Quantum Leap

University of South Carolina
Department of Physics and Astronomy

2019

University of South Carolina Physics and Astronomy and Thorlabs representatives Heath Smith, Longfei Ye, Ling Vang, and Adam Fisher (left to right) stand in front of the recently established clean room facility located in Sumwalt College on the Columbia campus.

Physics and Astronomy Nanomanufacturing Startup Now Part of Thorlabs

By Thomas Crawford

MagAssemble technology invented by Professor Thomas Crawford and launched by Physics and Astronomy graduates is acquired by worldwide photonics giant.

Currently three Physics and Astronomy (P&A) graduates and one senior undergraduate come to work at their "high-tech" jobs on the UofSC campus each day in the SmartState Center for Experimental Nanoscale Physics. Longfei Ye (Ph.D. in 2013), James "Adam" Fisher (B.S. in 2015), Mark "Heath" Smith (B.S. in 2015), and Ling Vang (B.S. expected December 2019 or May 2020) are all employees of Thorlabs Spectral Works or TSW, which is a new division of the giant photonics company, Thorlabs. Thorlabs has licensed patents and is commercializing technology based on research done in P&A Professor Thomas Crawford's laboratory over the past 14 years and is using the Center as a temporary home to jump-start its local R&D activities.

Thorlabs, which had revenues of $500 million in the past year, is one of the world's largest optics companies. Known for selling optical components to academics and researchers, they are similarly famous for their marketing style: T-shirts with sketches of dogs drawn by their founder and CEO Alex Cable and boxes of "Lab Snacks" (the boxes say "treats for humans") that are shipped together with the ordered optical and optomechanical components. The company is also known for their quick response to the demand of the market in addition to its quirky marketing style. The importance of diffractive micro-optics has grown in recent years, i.e. well beyond the diffraction gratings used for spectroscopy in niche laboratory settings. For example, a familiar everyday application is the iPhone's "face-ID" technology, which uses a patterned diffractive optic to bathe your face with 30,000 points of infrared light to verify it is really you that are looking at your phone. Thorlabs sees a growing need for these kinds of optics, as described in their *press release* upon acquisition of the MagAssemble technology.

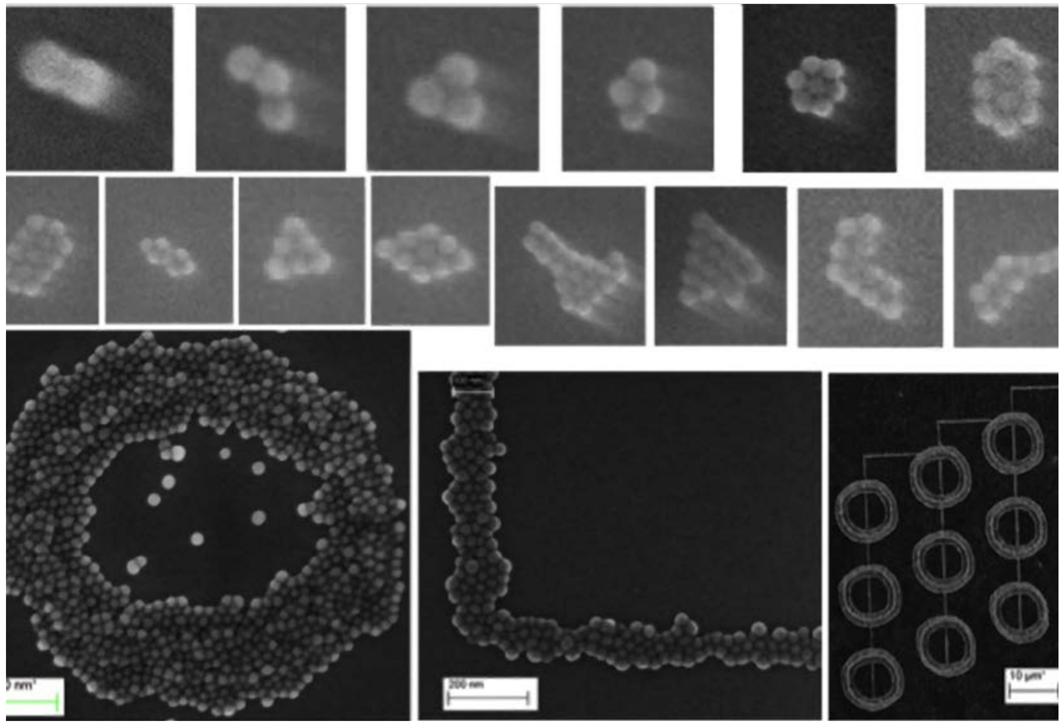


Figure 1: *Example Scanning Electron Microscopy (SEM) images of magnetic nanoparticle self-assembly.* ***Top:*** *Random self-assembled patterns of 25 nm diameter magnetic nanoparticles.* ***Bottom:*** *Programmed assembly of nanoparticles into torii, rectangles, and more complex structures using recorded patterns on disk drive media.*

Among other things, the Pattern Transfer Nanomanufacturing (PTNM) process is ideal for producing custom diffractive optical elements for use in the UV to IR spectral range. It can be applied to numerous substrate materials, including polymers, silicon wafers, fused silica, sapphire, and even optical fibers, thus creating laser quality, robust, miniaturized optical components.

So how did this UofSC P&A invented technology successfully transform from a startup idea into a new potential product that you can order from the Thorlabs catalog of 20+ thousand different items? The key enabler for this success story was South Carolina's investment in recruiting Endowed Chairs to lead Centers of Economic Excellence during the early 2000's, which is now known as the *SmartState* Program.

A key goal of the state of South Carolina's "Centers of Economic Excellence Endowed Chairs Act" was to foster focused Centers in exciting areas of research that would ultimately lead to commercial technologies and new jobs for South Carolinians. Former John Palms SmartState Chair and Professor of Physics Richard A. Webb (2004-2016) was the first Chair recruited to the state under this program and former Seagate Technology research scientist, Crawford, was Webb's first hire to join his Center.

Crawford's patented MagAssemble technology begins with a commercial disk drive, which is able to encode the 1's and 0's of data storage into the north and south magnetic poles of 5 nm diameter cobalt particles embedded in a thin film matrix of chromium. Importantly, the distance over which a magnetized region can change polarity is on the order of 1 nm. As a result, the magnetic field at the transition has a tremendous gradient near the surface and this gradient changes rapidly with height above the surface.

"Field gradients can be as large as 50 Mega-Tesla/meter near the surface, decreasing to only 1000 Tesla/meter at 1 micrometer above the surface. This is equivalent to a skydiver jumping out of an airplane with an acceleration of "g" and feeling g increase 50,000-fold before the skydiver reaches the earth," says Crawford.

Crawford's technology leverages this large gradient to apply a force to colloidally suspended magnetic nanoparticles that is sufficient to pull them to the surface at the magnetic transition and hold them in place. Colloidal suspensions involve a repulsive force between the suspended elements, which, in the case of a ferrofluid, are magnetic nanoparticles. This colloidal force opposes what the magnetic force at a recorded transition is trying to accomplish and resulting in the nanoparticles self-ordering or "self-assembling" into a quasi-crystalline hexagonal pattern (See Figure 1 for some self-assembled magnetic nanoparticle structures).

"To date we have programmed features as small as 3 nanoparticles across or ~ 65 nm, but they are not perfectly straight, as we cannot yet control the self-assembly process perfectly," Crawford points

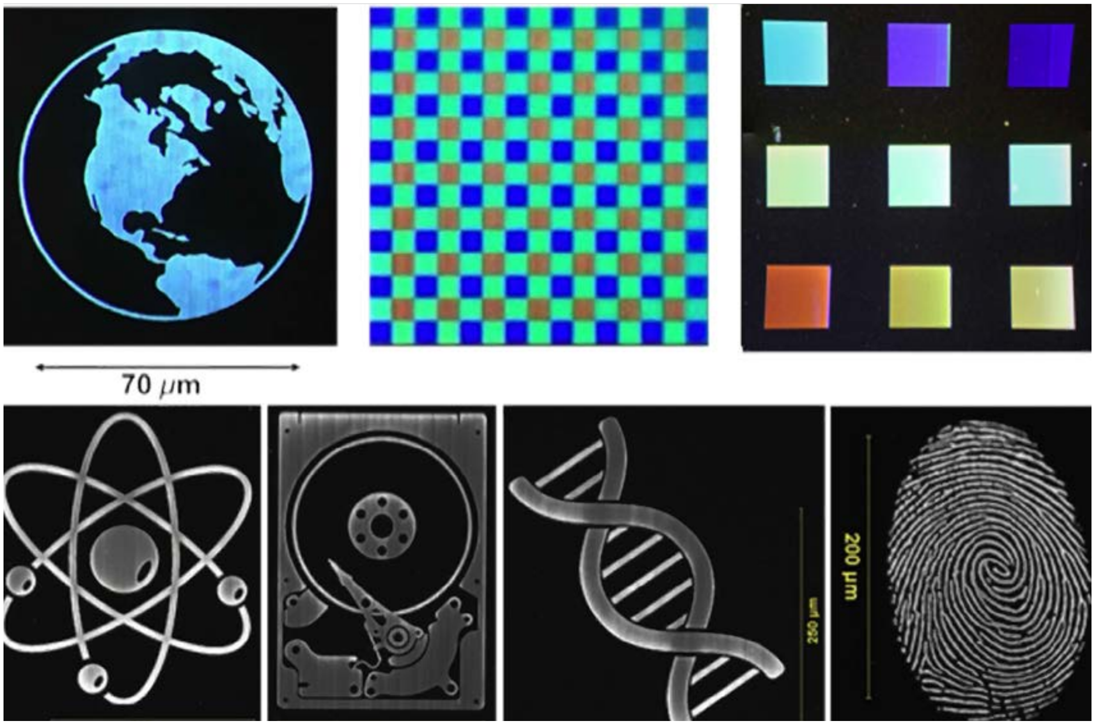


Figure 2: *Examples of optical diffraction from nanoparticles assembled into nanoscale gratings that are patterned at the macroscale (>50 µm) into a variety of recognizable images. For the multi-colored square patterns, each square has a different period grating diffracting a different color in the vertical direction.*

out. But, as Figure 1 shows, smaller sub-100 nm features can self-assemble independently of the programmed pattern, so the potential exists for full control over the patterning. Crawford's efforts with magnetic-field-driven self-assembly grew out of his desire to leverage his disk drive industry experience and the realization that the disk drive technology had advanced well past where nanotechnology was when he arrived at UofSC in 2005.

