast electronics (me); the creation of quantum dots of graphene which could lead to new ultrasmall electronics (Velasco); and the exploration of quantum fluctuations in "frustrated" magnets, which could be used in future quantum computing technology (Ramirez). While Professor Yan's lab is still under construction, as part of her future research she will synthesize new two-dimensional materials for optoelectronic applications and will use Transmission Electron Microscopy to image individual atoms in order to optimize the performance of the materials.

2019 REU cohort at the final research poster session.

As part of the initiative, the PBSci Division allocated four faculty positions to the Physics department over the past five years. In addition to myself, the list includes Assistant Professors Jairo Velasco Jr., Sergey Syzranov, and Aiming Yan. In the Chemistry department, Assistant Professors Alex Ayzner and Yuan Ping were also hired. There is an ongoing search for a new faculty member in Physics or Chemistry in Materials theory, with the successful candidate expected to start in Fall of 2021. The junior faculty have successfully obtained prestigious federal grants: Jairo Velasco was awarded a 2018 CAREER $565,000 grant by the National Science Foundation, Alex Ayzner was awarded a CAREER $675,000 award in 2019, and Yuan Ping was awarded a 2020 Air Force Office of Scientific Research Young Investigator $450,000 grant. We are also working on obtaining larger, collaborative grants. To that end, the UCSC Office of Research provided a group of us (Profs. Mircea Teodorescu and Holger Schmidt from ECE, Prof. Ping from Chemistry, Prof. Velasco, Dr. Sujoy Roy, and myself from Physics) earlier this year with a $60,000 seed grant to combine the disparate field of materials growth and robotics. An initial project is to use robots to accurately stack 2-dimensional atomic layers. When these layers are not precisely on top of each other, but at a slight angular offset, entirely new electronic behavior results, leading to the prospect of "twistronic" devices.

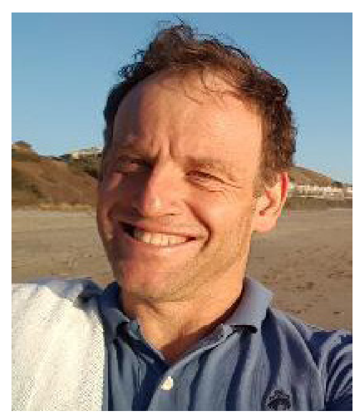
Team of happy students posing in the cleanroom after a long day of hard work. From left to right: Bruce Ji (BS 2019), John Davenport (PhD 2020), Alex Stram (BS 2020), Salma Lira (BS 2018), and an mBraun technician.

We are also teaming with national lab and industrial partners to work on projects of mutual interest. Three scientists from the Lawrence Berkeley Lab (LBL), Peter Fischer, Hendrik Ohldag, and Sujoy Roy, are Adjunct Professors in the Physics Department who are working with us to coordinate access to specialized X-ray scattering facilities at LBL, and to supervise the research of UCSC graduate students who wish to write their PhD dissertations on work related to materials research at LBL. In 2019, an agreement was signed between IBM Almaden and UCSC to enable joint research projects at both sites. Earlier this year, Holger Schmidt and I received funding from start-up company Magtera to develop a magnon laser to be used as an electrically controlled THz emission source. We hope to ramp up our industrial projects in the near future.

A new outreach activity has been made possible by the Initiative is the summer Research Experiences for Undergraduates (REU) program, funded by the National Science Foundation. Since 2017, the program has provided community college students and students from non-PhD granting institutions the opportunity to immerse themselves in high-level scientific research. Students usually live together in a dorm during the nine-week summer program and engage in professional development activities. A few UCSC undergraduate students also participate and serve as informal mentors and role models to the external participants. Over ten faculty members from Physics, Chemistry, and Electrical & Computer Engineering have hosted twelve students every year within their groups' research projects. Because of the COVID-19 pandemic, the 2020 program consisted of mostly online activities, requiring a significant effort by the faculty and the participants to adapt to the situation. Nevertheless, the 2020 participants were grateful that the program was run and viewed their participation as a positive contribution to the realization of their academic and professional goals.