Crawford's idea was to focus on studying the nanoparticle patterns that appeared on the recorded transitions rather than the recording components themselves. He submitted an invention disclosure on using the concept for nanoscale manufacturing of precision patterns and subsequently a research proposal to NSF that was selected for funding. Importantly, the NSF proposal included a societal study by UofSC Department of History professor Ann Johnson (of the Ann Johnson Institute) of how disk drive technology could surpass what was possible in nanotechnology without the broader nanotechnology community being aware of what it could accomplish.

But there was another piece that had yet to be proven that is critical to the MagAssemble technology. *"I had this P&A undergraduate named Jason Henderson (B.S. in Physics, 2011) who was working with me on the programmed nanoparticle assembly concept. Henderson found this polymer compound called "Disccoat 4220" on the Internet and asked me to order it. It was designed to protect recording media surfaces during various cutting and the like prior to assembly into a disk drive. He used a tool in Webb's cleanroom called a spin-coater to apply it to the disk media that was decorated with assembled nanoparticles. Then, with a piece of scotch tape, he peeled the polymer off the disk. What was amazing is that the nanoparticles came off with the polymer and they held their shape down to the nanoscale."* Crawford and Henderson named this technology Pattern Transfer Nanomanufacturing, or PTNM, and, ultimately, this particle transfer process became the key ingredient that transformed a novel method to make patterns out of nanoparticles into a potentially viable nanomanufacturing technology.

After Henderson graduated, he joined an optics company, OpTek Systems, in Greenville, SC. He indicated that they had a need for low cost patterned masks to use for laser-based imprinting onto the faces of optical fibers. This need seemed like an ideal application for the PTNM technology, and, as a result, Crawford launched UofSC startup MagAssemble in 2012 to try and provide these masks to OpTek. Starting on July 1, 2014, MagAssemble was funded by a NSF Phase 1 SBIR and then received a follow-on Phase 2 award that began on March 1, 2016. These funds covered salaries for two employees for five years from 2014-2019 and a significant percentage of the funds came to UofSC as a sub-award to support R&D activities to further 'de-risk' the PTNM technology. Over the SBIR phase 1/phase 2 timeframe, the technology advanced significantly. By mid-2019, the assembly precision had been improved to yield reasonable features as small as ~ 200 nm. These features could be transferred to optically relevant materials, particularly fused silica, and software had been developed to magnetically record arbitrary 2-D patterns that could then be coated with nanoparticles and transferred to a variety of substrates. Figure 2 shows how different period diffraction grating nanostructures can be recorded into larger macroscale patterns, i.e. from a globe to a fingerprint. This progress attracted the interest of another SC startup company, CIRTEMO LLC, which was commercializing Prof. Myrick's Multivariate Optical Computing technology. They offered a term sheet to acquire MagAssemble in April 2018. Working together, CIRTEMO and MagAssemble kept pushing the technology and trying to attract customers. In November 2018, CIRTEMO managed to schedule a call with Alex Cable of Thorlabs and his management team. After exciting initial conversations and a productive December meeting, it was ultimately CIRTEMO/MagAssemble's ability to execute on creating new prototypes and the potential breadth of applicability that enticed Thorlabs to acquire the company and team in May 2019.

After six months of continuing to advance the technology as TSW, this cadre of recent P&A graduates will not be coming to campus daily for much longer. Thorlabs is in the process of upfitting its own manufacturing/R&D space for TSW operations near the Columbia Metropolitan Airport and the team will move there after the renovations are complete. There are reasons to expect that they will still come to campus occasionally, such as to use the field-emission SEM in the Electron Microscopy Center or to make nanoscale patterns with the new NSF MRI-funded Heidelberg NanoFrazer that Professors Wu, Crittenden, and Crawford are installing in the Center cleanroom in early 2020. TSW is collaborating with Crawford on advanced metrology for the recording process and they are also working with UofSC Chemistry Professors Myrick and Angel. There are many exciting possibilities for additional collaborative interactions that can develop with Thorlabs over time.

Exciting Developments in the SmartState Center for Experimental Nanoscale Physics

By Yanwen Wu

This has been an exciting and eventful year for The SmartState Center for Experimental Nanoscale Physics. A few successes and changes have happened that will certainly brighten the future for the Center. Therefore, it is only appropriate to put a well-deserved spotlight on the SmartState Center for this issue of *Quantum Leap*.

Our cover story is on the licensing of the technology behind Dr. Thomas Crawford's MagAssemble startup company by the giant in commercial optical components, Thorlabs. Given the high failure rate of startups, this achievement is especially impressive.

In previous issues, we have been documenting the improvements being made to the Center's shared facility. These improvements included the re-outfitting of the wet lab space to a class-1000 clean room, the purchase of a load-locked evaporator, and the installation of an electronically controlled and logged access system to the clean room facility. This year, the big new addition to the shared-facility comes in the form of a NSF funded MRI instrument (over $700,000) awarded to Dr. Yanwen Wu. This instrument will replace the old JOEL SEM system in streamlining and expediting the micro- and nano-fabrication process. It will be instrumental in fostering collaborations and innovating exciting research both within and beyond the Center.

Last and not least, the most exciting news is the approval by the College of Art and Sciences of the search for a new SmartState Chair. Ever since the passing of Dr. Richard Webb in 2016, the Center members have been doing their best to take over the administrative tasks and keep the Center operational. It is clear from all the improvements made to its facility that this collaborative effort worked really well. However, this SmartState Center is long overdue for a leader with a clear vision and enthusiasm to take the center to the next level and be competitive on both the national and international stages. We are all very excited and optimistic of this new opportunity.

NSF MRI: Acquisition of the NanoFrazor – a unique AFM-based nanolithography tool to support multidisciplinary research and promote nanoscience in South Carolina and beyond.

The NSF funded Major Research Instrument (MRI) project is awarded to Dr. Yanwen Wu to fund the acquisition of the NanoFrazor Explorer nanopatterning instrument from SwissLitho. This instrument is to be hosted in the SmartState Center for Experimental Nanoscale Physics at the University of South Carolina. Advancements in the field of nanotechnology are responsible for accelerating development in numerous and diverse research disciplines including materials science, computation and information processing, photonics, biology, chemistry, and medicine. The ability to customize nanoscale structures and patterns, especially with a top-down approach, in an affordable and efficient manner, is highly desirable in all fields. The user-friendliness of the NanoFrazor will expedite the process of optimizing nano/micro-devices for practical applications in biosensing, information processing, energy storage, CO_2 capture, etc., as well as provide a unique tool to study novel materials and answer basic scientific questions in a wide range of fields. Its remote access capability and simple operation procedures also render it an ideal tool for training and outreach. Dr. Wu has established a partnership with the South Carolina State Museum and will be creating a set of public and educational outreach activities that utilize the NanoFrazor to promote nanotechnology and nanoscience to the general public as well as K-12 students.

CONTENTS

UPDATES FROM THE CHAIR AND DIRECTORS

RESEARCH GROUPS

EVENTS, EDUCATION, AND OUTREACH

STUDENT SPOTLIGHT AND ALUMNI NEWS

IN MEMORIAM

UPDATES FROM THE CHAIR AND DIRECTORS

Message from the Chair

By Ralf Gothe

A year has passed by and I feel at least two years older and maybe wiser. There is always something important that needs attention and does not adhere to a normal work schedule. My message to you is in a sense no different, and knowing the final due date means to push it further and further ahead until the only other choice would be not to write one at all. But that would sadden me tremendously, since highlighting a few developments in the department is an opportunity not to be missed and having the privilege to wish you all Happy Holidays and all the very best for another year to come, gives me immense pleasure. Take a closer look into our latest *Quantum Leap* edition and enjoy exploring different facets of who we are and updates on what has happened.

Although I am happy that we have successfully concluded our fall 2018 search for the Tenure-Track Assistant Professor in Theoretical Physics by hiring Alexander Monin, it also distresses me that his visa application is yet not settled. Alex is still researching fundamental properties in quantum field theory and teaching at the University of Geneva, but we are eagerly awaiting his engaging, energetic, and innovative contributions to our faculty and hope to finally get him here for the spring 2020 semester. We are also currently searching for the next endowed chair in Condensed Matter Physics to sustain the SmartState Center for Experimental Nanoscale Physics who will

Winners of our departmental Graduate Awards (April 2019): From left to right: Thomas Richardson (Teaching), Iuliia Skorodumina (Research), Bryan Chavez (Service), Nick Tyler (Teaching).

create more synergy in nanoscale physics within the department and beyond, even statewide and nationwide.

Unfortunately, we also lost a strong faculty member with Vincente Guiseppe's departure this year. He has moved to Oak Ridge National Lab, where he has accepted a Physical Sciences Directorate position in the Neutrino Physics Division. Although we could not entice him to stay, I wish him and his family all the best. We will miss you dearly for a long time to come.

Just two weeks ago, we hosted two external reviewers, Joseph Hamilton (Vanderbilt University) and David Tanner (University of Florida). We highly appreciated their efforts, suggestions, stimulating discussions, and openness and look forward to their report. The College of Arts and Sciences requests an external review of the department every ten years. Historically, the balance between positive and negative outcomes of such reviews is not in favor of the departments, but let us cross our fingers and hope that many of the changes we are currently pushing will flourish and be supported by the college. Some of these changes with large impact include the conversion of our intro-level classes to integrated course and laboratory teaching units emphasizing on strengthening active learning, the now truly urgent need to hire more tenure-track faculty as we are severely lagging behind, and most urgently the already mentioned high-caliber SmartState Center hire.

Since I always have to remind myself, particularly after another overwhelming day, why I love to do what I do, let me define part of my last year's epilogue as the theme of my chairmanship. *Indeed, many things have changed since I came to the University of South Carolina and to the Department of Physics and Astronomy in 2002, but some things will never change such as my love for being here and my elation to be part of a bigger family that strives to achieve the best and cares about everyone.* Holding an ever-growing family together is a challenge that we can only master together as we share our resources, time, talents, experiences, and joy with each other whenever we can. Not all days well lived are happy days, but each day well lived builds the foundation for a happy life.

News from the Director of Graduate Studies

By Vladimir Gudkov

We welcome six new students to our graduate program from four countries: United States (3), India (1), Nepal (1), and Ukraine (1). One of our new students, Dyk Chung Nguyen, has been awarded a Graduate Stipend Enhancement Award from the College of Arts and Sciences.

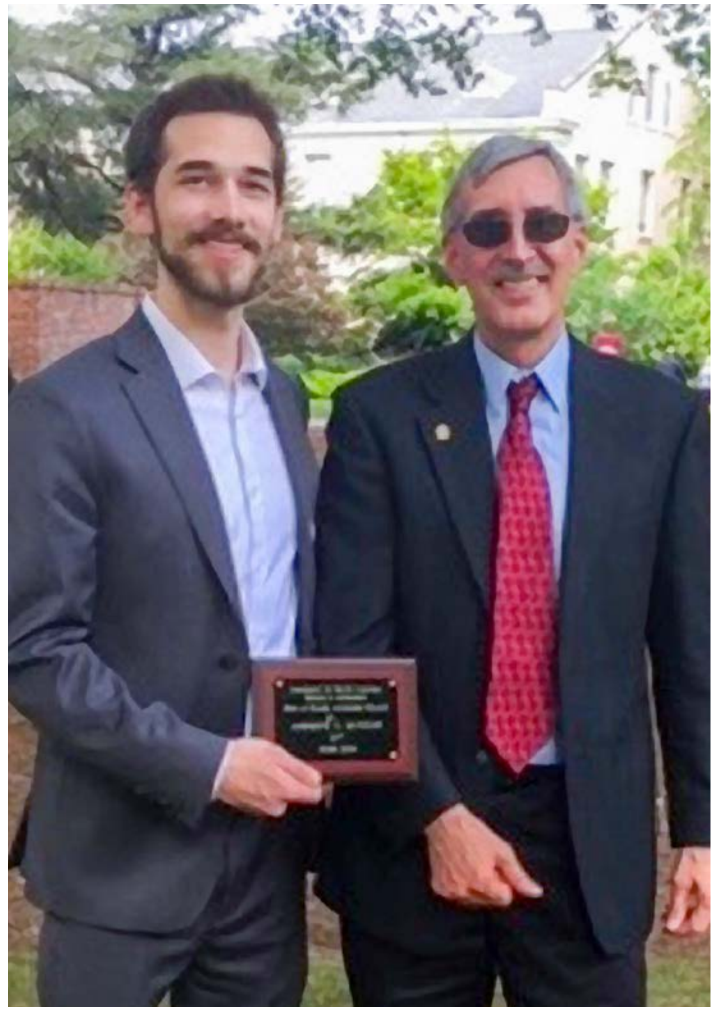
Our students continue to excel. Within our department, **Iuliia Skorodumina** was selected for the Graduate Student Research Award, **Thomas Richardson** and **Nick Tyle**r for the Graduate Student Teaching Award, and **Bryan Chavez** for the Graduate Student Service Award.

Both **Kyle Lackey** (Kulkarni) and **Justin Roberts-Pierel** (Rodney) received a NASA/South Carolina Space Grant Consortium Graduate Research Assistantship. Justin also received a NASA FINESST Award and a number of other professional accolades within the last year as well. **Saba Arash** (Wu) was the recipient of a SPARC Graduate Research Grant through USC's Office of the Vice President for Research.

The Department of Physics and Astronomy is continuously working to improve the quality of the program and better fulfill the needs of our students. We look forward to another productive and prosperous year ahead.

Congratulations to our recent graduates!

Doctoral: Barnali Chowdhury, Ning Lu



Andrew Dunton (left) received the Nina and Frank Avignone Fellowship Award at Awards Day on the USC Horseshoe in April 2019. Undergraduate Director Dr. Jeff Wilson (right) attended and presented Andrew with this special recognition.

News from the Director of Undergraduate Studies — Experimental or Theoretical?

By Jeff Wilson

That was the first question that grad students asked each other when we met together during my first year as a graduate student at Purdue University. Of course, we all thought we wanted to be theorists. Back then, our undergraduate programs were patterned around giving us a broad background in the theoretical underpinnings of our field, but had very cursory experiences in the experimental side. It took me about two more years of graduate courses and summer research experience to realize that my real interests and talents were in experimental physics. Ninety percent of my fellow students discovered the same thing and also ended up as experimentalists. That was fortunate, as there wouldn't have been enough theory positions to go around anyway.

The American Physics Society Phys21 report *"Preparing Physics Students for 21st-Century Careers"* summarizes the career destinations of Physics B.S. graduates. About a third of graduates find direct employment, a third go on to graduate school in physics, and most of the rest go to graduate school in some other discipline. The report also noted that the top skills desired by private sector employers of physics graduates were the ability to solve technical problems, the ability to work on a team, and the ability to do quality control. These are skills that are naturally encountered in modern experimental physics and can be intentionally designed into physics laboratory courses.

We have taken elements of this report to heart and we are in the middle of a multi-year process to transform our undergraduate program. Our first steps involved adding more inquiry and collaboration to our advanced laboratory courses. Our current focus is to convert our introductory courses to a lecture-studio format. This type of teaching uses class time for small group problem solving (interactive engagement) and spends less class time on content delivery (flipping the classroom). Our intention is for coming generations of students to have a better understanding of physics as an *experimental* science when they leave us. Hopefully, they'll be able to do a better job of answering the "Experimental or theoretical?" question than I did.

RESEARCH GROUPS

News From Milind Kunchur's Group

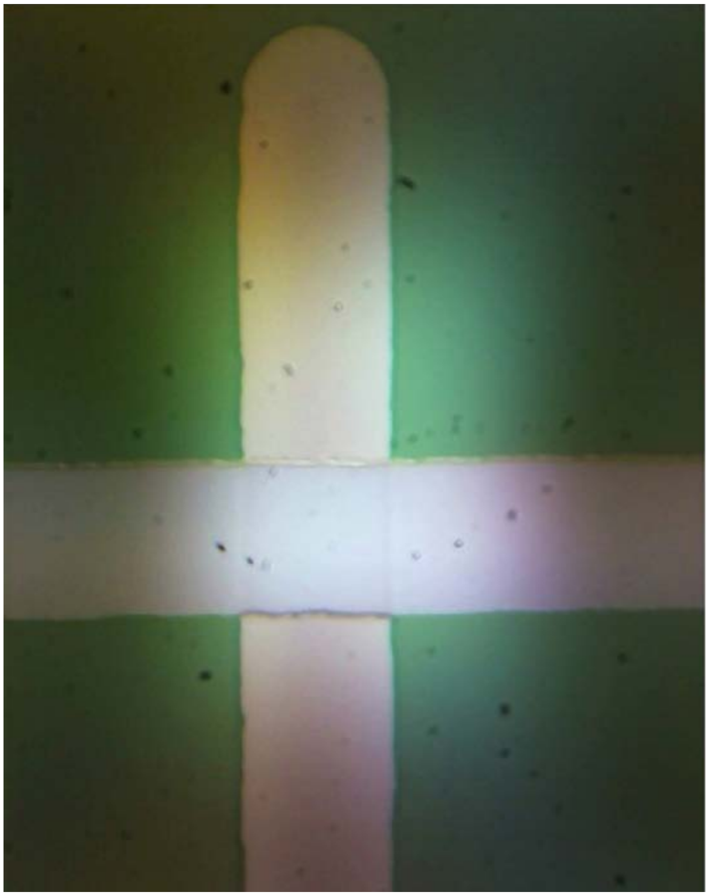
Professor Milind Kunchur's group investigates phenomena in superconducting nanowires and thin films, as well as other condensed-matter systems, at ultra-short time scales and under extreme conditions of current density, electric field and dissipation levels. This has led to the discovery or quantitative confirmation for the first time of the following phenomena/regimes: free flux flow, hot-electron vortex instability, flux fragmentation, vortex explosion, flux-creep based memory effect, current-induced pair breaking in a high-temperature superconductor, and superfluid ballistic acceleration. Dr. Kunchur's group also developed new instrumentation and methodology for testing the temporal-resolution capabilities of human hearing as well as the neurological understanding of this fundamental perception. Kunchur's doctoral student, Charles Dean, graduated in May 2019 and now holds a faculty position at Allen University (Columbia, SC). Two undergraduate students—Leslie Thelan and Kailey Sinclair—worked in Dr. Kunchur's group during 2019. Kunchur was invited to give the evening plenary talk at the Fall 2019 South Atlantic Coast Section of the American Association of Physics Teachers (SACS-AAPT) conference. Dr. Kunchur also published an extended (16-page) single-author paper in the *Condensed Matter* journal.

Memristors for Brain-Like Computing

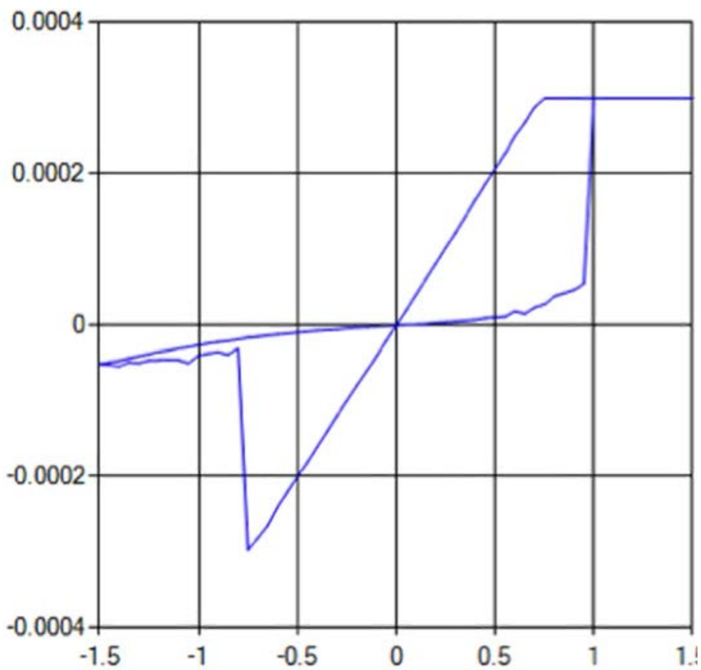
By Yuriy Pershin

Recently Yuriy Pershin, Timir Datta, and graduate student Jinsun Kim have employed high vacuum thin film facilities of our SmartState Center for Experimental Nanoscale Physics to successfully fabricate memristor devices. Memristors are electronic components that promise to revolutionize electronic technology as they conveniently integrate a memory feature with the functionality of usual resistors. Not surprisingly, in 2008, *IEEE Spectrum* described the first experimental demonstration of memristor effect by a group of researchers at Hewlett Packard (HP) as “the greatest electronics invention of the last 25 years.” When combined into networks, memristors act as massively-parallel processors that both compute and store information on the same platform, similar to the operation of biological neural networks.