Finally, in the planning stages is a graduate (MS and PhD) program in Materials Science and Engineering that is expected to launch in 2021 or 2022. The goal of the program is to create academic opportunities for new generations of leaders in developing the physical basis of modern technology. This will of course expand the physics pool of graduate students to those with undergraduate degrees in Materials Science, Mechanical Engineering, or Chemical Engineering, in addition to Physics, Chemistry, or Electrical Engineering. The undergraduate aspect of the program at this point will consist of introductory materials science courses and may lead to a more comprehensive effort in the future.

In short, Materials Science and Engineering is alive and well at UCSC, and physics will continue to play a key role in the research and academic aspects of the Initiative. Stay tuned for new developments!



David Lederman, Physics Professor and Director of the Materials Initiative.

Student Groups Maintain Support

by Ava Webber

SPS board and members meeting to make plans for their group. From left to right and top to bottom: Marina Huang, Alberto Baez (President), Siuling Pau-Sanchez (Mentoring Coordinator), Cameron Clark (Mentoring Coordinator), Nicole Man (Outreach Coordinator), Monica Leys (Outreach Coordinator), Karoli Clever (Outreach Coordinator), and Vanessa Alarcon.

Members of WiPA at a weekly social Zoom meeting. From left to right and top to bottom: Professor Tesla Jeltema (Founder of WiPA), Ava Webber (undergraduate Co-President), Eva Zlimen, Julia Stewart, and Lillian Santos-Olmsted (Outreach Coordinator).

In the midst of the current pandemic, students have found it increasingly challenging to adjust to online schooling, making it easy to feel separated from the UCSC community. As a result, many feel left in the dark about how to create meaningful experiences and seize opportunities. Clubs and social groups see this challenge, and are continuously searching for new ways to bring students together. The student run groups of the physics department are rising to the occasion with the virtual communication resources available, and dedicating time to making today's college life as tuned in and accessible as possible.

UCSC's chapter of SPS (the Society of Physics Students) has launched into winter quarter with a wealth of informational Zoom meetings about NSF's Research Experience for Undergraduates (REU) program. These meetings included a talk with Professor and Chair of Astronomy and Astrophysics, Raja Guha Thakurta about getting involved with research, a "Q and A" session with undergrads about their personal REU experiences, and an application writing workshop hosted by SPS President, undergraduate Alberto Baez. The group has also done a wonderful job keeping students in contact with their classmates through the app "Discord," where they have created specific groups for every physics, astro, and math course available to physics students. The board members of SPS work diligently to moderate the use of the app, and students find it easy to ask questions and make friends in both text chats and group voice calls there. The SPS Discord server offers a level playing field for any student to ask any question, as others will consistently jump in to offer a helpful response or to work together. This medium of communication is also being used as a method of remote tutoring in which graduate student TAs can offer help beyond regular discussion sections and office hours, accessible at any time.

In an effort to keep strong ties to women and gender minorities in physics during this time away from campus, UCSC's WiPA (Women in Physics and Astronomy) group has also remained active, holding weekly meetings as virtual spaces for our members to find community, play games together, and take breaks from rigorous studies. Among these meetings are those of a new group that has blossomed from WiPA—the Transgender & GNC (gender non-conforming) in Physics and Astronomy Coffee Hour. Created and led by UCSC alum Lena Eiger (pictured on page 11), this hour is reserved for meaningful discussions to aid students of various gender groups with navigating physics in an inclusive environment. WiPA has also continued to hold chats with invited guest speakers, giving members a chance to meet professional women and gender minorities in the physics field from all over the world, who come to share their experiences and obstacles. The WiPA outreach team is currently creating a program for volunteers to supply remote learning support at grade schools local to the Santa Cruz area such as tutoring, in-class technical support, and presentations about being in STEM.

Yet another holistic student group is ACS (A Counter Space), established in 2019 by undergraduate Verenise Martinez and recently graduated student Nicole Man for the empowerment, support, and inclusiveness of women of color in UCSC's physics and astronomy departments. This group has strongly maintained its goals and purpose through the pandemic, offering regular meetings for its members to share their interests, and to study literature relevant to the experiences of women of color in STEM fields with deep reflection. ACS also invites guest speakers to share their personal and professional paths, allowing members to learn from and network with established female scientists of color. All of these tools offer much support for women of color to become better equipped as they pursue careers in physics and astronomy.