Structurally, our memristors consist of metal/insulator/metal films (such as Ag/SiO_2/W) of nanoscale dimensions. Their operation relies on redox reactions to form and dissolve a conductive filament, which determines the memristor state. Very promising results were obtained in the initial measurements by



Optical microscopy image of a cross-bar array memristor.



Example of I-V curve (current is in the vertical direction). The history-dependent slopes are the sign of the memory effect.

Kim, who has confirmed the presence of resistance switching effect. However, her measurements have also shown the importance of stochastic processes and a possible interplay of two resistance switching mechanisms. Before using memristors in brain-like neuromorphic computing architectures – the future goal of Pershin, Datta, and Kim – devices with a more deterministic switching need to be created.

Experimental Nuclear Physics Group

By Ralf Gothe, Yordanka Ilieva, and Steffen Strauch

The study of the atomic nucleus and its constituents at the quark level is at the core of our research. We are leading experiments at one of the flagship facilities for nuclear physics research in the U.S., the Thomas Jefferson National Accelerator Facility (JLab) that recently has been upgraded to higher energies and at the Paul Scherrer Institute (PSI) in Switzerland. We have also been responsible for the construction of critical equipment for major nuclear physics experiments at JLab and PSI. Our studies on Quantum ChromoDynamics (QCD) and nuclei are recognized as U.S. nuclear science frontiers and our research helps to address basic questions such as: what is the origin of confinement and most of the visible mass in the universe, what is the nature of neutron stars, and what are the properties of dense nuclear matter? Answering these and related questions is a complex task requiring dedicated experimental observations and careful testing of theoretical predictions against measured observations.

Currently, our group is comprised of faculty members Ralf Gothe, Yordanka Ilieva, and Steffen Strauch, graduate students Anne Flannery, Gary Hollis, Lin Li, Chris McLauchlin, Nicolas Recalde, Brandon Tumeo, Nick Tyler, Krishna Neupane, and Iulia Skorodumina, and many undergraduate students joined us to work on various research projects.

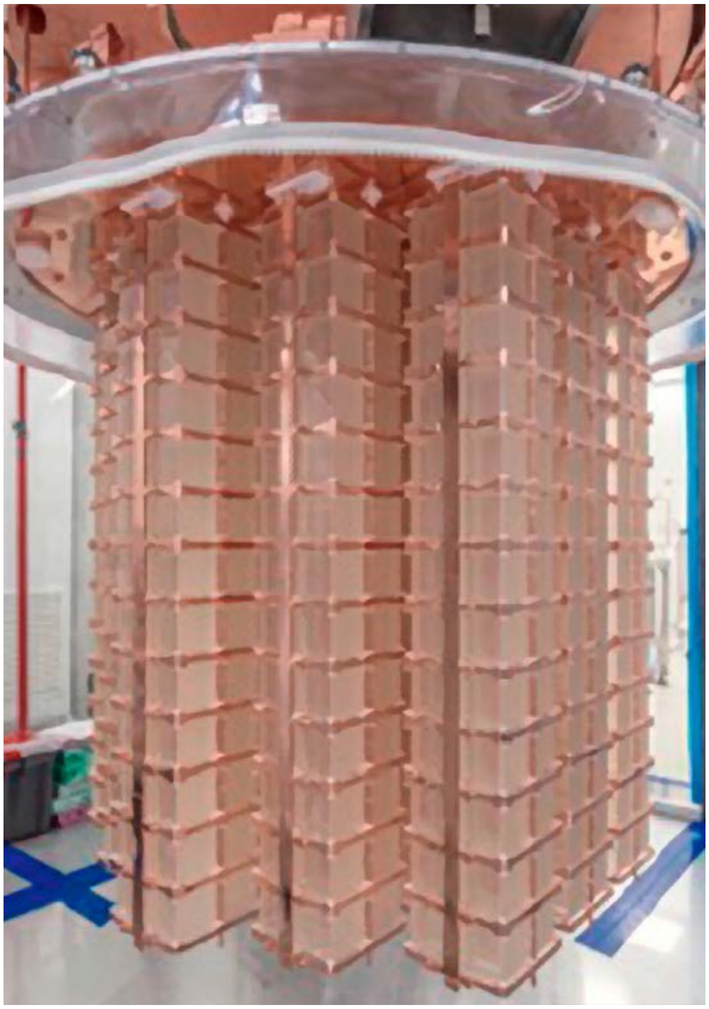
The most exciting news from the past year is that three of our experiments in Hall B at Jefferson Lab took production data successfully. In two of these, a highly energetic electron beam smashed into a proton target, which caused a spray of nuclear reactions that were then measured by the new CEBAF Large Acceptance Spectrometer (CLAS12). In the third experiment, deuteron nuclei were used as the target. We will use these novel data to gain insight about the role that gluons play in nuclei, to search for new excited states of the nucleon, and to probe deeper into the origin of the visible mass in our universe. Krishna Neupane extracted already, with the help of Nick Tyler, first acceptance-corrected yields for one of the more complicated multi-particle final states to achieve these goals. The experiments currently provide Ph.D. data for two USC students. Y. Ilieva spent the Spring 2019 semester at Jefferson Lab supporting the CLAS12 experiments.

We are happy to welcome Anne and Brandon, two new graduate students, into our group. Anne and Brandon have a B.Sc. degree from USC and Florida International University, respectively. Anne is doing research with S. Strauch on the MUSE experiment while Brandon is working with Y. Ilieva on photoproduction off deuteron using CLAS data.

Members of the Experimental Nuclear Physics Group captured on the Horseshoe. From left to right, front row: Krishna Neupane, Nick Tyler, Chris McLauchlin, Lin Li, Iuliia Skorodumina, and Anne Flannery; back row: Ralf Gothe, Steffen Strauch, Yordanka Ilieva, and Brandon Tumeo. Not pictured: Gary Hollis and Nicolas Recalde.

Over the last years, the question of the correct value for the proton charge radius has kept the field busy. New electron-scattering and hydrogen-spectroscopy experiments have reported their results. Our NSF funded Muon Scattering Experiment (MUSE) at PSI is also poised to address the proton-radius puzzle. MUSE is a scattering experiment of muons and electrons off a proton target that aims to compare the extracted proton charge radii for these two leptonic probes. Also unique to MUSE is its capability to measure two-photon exchange processes directly in the scattering reaction. We are excited that Anne Flannery joined our group as a graduate student this past summer. Anne has supported the MUSE project already as a USC undergraduate student. She has since been at PSI for extended stays to help commission the detectors that our group built for the experiment. The group will continue to play a leading role in MUSE with our development of the detector simulation and the management of the operation. Lin Li received an invitation to present a MUSE talk at the SESAPS 2019 meeting in Wrightsville Beach, NC and Anne presented her work on detector energy calibrations in a talk at the DNP 2019 meeting in Crystal City, VA. Steffen Strauch leads this project.

Since the 2018 report of the National Academy of Sciences (NAS) endorsed the scientific case of a U.S. based Electron-Ion Collider, the long process of realizing the collider is speeding up with the anticipated Critical-Decision-0 expected from the Department of Energy later this year and a site selection in 2020. For all who have been working to make the EIC happen, this means very busy years ahead. As part of the JLab R&D efforts related to building an EIC in the U.S., our group is responsible for the maintenance and operation of a dedicated test facility at Jefferson Lab, where the performance of small size photon sensors in high magnetic fields can be evaluated. After setting up the facility in 2014, we carried out a series of tests of micro-channel-plate photomultipliers (MCP-PMT) in magnetic fields of up to 5 Tesla. We have received funding to continue this activity in 2019–2020 through a collaborative *EIC PID Consortium* proposal and plan more measurements in Summer 2020. Undergraduate student Alan Rowland and graduate student Brandon Tumeo contributed to this project. In both 2019 and 2020, Alan was accepted to present a poster on this research in the Conference Experience for Undergraduates (CEU) at the Fall Meeting of the Division of Nuclear Physics of the American Physical Society.



Tellurium crystals that make up the heart of the CUORE experiment at the Laboratori Nazionali del Gran Sasso in Assergi, Italy.

Particle Astrophysics Group

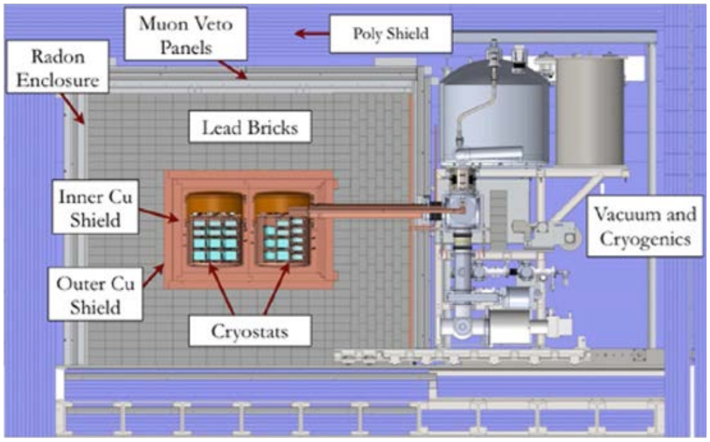
Faculty: *Frank Avignone, Richard Creswick, Vincente Guiseppe, Carl Rosenfeld, David Tedeschi, and Jeffrey Wilson*
Graduate Students: *Douglas Adams, Christopher Alduino, David Edwins, Thomas Lannen, and Kevin Wilson*
Recent Ph.D. Graduates: *Dawei Li (2016), Nicholas Chott (2017), and Clint Wiseman (2018)*

Particle Astrophysics focuses on phenomena in astrophysics and cosmology associated with the properties of elementary particles including neutrinos, axions, and candidates for Cold Dark Matter (CDM). In 1933, Fritz Zwicky discovered that far more mass is needed to explain the dynamics of the Coma Cluster of galaxies than can be accounted for by stars, gas, and dust alone. The gravitational influence of CDM on the velocity distribution of stars in spiral galaxies is now well established by Galactic Rotation Curves. The USC group was a pioneer when, in 1985, it led the first *terrestrial* search for CDM in the Homestake goldmine in Lead, South Dakota. The results eliminated heavy Dirac neutrinos as the major component of CDM over a very large range of neutrino masses. The USC Group also led the first search for axions emitted by the Sun. Axions are elementary particles predicted by the theory of Roberto Peccei and Helen Quinn that explains why the strong interaction, described by quantum chromodynamics (QCD), does not violate charge-parity (CP) symmetry. Without the Peccei-Quinn solution, or some alternative one, the CP-violation predicted by QCD would result in an electric dipole moment of the neutron about ten orders of magnitude larger than the experimental upper bound. One USC-led axion search was based on an analysis developed at USC by Rick Creswick using the coherent Bragg conversion of axions to photons in single crystals to predict a characteristic time-dependent event rate. This technique was used by other groups worldwide. Rick continues to provide critically important theoretical guidance to all of our efforts. His student, Dawei Li, recently made a further improvement in the technique and applied it to the data from the Cryogenic Underground Observatory for Rare Events (CUORE) now operating in the Gran Sasso Laboratory in Assergi, Italy. Vince Guiseppe, recently led a new search for solar axions produced by the atomic transitions in the core of the Sun. This was the subject of the Ph.D. dissertation of Dr. Clint Wiseman.

Our main current effort concentrates on two searches for the exotic neutrino-less nuclear double-beta decay ($0\nu\beta\beta-$ decay), which is only possible if neutrinos have mass and are their own antiparticles (Majorana particles). This decay mode would also violate the law of lepton-number conservation. Neutrino oscillation experiments clearly demonstrate that neutrinos have mass, but they can only measure mass differences of the mass eigenstates. The measurement of the rate of $0\nu\beta\beta-$ decay would determine the absolute masses of all three neutrino-mass eigenstates.

The USC group was deeply involved in the construction of the CUORE double-beta decay experiment in the Gran Sasso Laboratory from the very beginning. CUORE, is an array of ~750 kg of TeO_2 cryogenic detectors operating at ~11mili-Kelvin. It is in full operation and performing well and continuously acquiring excellent data. Our group's main responsibility was the fabrication of the front-end electronic system led by Carl Rosenfeld. Jeff Wilson brings computational expertise in Monte Carlo simulations using the most up-to-date data analysis techniques. He previously worked on data analysis for the BaBar experiment at the Stanford Linear Accelerator Collider (SLAC) facility. Jeff has guided several graduate students in their orientation to the CUORE computational tools. Our group is applying a new concept of using the CUORE array to study the $0\nu\beta\beta-$ decay of ^{130}Te to the first excited 0^+ state in ^{130}Xe followed by a gamma-ray cascade to the ground state. By tracking these gamma rays, it is possible to dramatically reduce or possibly eliminate the background. Our group introduced this technique by applying it to data from the first prototype, CUORICINO. It was recently applied to the data from CUORE-0, a single CUORE tower as a prototype.

Our group played a leading role in development of the Majorana Demonstrator, led by Vince Guiseppe. The Demonstrator is a



Schematic of the Majorana Demonstrator located at the Sanford Underground Research Facility (SURF) in Lead, South Dakota. The Demonstrator holds the Germanium crystals for our search for neutrinoless double beta decay.

21-million dollar R&D project designed to establish the feasibility of building and operating a ton-scale ^{76}Ge double-beta decay experiment. The principal technology used in Majorana is a vastly improved version of the IGEX experiment, led by the USC group in the 1990s. The collaboration has two detector modules operating with a detector mass of 45 kg, including 30 kg enriched to 86% in ^{76}Ge, contained in a low background shield. Majorana is now operating and collecting data for a sensitive search for neutrino less double-beta decay of ^{76}Ge. Ph.D. student Clint Wiseman spent significant time on-site participating in the loading and installation of the strings of Ge detectors that form the array inside the vacuum cryostat module. Clint also played a major role in the commissioning and fine-tuning the detector electronics to optimize their performance. David Tedeschi contributed to the commissioning activities and leads the data production while maintaining a smooth transfer of the new data collected to off-site locations for processing. In addition, he tracks the run status in real time through his custom-run database. Vincente Guiseppe led the construction of the experiment's shield. He is now on leave at Oak Ridge National Laboratory in Oak Ridge, Tennessee. Clint Wiseman also studied the low energy response of the detectors to understand the sensitivity to new physics for the search for dark matter interactions or the presence of solar axions. Clint is now a postdoctoral research associate at the University of Washington.

The group recently became a member of an expanded ^{76}Ge neutrino-less double-beta decay experiment collaboration called LEGEND. The new collaboration will begin by merging the detectors from both Majorana and GERDA, installing them in a modified GERDA cryostat and fabricating new detectors to have 200 kg of enriched Ge detectors in the Gran Sasso Laboratory in Assergi, Italy. This will be the next step towards the construction and operation of a ton-scale, ^{76}Ge double-beta decay experiment. Our group looks forward to an exciting future continuing its work on the cutting edge of particle astrophysics.

Theoretical Physics Group

Members: *Brett Altschul, Richard DeCosta, Vladimir Gudkov, Pawel Mazur, Thomas Richardson, Matthias Schindler*

After two years in South Carolina, postdoctoral researcher Alessandro Baroni accepted a position at Los Alamos National Laboratory. We wish him the best of success and hope to continue our collaboration with him going forward.

Over the summer, graduate student Thomas Richardson participated in the 2019 Doctoral Training Program at the European Centre for Theoretical Studies in Nuclear Physics and Related Areas (ECT*) in Trento, Italy. This three-week-long summer school brought together students from around the world to attend lectures by and interact with experts in effective field theory methods. Topics included precision heavy-flavor physics, nuclear forces from lattice QCD calculations, searches for physics beyond the standard model, and jet physics at the Large Hadron Collider (LHC).

Profs. Altschul and Schindler completed an extensive study of Lorentz violation at the level of pions and nucleons. This work builds on and significantly extends earlier work done in collaboration with former graduate student Rasha Kamand. Profs. Gudkov and Schindler are continuing their research into potential violations of fundamental symmetries in nuclear systems. In particular, Dr. Gudkov is working closely with colleagues at Oak Ridge National Laboratory and in Japan to study the possibility of measuring the nonconservation of time reversal invariance using neutron beams.

Professor Mazur continued his investigations of gravitational waves emitted by perturbed slowly rotating gravastars, which are black holes with a regular interior. This work is relevant for the development of the late-time templates for the gravitational wave (GW) detectors. The modeling of the final chirp in the gravitational wave spectrum produced in the binary merger of black holes is made possible by computing analytically the spectrum of quasi-normal gravitational modes, which are resonances in the associated scattering problem. One computes GW perturbations of the exterior Kerr black hole metric with an appropriate choice of boundary conditions in the interior of a hole. If the rotating black hole has a regular interior, and thus it is a gravastar, one finds that the spectrum of GW quasi-normal modes changes in comparison to the case of singular interior boundary conditions. The computation of the spectrum of GW resonances could not have been done earlier because the regular interior Kerr black hole solution was previously unknown, however, it can now be computed for the case of slow rotations.

EVENTS, EDUCATION, AND OUTREACH

American Astronomical Society president Dr. Megan Donahue presents her public lecture, "Galaxies and Super-Massive Black Holes: Galaxies at the Edge of Time," at the W.W. Hootie Johnson Performance Hall in April 2019. Photo credit: The Daily Gamecock.