The physics student groups of UCSC have put great amounts of thoughtful effort into supporting our community, in ways that reflect the overall strong collaboration and respect for their peers that physics students continue to demonstrate, even when apart from one another.

From left to right: Verenise Martinez, Professor Aiming Yan, and Nicole Man. Verenise and Nicole created ACS in 2019, and Verenise continues to lead the group at present. (This photograph was taken pre-pandemic).

Click on the logos below for links to each student group website.

WiPA UCSC

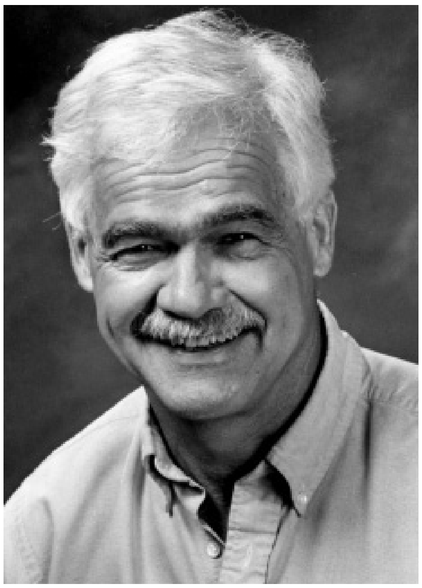
A COUNTER SPACE FOR BIPOC IN PHYSICS AND ASTRONOMY

SPS

Michael Nauenberg

December 19, 1934 – July 22, 2019

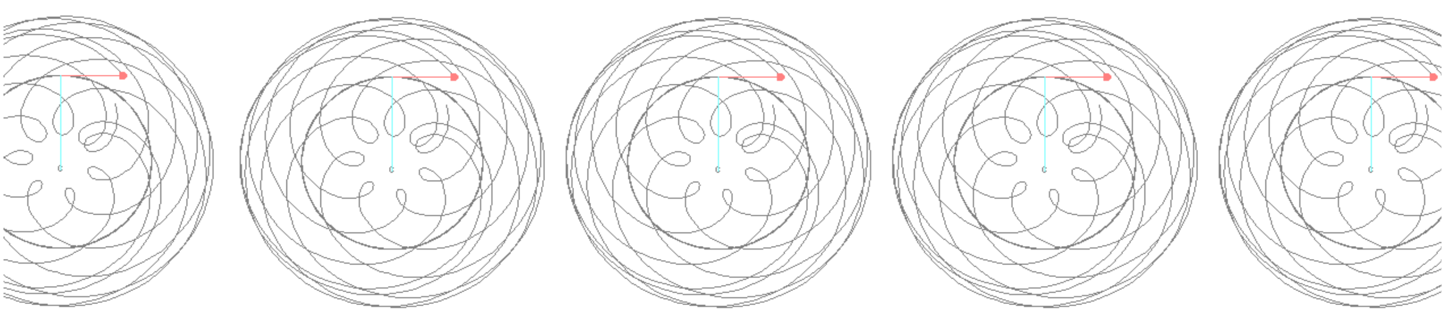
by Arthur Ramirez



Michael Nauenberg, Professor Emeritus, passed away on July 22, 2019. An obituary for him can be found here.

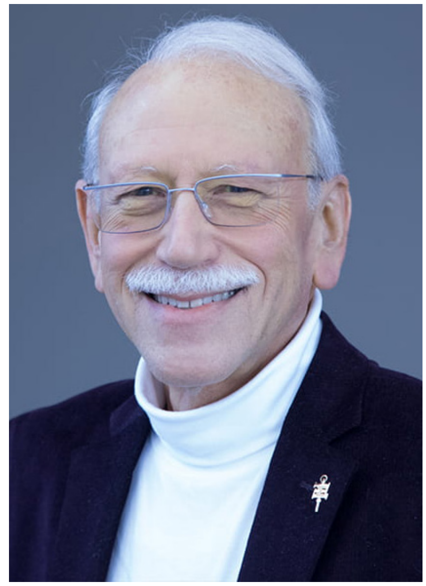
Michael was a mainstay of the physics department and, indeed, was one of the department's founding members, having joined the UCSC faculty in 1966. Michael's passions included not only physics but also service to the University, as he was instrumental in founding Stevenson and Crown Colleges.