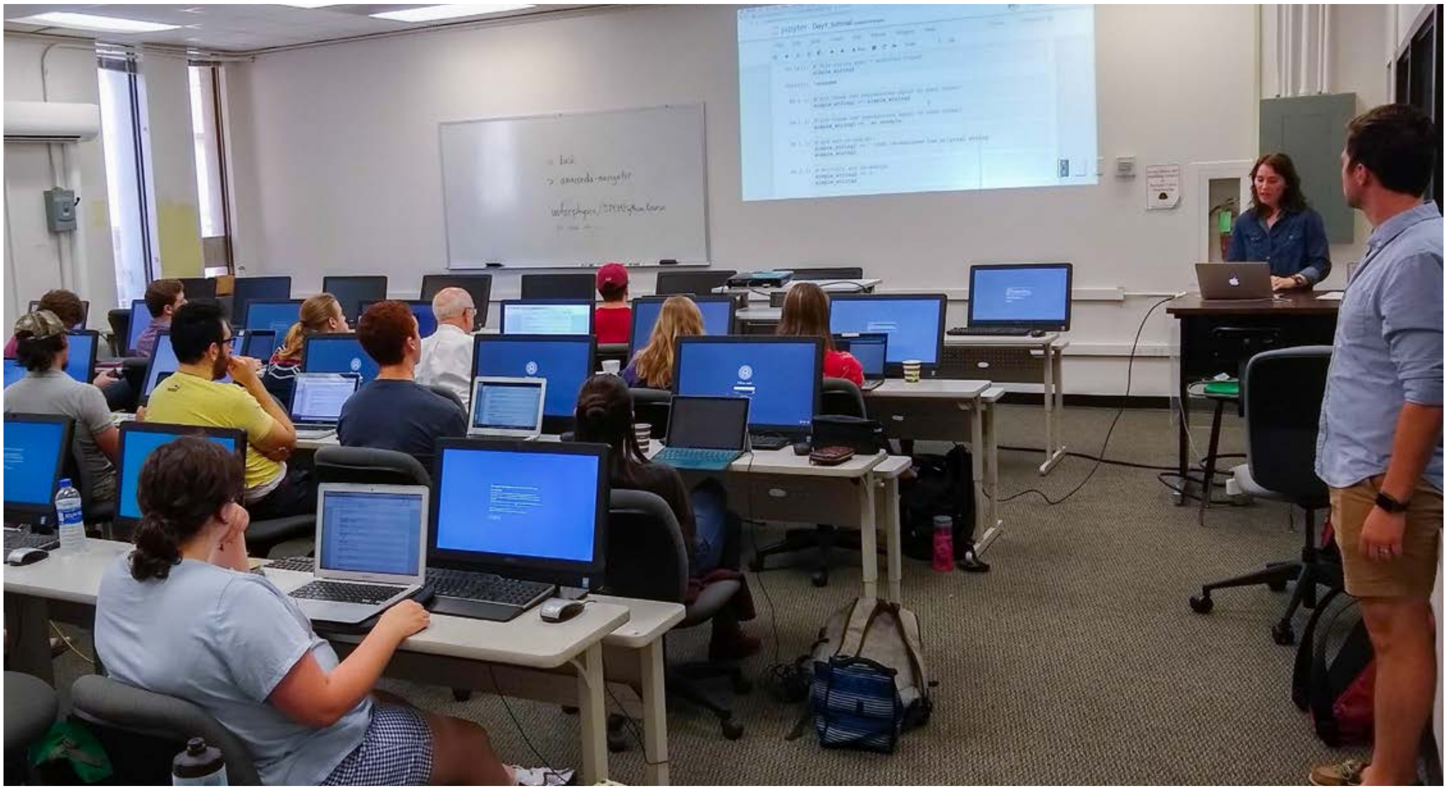
Midlands Public Outreach in 2019

By Steve Rodney and Sam Beals

Our department continues to be active in a wide range of public outreach activities, working with partners around Columbia and across the Midlands. Over the last year, we have had students, staff and faculty volunteering for the Midway Physics Day at the State Fair, engaging visitors at the SC State Museum for Astronomy Day, helping to host free public talks in our "Distinguished Lecture Series," supporting the weekly public observing nights at our own Melton Memorial Observatory, and much more.

In the summer of 2019, several of our graduate students introduced a new public outreach activity in the form of a one-week "Python for STEM" training course. This attracted nearly 50 participants, from high school to post-baccalaureate, and included many USC students from a variety of departments. Participants learned basic coding skills and how to apply them to real-world data problems. The week was a resounding success and we hope to offer an expanded two-week version in 2020.

Since the previous edition of *Quantum Leap,* we had the special pleasure of welcoming both Dr. Megan Donahue (President of the American Astronomical Society) and Dr. Arthur McDonald (winner of the 2015 Nobel Prize in Physics) to the Columbia campus to give public lectures, collaborate with our department's faculty and students, and experience a bit of southern culture



Graduate student Francie Cashman instructs students on a wide variety of Python programming topics at the training session held in June 2019. Other coordinators include Dr. Steve Rodney, Doug Adams, Justin Roberts-Pierel, and Nick Tyler.

while in Columbia. Both visits were productive, educational, and enjoyable for everyone involved. We hope to continue enhancing our "Distinguished Lecture Series" with a wide array of speakers from the various realms of both physics and astronomy and greatly appreciate the ongoing support from the College of Arts and Sciences, the Office of the Provost, and the Office of the Vice President for Research.

If you are interested in participating in future outreach events, we would love to have you. These activities are an important part of our department's service and they help maintain our connections to the surrounding community. If you are interested in participating at future events, please contact **Sam Beals** *(beals@mailbox.sc.edu)* or **Steve Rodney** *(srodney@sc.edu)*.

Astronomy Day at the South Carolina State Museum

By Bryan DeMarcy

This year marked a milestone anniversary for astronomy and space exploration. July 20, 2019 was the 50th anniversary of the historic Apollo 11 Moon landing where astronauts Neil Armstrong and Buzz Aldrin became the first humans to walk on the Moon. The South Carolina State Museum opened a new "Apollo 50: Journey to the Moon" exhibit to commemorate the anniversary while also sharing the rich history of South Carolina's involvement in the Apollo missions.

In addition to the new exhibit, the museum hosted an "Astronomy Day" event on Saturday, July 27, 2019. The entire day was devoted toward awareness in the STEM fields. There were several booths with hands-on science activities for kids. A NASA Solar System Ambassador, John Hodge, gave scheduled talks about the Apollo missions while another NASA Solar System Ambassador, Ian Hewitt, offered solar observing in front of the museum. Guests were invited to participate in a raffle for the opportunity to win a free telescope that was donated by Explore Scientific and the museum's planetarium also offered a special live sky show focused on the Apollo missions.

Several of the museum's community partners set up booths at the event to promote their organizations while offering a hands-on STEM activity for families. Among the community partners present were the Lowcountry Stargazers, Roper Mountain Astronomers, Grand Strand Amateur Astronomy Club, NASA Solar System Ambassadors, South Carolina State University, and the USC Department of Physics and Astronomy.

USC students Justin Roberts-Pierel, Joey Zambelas, Alan Rowland, Eric Rohm, and Asher Wood volunteered their Saturday to assist at the event. The students shared information about the department to museum guests while teaching kids about angular momentum using a turntable and small weights. It is a simple activity, but always fun to see the excitement (or fear) on a guest's face as their angular velocity increases when they bring their arms close together. Guests who visited the booth left with smiles on their faces and had only nice things to say about the department's student volunteers. Thank you to these

USC representatives Asher Wood, Eric Rohm, and Dr. Yordanka Ilieva explain the concept of angular momentum to interested guests at SCSM's Astronomy Day.

wonderful students for volunteering their time to promote the department and STEM within the local community. We should also thank Sam Beals, James Clawson, Dr. Yanwen Wu, Dr. Steve Rodney, and Dr. Varsha Kulkarni for helping to coordinate USC's involvement in the event.

The museum had 1,065 guests attend their 2019 Astronomy Day. A similar event will likely be offered annually and we look forward to having the Department of Physics and Astronomy participate in future Astronomy Days!

Astronaut Clay Anderson Public Lecture

By Bryan DeMarcy

The Department of Physics and Astronomy partnered with the Midlands Astronomy Club to host a public lecture by retired United States astronaut Clayton C. Anderson. Clay was in Columbia to serve as the keynote speaker for a regional planetarium conference and offered to give a free public lecture since he is a close friend of Midlands Astronomy Club member Jack Dunn.

The public lecture was held on Thursday, June 6, 2019 at the W.W. Hootie Johnson Performance Hall in the Darla Moore School of Business. There were 155 people in attendance with families representing a bulk of the audience.

The talk was light-hearted in nature and designed to inspire both children and young adults. Clay started the lecture by sharing some unique stories from his childhood. Born in the small town of Ashland, Nebraska, he was 10 years old when Neil Armstrong and Buzz Aldrin first walked on the Moon. Clay realized that he wanted to be an astronaut after watching the Apollo Moon landings with his family.

The lecture was broken down into four key parts:

1. Have a dream
2. Persevere
3. You don't have to be a genius
4. Be proud of yourself

Each part focused on Clay's personal experiences and his journey from Earth to space. Perhaps the most inspiring story he shared was one of perseverance. It took Clay 15 attempts before he was accepted to the astronaut corps!

During his time as an astronaut, Clay spent over 167 days in space with 38 hours and 28 minutes of spacewalking time including a five-month tour on the International Space Station. He served in missions STS-117 and 131 and International Space Station Expedition 15 and 16. Clay spent 30 years with NASA, which included 15 years in the astronaut program. He is also

Retired astronaut Clay Anderson provides an engaging and humorous public lecture to both the university and local communities. Photo credit: Sam Wolfe (Midlands Astronomy Club).

Following the lecture, the USC Bookstore and Barnes & Noble College hosted a book signing featuring Clay's three books for sale outside the W.W. Hootie Johnson Performance Hall.

the only Nebraskan to fly in space.

Anderson retired from NASA in 2014 and teaches aerospace engineering at Iowa State University along with lecturing and speaking as a motivational speaker by sharing his experiences both training for and living in space.

The USC Bookstore and Barnes & Noble College hosted a book signing immediately following the event and had Clay's three books available for sale. For more information about Clay Anderson, check out his website at *www.AstroClay.com*. Sam Beals assisted with planning for the Department of Physics and Astronomy while former USC graduate Bryan DeMarcy coordinated the Midlands Astronomy Club's efforts. USC students Camille Yoke and Tom Lannen helped with the "Q&A" portion of the talk as well. This event would not have been possible without the ongoing support of our terrific volunteers!

Keeping the Momentum Going at Midway Physics Day 2019

By Sam Beals

Over 25 years ago, a unique idea was inspired at the University of South Carolina. Dr. Richard Childers and his team of fellow physics faculty began piecing together the foundations for Midway Physics Day, which has now become an annual occurrence that high schoolers and their teachers truly enjoy attending at the South Carolina State Fair. Many of our Midway Physics Day "veteran" teachers frequently express that the event boosts enrollment in their science courses and they are extremely grateful to be able to include this special day in both their curricula and lesson plans year after year.

Graduate student Lin Li helps high school students understand various principles of light by playing with our giant polaroid sheets.

This year, the event took place in a new location, which was the South Gate Entertainment Tent located just inside the main gate. The close proximity of the tent to the parking lot and other nearby fair attractions was ideal for everyone involved and participants enjoyed being able to get started right away. Our faculty and student mentors welcomed over 2,700 students and 63 high schools with a wide variety of "real physics" demonstrations. These demonstrations provide students from all academic backgrounds with a unique opportunity to understand various physics principles occurring in the world around them. Afterwards, students can apply the scientific knowledge they just learned on popular fair rides such as ferris wheels, roller coasters, rotating swings, and many more. What makes Midway Physics Day so rewarding for students is that each one has his or her own takeaway – there is something for everyone!

We were also fortunate to have the 2020 South Carolina Teacher of the Year in our midst! Special guest and past Midway Physics Day participant Ms. Chanda Jefferson (Fairfield Central High School) joined us at the Fair and eagerly led a few physics demonstrations while collaborating with fellow teachers on how to implement enriching teaching strategies in high school science courses. Her passion for teaching the next generation in our state is very evident in all she does!

Govinda Kharal, a second-year graduate student, demonstrates electromagnetic propulsion using our desktop ring launchers to curious high schoolers.

The Department of Physics and Astronomy is always appreciative of our main coordinators, Jeff Wilson and Dave Tedeschi, the departmental faculty and student mentors who devote their time and energy to the demonstrations, as well as Nancy Smith and her outstanding logistical team at the State Fair. We were thrilled that we could create some of our own "prize-winning memories," which was this year's State Fair theme as they celebrated their 150th anniversary.

For more details on Midway Physics Day, please visit our website at *go.sc.edu/midwayphysicsday*. We look forward to the next one in October 2020!

"Science on Tap" in the Midlands

By Bryan DeMarcy

USC graduate student Francie Cashman was asked to present her research at a local brewery for a new program that started in the Midlands called "Science on Tap." Francie was the opening speaker to kick off the new series on May 11, 2019. She gave an excellent talk entitled "Illuminating How Galaxies Evolve Using Quasars." During the talk, Francie gave an overview of quasars and how they are used to probe intervening galaxies that lie between Earth and the background quasar. Her presentation was well received among the 38 people in attendance.

Graduate student Francie Cashman presents her research on quasars to a crowd of science enthusiasts at the first "Science on Tap" get-together in May 2019.

"Science on Tap" is a joint effort between both the South Carolina State Museum and Midlands Astronomy Club to get the Midlands community deeper engaged in science. The programs are held at the Hunter-Gatherer Brewery and Taproom near the Jim Hamilton-L.B. Owens Airport and feature short and informal talks from local scientists. After the talks, telescopes are set up outside to observe the night sky (weather permitting).

STUDENT SPOTLIGHT AND ALUMNI NEWS

John Kappel, the Society of Physics Students Vice-President, advising freshman physics major Jacob Dunbar on how to get involved in research. Many students find it useful to have casual discussions with their peers before going to instructors.

STUDENT SPOTLIGHT

Field Lines: The Forces Between Students and their Instructors

By Benjamin Ranson (Class of 2022)

It was mid-June 2019 and I had been working on the Majorana Demonstrator project for about seven months as a volunteer under Dr. David Tedeschi. I was in the middle of a conference call with a number of longtime members of the project. I was dreadfully nervous about presenting some recent analysis and I was struck by the cliche thought, "is this real physics?"

There was a sharp contrast between the derivations and theory, which composed my classes and the actual research work I had done so far. It was mostly programming, going through old code, looking at documentation, and, above all, it was graphing things. My classes had barely prepared me for this. I had never taken a physics class that even mentioned computers (although some in this department aim to fix that).

I do not believe my physics classes are useless. The very same physicists I was conferencing with, the ones who made all the choices as to what should be done and how, based their choices on the training and experience they had received over years of education. Plenty of it was from the classroom. My conclusion is that a good physics education must consist of both formal lectures and practical research. Beyond just my anecdotal story, this is, by and large, the thinking of my peers and mentors as well. How do we properly prepare students in the classroom for their post-degree role?

It is very rare for an instructor to guide a class of physics students flawlessly from ignorance to complete understanding on a subject. Perhaps it is just "Stockholm syndrome," but I don't see this as a bad thing. One might claim that the failure to teach a subject to a student is the failure to prepare them for their degree. This is a flawed perception. A physics degree is not about understanding physics. It is about receiving the preparation to think, act, and ultimately be a physicist. A physicist must be able to teach themselves new things and it only makes sense to ease physics students into doing the same.

Therefore, a struggling student is a learning student, right? Well, the math concepts and procedures in physics are not easy. Students are rarely their own best instructor. One would think that physicists of all people would understand that someone cannot "pull themselves up by their bootstraps." Struggling students need to be pointed toward helpful resources: the failure to do so will massively decrease a student's chances at success. I have found that, in the USC Department of Physics and Astronomy, all of us, both students and instructors, have been very good at doing this. That being said, there is a hole in our current method. Whether you are an instructor or a student, you should understand that students will not always ask questions when they are confused and will not always share their thoughts when they disagree. The reasons for this range from embarrassment, intimidation, or a simple mismatch of personalities. We can fix this issue. Students can work together to explain concepts to one another in or outside of class. Conveniently, this is wonderful training for the real collaboration that physicists must do. Teachers should be aware of this hidden confusion and point students toward these resources, even if nobody explicitly asks for them. For this kind of help, I would personally recommend the Society of Physics Students here at USC, of which I am the current treasurer.

Everything I have observed and prescribed with regard to the classroom also applies to research mentors and their student assistants. Research has its own special hurdle as well. Students often have to do practical work with theory that they do not fully understand. When a student lacks context for their work, it becomes meaningless. Once again, we have to work together to fix this issue. Instructors, do not just teach students how to do lab or analysis work. Instead, show them why it is done that way. Prepare them to make their own experimental-design decisions so that they will be ready to lead their own projects or be excellent members of the work of others. It goes without saying that students involved in lab work must understand that they will get more out of their position if they do it for the preparation and not the paycheck.

So, what is the efficacy of physics education as we practice it? Only data about pass/fail rates, student satisfaction, and employment rates can properly tell us that. I pass on that judgment here. I simply implore all of us (students, instructors, researchers, and mentors) to better understand what our roles are in the greater context of the path to becoming a physicist.

Interested in learning more about the Society of Physics Students? Contact our president, **Alan Rowland** *(alanmr@email.sc.edu),* for more information.

ALUMNI NEWS

From Graduate Student to Assistant Professor

By Nahid Swails

I am a Ph.D. graduate from the Department of Physics and Astronomy as of Summer 2018. I worked in Dr. Milind Kunchur's group during the last few years of my Ph.D. program specializing in condensed matter physics. My graduate school experience was unforgettable and made me stronger as a person. I was not entirely sure what I wanted to do when I was getting close to graduation. I started learning coding and discovered that one of my options was to continue as a data scientist. However, I also enjoyed teaching when I was in the graduate program, so the possibility of being a faculty member was also tempting.

I listened to my heart and decided to go with academia. It is highly unlikely that you will find the perfect job right out of school, so you will need to prioritize aspects of each position to identify the best job. This is different for everyone. For me, some of my top priorities regarding where to work were a diverse department (age, gender, background, etc.), a department with a strong and accessible department chair, the location of the job, and a job where I would likely receive tenure. It was also important for me to be in a department with good people who could serve as faculty mentors as I began my career. Regardless of the type of faculty position that you seek, you should be clear about research, teaching, and service expectations. I was looking for an academic position that balanced time between both teaching and research. Ahead of interviewing, you should think about what aspects are priorities versus those that you would be willing to compromise. While I was interviewing for various positions, I kept detailed lists to evaluate these factors. After being offered a position, there is an opportunity for you to negotiate some of the aspects that are important to you, but there is no guarantee you will get everything you want.

I received three faculty job offers from three different colleges around the Columbia area. After thinking it through, I decided to go with a position at USCL. The University of South Carolina Lancaster is a public university located in Lancaster and one of the four regional USC campuses. The size of classes is smaller than at most colleges, which makes it more accessible for me to get to know my students and make a bigger impact. The

Dr. Nahid Swails

environment I am working in is great and every single person that I work with makes me feel like part of a bigger family. As of Fall 2019, I accepted a tenure-track position at USCL and am going to begin my research on additive manufacturing, which I am really looking forward to starting. Additive Manufacturing (AM) is a recently introduced technique to produce parts with high complexity (e.g., holes, curves, etc.), which cannot be fabricated by conventional techniques. All jobs have their own struggles and it is not all sunshine and rainbows. However, I think it makes a big difference if you try to enjoy the ride. The keys to success are not giving up and following your heart. I am proud to call myself a Gamecock!

From Gamecock to Boilermaker

By Zach Davis

I commonly think about my time at USC. Coming from the small town of Brunson in the lowcountry of South Carolina, finding my way to the university was mostly an accident. After graduating from high school, I started at a local USC campus simply because I had no other plans. Shortly after, I transferred and found that becoming a Gamecock was by far the most fortuitous path my life could have taken.

After transferring to USC in 2014, I only had a vague idea of pursuing physics. Starting my physics courses would come with some stumbles. I was not accustomed to the academic environment and it would take some time for me to develop the proper tools to flourish. This is where my fondest memories of USC originate. The Department of Physics and Astronomy provided me with professors and peers that created an environment in which I would be able to develop into an academic. Professors such as Dr. Yanwen Wu and Dr. Scott Crittenden served as excellent advisors and mentors who patiently guided me in my early physics career. Though my professors were (and still are) a great resource, I made additional strides in development as a student through my peers at USC. Although my reasons to study physics are hard to pin down, my reasons for prevailing are clearly the connections that I made during my time at USC.

After graduating in 2017, I took a year to travel and explore. Afterwards, I applied to several schools including Purdue University in West Lafayette, Indiana. After being wooed to come to Purdue, I excitedly started school there as quickly as I could. At Purdue, I immediately started teaching, taking classes, and performing research. With this heavy workload, I felt very fortunate to not have experienced as much stress as I did during my first year of undergraduate work. I credit this mostly to the skills I learned during my time at USC, which helped prepare me for more rigorous workloads.

Currently, I am in my second year at Purdue and work in theoretical astrophysics. I am concentrating on finding the origins of Ultra High Energy Cosmic Radiation (UHECR). Specifically, I am looking to see if magnetic reconnection (a process that can release energy through topological changes in the magnetic field) can be given computational credence as the primary mechanism for accelerating UHECRs. Currently, this means working on Particle in Cell (PIC) simulations capable of simulating plasma in astronomical phenomena like AGNs and GRBs for long enough to accelerate particles seen at the very extreme of the cosmic radiation spectrum ($E>1e18$ eV). This is problematic because the longer the simulation runs, the larger the particles' (cells') energy and the smaller the time step (resolution) needed to create accurate results. Eventually, this becomes too computationally taxing. To overcome this issue, I am looking at ways to reduce the number of tracked particles by treating some of the lower energy particles as a fluid. This approach may lose some information, but will allow simulating the plasma at higher energies.

I have always been a student at heart. As I progress further into my career, I stray further from the classroom. However, I want to continue developing and learning every day. The natural path for this has always seemed to be academia. My time in academia has only made me feel more resolute in this idea and I intend to follow it through to a postdoctoral position and eventually a path to professorship.