He represented UCSC to the outside world, contributing letters to the editors of *Physics Today* with great regularity. In later years, Michael was unusually active in department functions, for a Professor Emeritus. He attended almost every physics colloquium, and most faculty can remember colloquia at which Michael stirred the discussion. In this regard, he embodied the physics ideal, namely an unwavering quest for truth and clarity, coupled with energy and good humor. He served as an example for both students and faculty of a life committed to physics. He will be deeply missed by the community he helped to forge, and remembered for his fruitful dedication.



This graphic was created from an animation by Michael Nauenberg of a 3-dimensional period orbit for n equal masses, which move symmetrically under the action of gravitational forces. This animation and other such animations of Michael's creation can be found on his website under the section header "Animations of periodic orbits."

The 2020 Julius Edgar Lilienfeld Prize



Early last year, Distinguished Professor Emeritus Joel Primack was awarded The American Physical Society's 2020 Julius Edgar Lilienfeld Prize.

The prize recognizes Primack "for seminal contributions to our understanding of the formation of structure in the Universe, and for communicating to the public the extraordinary progress in our understanding of cosmology." One of the APS's highest honors, the Lilienfeld Prize recognizes outstanding contributions to physics by a single individual who also has exceptional skills in lecturing to diverse audiences.

He is one of the leading creators and developers of the modern theoretical model of the universe structured around cold dark matter with a cosmological constant, which explains why galaxies exist, how they form, and how they are distributed in space. For example, although our own Milky Way galaxy and many other nearby galaxies are disk-shaped, by comparing Hubble Space Telescope images with their supercomputer simulations, Primack and his colleagues recently discovered that most galaxies start out pickle-shaped due to the filamentary distribution of dark matter in the early Universe.

"Joel Primack is an inspired choice for this year's Lilienfeld Prize," said APS President-Elect Philip H. Bucksbaum, chair of the 2020 prize selection committee. "He has contributed greatly to our current understanding of the fundamental makeup of the Universe and has helped to establish the paradigm of cold dark matter cosmology." Equally important is his work as an effective voice for science in the public and in public policy, not only through lectures and books to general audiences, but also through active participation in policy initiatives.

Graphic Image Credit: NSF

Undergraduate Award Winners

Deans', Chancellor's, and Steck Undergraduate Awards

Dean's Award to the following students:

- Vernon Wetzell
- Violet Piper
- Phoenix Gallagher
- Lena Eiger

Chancellor's Award awarded to the following student:

- Vernon Wetzell

Kenneth and Ann Thimann Scholarship: Undergraduate

- Sandra Nair

URST (Undergraduate Research in Science and Technology) Awards-PBSci Division

- Rafael Nunez
- Emily Hoang
- Caelum Rodriguez

Marilyn Stevens Award: Undergraduate

- Nicole Man
- Monica Leys
- Sandra Nair

Ron Ruby Research Awards

- Emily Hoang
- William Ryan

Goldwater Scholarship

- Elizabeth Yunerman

Elmer A. Fridley Scholarship

- Jamie Law-Smith

Graduate Award Winners

Chancellor's Dissertation-Year Fellowship

- Cole Helling ARCS award

ARCS Award

- Spencer Everett

Outstanding TA Award

- Heather Mentzer
- Nolan Smyth
- Logan Morrison
- Dominic Pasquali
- Nicholas Hamer

Congratulations to all award winners!
See the following two pages for key information about each award.

Information About Awards:

UNDERGRADUATE

Deans', Chancellor's, and Steck Undergraduate Awards

These awards recognize exceptional achievements in research projects or other creative activities, in order to both encourage outstanding scholarship and promote research as an important part of undergraduate education. In the Physical and Biological Sciences, the students submit a completed thesis, usually a senior dissertation.

Undergraduate Research in Science Awards: sponsored by the PBSci Division

These awards recognize undergraduate research in science and technology administered by the Physical and Biological Sciences Division. Multiple awards may be issued ranging from $500 to $2000. There are three sources for the funds behind this call: one is designated for research in coastal sustainability (Gunderson Family Student Research in Coastal Sustainability Award), one is designated for research in Earth and ocean sciences (Kathryn D. Sullivan Award), and the largest is open to projects in any discipline that uses the scientific method (Undergraduate Research in Science and Technology Award).