Annastasia Haynie

From One USC to the Other

By Annastasia Haynie

After spending four years explaining to friends and family that I was attending USC in *South Carolina,* I moved across the country to USC in *Southern California*. This life transition was only made possible by the growth and development I experienced as a student and scientist while I was an undergraduate in Physics & Astronomy at (the *real*) USC. I graduated with a B.S. in Physics and a minor in Astronomy in May 2018, after spending several years conducting research under both Dr. Thomas Crawford and Dr. Steven Rodney. I was also a member of the Society for Physics Students (SPS), advised by Dr. Yanwen Wu, and a member of the service sorority Omega Phi Alpha. Some of my fondest memories of USC are from my involvement in departmental events such as Midway Physics Day at the S.C. State Fair, Total Eclipse Day in August 2017, and being able to present my Type Ia Supernovae research with Dr. Rodney at the January 2018 American Astronomical Society meeting. I began my academic career at USC a little unsure about my major, but graduated with the confidence that I was both on the right track and well prepared to take the next step toward my goals.

Since leaving USC, I have finished my first and begun my second year at the University of Southern California as a Physics & Astronomy Ph.D. student. After some brief academic hazing in the first year, I successfully passed my screening exam last March, allowing me to move forward in the program. Now, as a second year student, I am in the midst of finishing up my core classes, working as a teaching assistant, acting as the Vice President for the Graduate Association for Students in Physics (GASP), and conducting research at Carnegie Observatories in Pasadena, California with Dr. Anthony Piro. If it sounds like I am in a little over my head, then you're right! But that is nothing new for me. Staying involved in my department is part of who I am as a student and who I hope to be as a professor one day. With GASP, I help plan events to improve the overall graduate student experience (i.e. free food). We hold events similar to those organized by SPS, such as public or departmental talks, observing nights with our on-campus telescope, panels with our undergraduate counterparts, and professional development opportunities for students. As a TA, I often pull from my experience as a "peer leader" in Dr. Rodney's Introduction to Astronomy (ASTR 101) course to help students stay engaged with the subject material and think creatively about modern topics in astronomy.

I chose to attend the University of Southern California for graduate school because it afforded me the opportunity to conduct my research at Carnegie Observatories, which hosts a broad range of cutting edge research in astronomy and astrophysics. I began my first project at Carnegie this past May, where I still study supernovae, but now I focus on numerical simulations of core-collapse events in red supergiants (RSGs). I am interested in studying the full diversity of shock breakout phenomena associated with core-collapse scenarios, focusing on how the presence of circumstellar material (CSM) changes the observables associated with the shock breakout signal. There is growing evidence that CSM around RSGs is more common than originally thought and may even be the key to understanding the transition between classes of core-collapse supernovae.

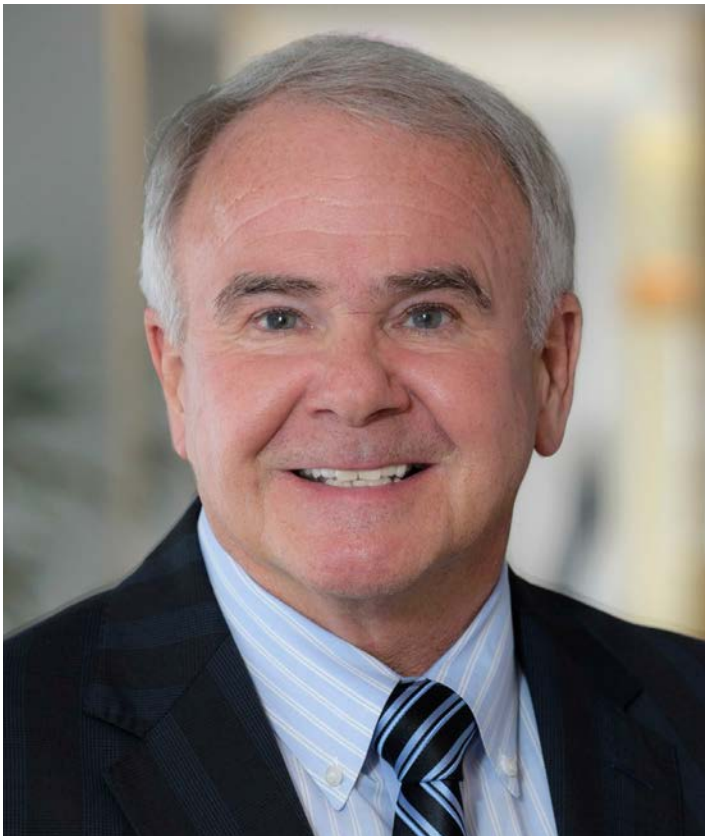
While I am very happy as a graduate student (enjoying the still warm, but much less humid weather in Los Angeles), I miss USC so much. I will always be proud to be a Gamecock. Forever to thee.

Dr. Gerald Harmon – Winner of the 2019 Distinguished Alumnus Award

The annual Distinguished Alumnus Award honors a graduate whose professional and personal life has exemplified dedication and excellence in leadership, citizenship, and voluntarism while offering a lifetime of devotion to the University of South Carolina.

We are proud to announce that this year's recipient is one of our own, Dr. Gerald E. Harmon, who received a Bachelor of Science

IN MEMORIAM

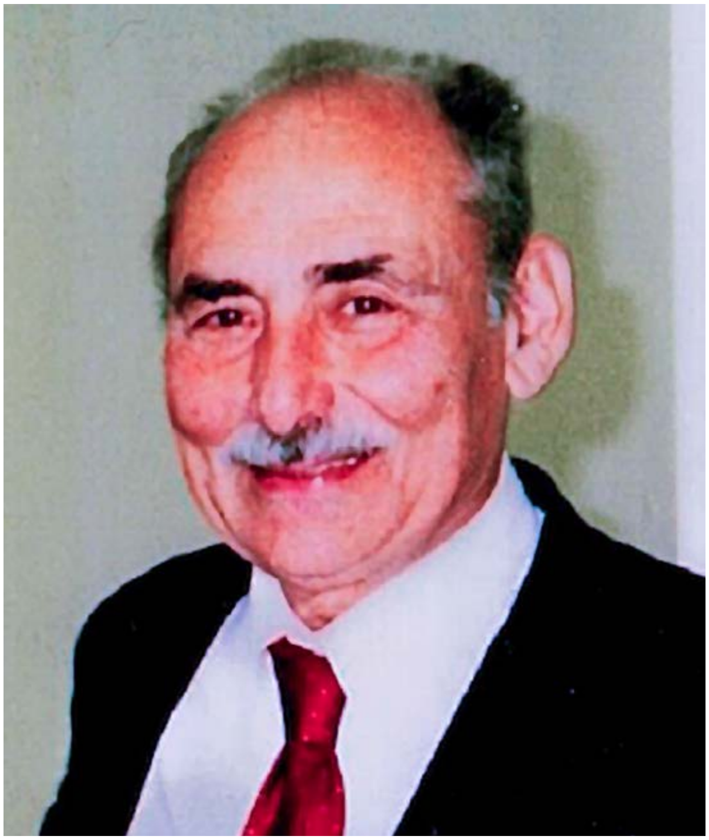


Dr. Gerald Harmon

in Physics from USC in 1973. Dr. Harmon greatly enjoyed his time as a student in our department while learning from some of his role models, which include Dr. Frank Avignone, Dr. O.F. "Mike" Schuette, and Dr. Sam Finklea. Even after leaving the university, Dr. Harmon continued to connect with fellow physicists and their families, many of which were Gamecocks!

Dr. Harmon has held several leadership positions in the South Carolina Medical Association, including chairman of the board and president. He serves as a clinical professor at two of South Carolina's medical schools, a commitment that has been well recognized as he has been named "Community Educator of the Year" by both the South Carolina Academy of Family Physicians and the South Carolina Area Health Education Consortium.

Harmon served the nation in both Operations Desert Shield and Desert Storm and later in Operations Iraqi Freedom and Enduring Freedom, holding responsibilities as chief surgeon for the National Guard Bureau and assistant surgeon general for the U.S. Air Force. He retired from the United States Air Force with the rank of Major General. Also, Harmon has since been recognized as a Distinguished Graduate of the College of Arts and Sciences. He received his medical degree from the Medical University of South Carolina and an honorary Doctor of Public Service from the University of South Carolina in 2018 while serving as a commencement speaker.



In Memory of Horacio Farach

By Frank Avignone and Rick Creswick

The department mourns the loss of Distinguished Professor Emeritus Horacio Farach who passed away this year. Although officially retired since 2003, he continued to collaborate in research and visit the department from his home in California. During his long career at USC, Professor Farach won the Russell Research Award along with three major USC teaching awards, the Jesse W. Beams Medal of the APS, the prestigious Luis Leloir Medal of Argentina, two Fulbright-Hays Program Awards to Italy, and the Major Notables of Argentina (equivalent to our National Medal of Science).

Horacio Farach was a world-renowned expert in electron paramagnetic resonance. With Professor Charles Poole (USC), he wrote major textbooks on the subject and eventually brought the technology back to the University of Buenos Aires, where he established a complete laboratory in the Department of Biophysics. For this, the President of Argentina awarded him the Luis Leloir Medal in 1996.

He was a totally devoted teacher in the lower division physics courses populated by many non-physics majors, including premedical students. One of his famous statements to the press, "I try to be available to my students all day every day - and they have my home phone number. For me, it is an honor that a student has the confidence to call me at 11:00 in the evening to ask a question about a problem."

Horacio was born in Northern Argentina in 1923 and educated at the University of Buenos Aires. He was originally a secondary school mathematics teacher, but continued his studies earning his Ph.D. degree in physics in 1962. He served on the faculty there until 1966 when political unrest in Argentina resulted in a military coup led by General Juan Carlos Onganía. The campus demonstrations led to brutal beatings (some fatal), which led to the resignation of the majority of the university faculty. Horacio resigned and eventually found his way to both the United States and USC.

At USC, Horacio had a prestigious career and served as the Associate Department Chair and Director of Graduate Studies for 18 years. He was distinguished in the areas of teaching, research, and service. Horacio was a wonderful friend to have as well as a dedicated teacher and valuable colleague. He will be missed by all who knew him.

At the end of life, everyone leaves a legacy. Those which some leave, have great lasting impact on many lives. Horacio Farach left one of those.

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Space Elements imaged by Alex Mowery from the Melton Observatory

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