Koret Scholars Program (not offered in 2019-20)

The Koret Scholars Program provides funding for a variety of undergraduate research projects and experiences. The program supports scholarships for undergraduate research projects with faculty and graduate student mentors, undergraduate and graduate student research internships with the Student Success Evaluation and Research Center, and expansion of the year-long College Scholars research development program.

Marilyn Stevens Memorial Scholarship

The Marilyn Stevens Memorial Scholarship is an award designed to honor the former Department Manager of Physics, Marilyn Stevens. It is given to a current upper-division physics undergraduate student and a current physics graduate student. Fellow students, faculty, or staff nominates prospective recipients. The award considers academic excellence, community service, service in and out of UCSC, and any outstanding contribution made to the Physics Department.

Ron Ruby Memorial Scholarship

Ron Ruby was a founding faculty member of the Physics Department. A memorial scholarship for undergraduates was set up in his memory. The Ron Ruby Scholarship is intended to reward the most promising young physicists while also honoring Ron's vision of providing greater access to quality college education. Both merit and financial need are considered in making the award. The department considers diversity an important academic value, so the Ron Ruby Scholarship shall be awarded preferentially to one or more students who have demonstrated potential for leadership in promoting cross-cultural understanding and/or those who have an outstanding record of service dedicated toward helping educationally disadvantaged students. However, recipients will be selected without regard to their race, gender, color, ethnicity, or national origin. U.S. citizenship is not required.

Kenneth and Ann Thimann Scholarship

1984 Dr. Kenneth Thimann, founding Dean of the PBSci Division, and his wife, Ann, established this award. Scholarships are awarded at the end of the academic year to a graduating UCSC senior, who has been accepted to graduate school and shows the most promise as a future scientist in one of the disciplines of biology, chemistry, physics, and earth sciences.

Elmer A. Fridley Award

This is a merit-based scholarship and is awarded to a continuing student in the physical sciences (chem, math, physics, astro, etc), either graduate or undergraduate. The winner is selected on academic merit, faculty support and recommendations.

Goldwater Scholars Award

The Goldwater Scholarship is a prestigious national competition for undergraduates in the fields of mathematics, science, and engineering. The scholarships provide up to $7,500 per year for sophomores and juniors from across the country to cover the costs of tuition, fees, books, and other expenses.

GRADUATE

ARCS Award

A national organization, the ARCS (Achievement Rewards for College Scientists) Foundation provides funds for scholarships to deserving graduate students in the fields of natural science, mathematics, medicine, and engineering. Departments submit their single best student for consideration for the 10 awards.

Marilyn Stevens Memorial Scholarship

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President's Dissertation-Year Fellowship and Chancellor's Dissertation-Year Fellowship

Dissertation-Year Fellowships (DYFs) are state-funded, merit-based fellowships awarded on a competitive basis to doctoral graduate students who have overcome significant social or educational obstacles to achieve a college education, and whose backgrounds equip them to contribute to intellectual diversity among the graduate student population. The President's and Chancellor's DYFs are quarterly or year-long fellowships that provide a stipend of approximately $21,000 plus payment of resident tuition for the academic year.

Outstanding TA Award

This is the annual award for recognition of their outstanding performance as a Teaching Assistant during the Fall 2019, Winter 2020, and Spring 2020 quarters. Faculty and staff nominate students who are evaluated based upon the faculty endorsement and their teaching evaluations.

Stay Connected

Check out our website at physics.ucsc.edu.

Follow us on instagram: @ucscphysics.

Like us on facebook: https://www.facebook.com/ISB211/.

Stay updated on our latest department news here: https://www.physics.ucsc.edu/news-events/news/index.html.

Giving

Gifts of any size to the physics department are deeply appreciated. Even small gifts into the **general fund** will help to support our student programs and student groups, as well as resources for graduation, our annual picnic, and other social gatherings, which we are looking forward to once the pandemic subsides. Please see the website link below for more information. Thank you!

Department Facts & Figures

Undergraduate Students	420
Graduate Students	73
Ladder Rank Faculty	21
Adjunct Faculty	9
Lecturers	3
Research Faculty	8
Postdocs	14
Department Staff	5

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