Quantum Leap
University of South Carolina
Department of Physics and Astronomy
2016

President Barack Obama joins recipients of the Presidential Early Career Award for Scientists and Engineers (PECASE) for a group photo in the East Room of the White House, May 5, 2016. (Official White House Photo by Lawrence Jackson).

Matthias Schindler is a Winner of the Presidential Early Career Awards for Scientists and Engineers

By Vladimir Gudkov

Congratulations to Dr. Matthias Schindler, a recipient of the Presidential Early Career Awards for Scientists and Engineers (PECASE), the highest honor bestowed by the United States Government on science and engineering professionals in the early stages of their independent research careers. The PECASE Awards are intended to recognize some of the finest scientists and engineers who, while early in their research careers, show exceptional potential for leadership at the frontiers of scientific knowledge during the twenty-first century.

Dr. Matthias Schindler is recognized "For innovative theoretical research to establish a systematic framework for the description of parity violation in few-nucleon systems, for calculating reliable and testable relations between observables in light nuclei, and for scientific leadership in the area of parity violation."

Matthias joined the Department of Physics and Astronomy in January 2011. He received his doctoral degree in physics from the University of Mainz, Germany, in 2007. Before joining USC, Matthias held research positions at Ohio University and the George Washington University, where he mainly worked on theoretical approaches to describing two and three-nucleon systems. He is a member of the executive committee of the American Physical Society Topical Group on Few-Body Systems and Multiparticle Dynamics and has co-authored a graduate-level textbook on chiral perturbation theory. His current research focuses on the study of fundamental symmetries in nucleon interactions, which he is doing with a close collaboration with the fundamental neutron physics group at Oak Ridge National Laboratory, and with students and colleagues at our department.

More on the 2016 Presidential Early Career Awards for Scientists and Engineers can be found via the following websites:

- *https://www.whitehouse.gov/the-press-office/2016/02/18/president-obama-honors-extraordinary-early-career-scientists*
- *https://www.whitehouse.gov/blog/2016/05/05/honoring-federally-funded-scientists-and-engineers-forefront-research-and-discovery*
- *http://science.energy.gov/about/honors-and-awards/pecase/2016-ceremony/*

UNIVERSITY OF SOUTH CAROLINA

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UPDATES FROM THE CHAIR AND DIRECTORS

Message from the Chair

By Milind Purohit

Just a brief update from the chair's office this time. Our faculty were in the spotlight again during the last academic year! Prof. Matthias Schindler wowed us by winning not only USC's "Breakthrough Star" award, but he had the exceptional honor of being invited to the White House by President Obama where he received the prestigious Presidential Early Career Award for Scientists and Engineers (PECASE) in April.

Our newest faculty member and astronomer, Prof. Steven Rodney, has impressed students, faculty, and administrators with his teaching skills, stellar research, and abilities. He succeeded in creating an exciting new Carolina Distinguished Lectureship series in Physics and Astronomy. He has already invited two big names this year, including a Nobel Laureate, to come visit our campus and give public lectures and other talks. We've had one of these already, by Mario Livio (Space Telescope Science Institute), and are looking forward to a visit by Adam Riess (Johns Hopkins; 2011 Nobel Prize) in January.

Other news is not so good this year. Our most highly distinguished professor, Richard Webb, and our distinguished emeritus professor, John Safko, both passed away this year. Also, the college budget went into the red, and, consequently, all departments in the college, including ours, are facing very significant and deep cuts in support for teaching, for graduate students, and almost everything else. Educational Foundation grants are effectively bailing us out, and we hope that in a year or so the worst will be over. Now's the time to contribute to the Educational Foundation funds for our department if you are in a position to do so!

News from the Graduate Director

By Richard Creswick

New Students: The Department of Physics and Astronomy welcomes five new graduate students this year, and we are happy to say that Rahman Mohtasebzadeh has returned to the department from Afghanistan to work with Professor Crawford for his PhD.

PhD: Students who completed their PhD degrees in the past year are Tongtong Cao (Ilieva), Libo Jiang (Mishra), Dawei Li (Creswick), and Bochen Zhong (Webb/Crawford).

MS: Katia Gasperi (Wu) and Sean Morrison (Kulkarni) received Master's degrees in December 2015.

Postdoctoral Fellows: Recent graduates Libo Jiang and Tongtong Cao acquired postdoctoral fellow positions at the University of Pittsburgh (Pittsburgh, PA) and Hampton University (Hampton, VA) respectively. Also, Dawei Li is continuing his research with the Particle Astrophysics Group at USC.

Scholarships and Awards: The "Graduate Service Award" was given to Francie Cashman, the "Graduate Teaching Award" went to Dawei Li, and Ye Tian and Tongtong Cao shared the "Graduate Research Award."

Clint Wiseman (Guiseppe) recently received a prestigious DOE graduate fellowship to work at Los Alamos National Laboratory (Los Alamos, NM) in Spring 2017. Ye Tian (Gothe) also acquired an invitation to attend the "Rising Stars in Physics" workshop to be held at MIT (Cambridge, MA). Francie Cashman (Kulkarni) attained the NASA/South Carolina Space Grant Consortium graduate fellowship, which will support her research for three years.

The GAANN fellowships have run their course with great success. All of the GAANN participants who took the departmental "admission to candidacy" exam passed and are now working in various research groups. Given the accomplishments of our students, we are hoping that Congress and the NSF will fund another round of grants.

News from the Director of Undergraduate Studies

By Jeffrey Wilson

Last year, we added an instructor, John Cook, to our introductory program and were able to offer more sections and decrease student/teacher ratios in many of our 200-level physics courses. This year, we have begun implementing updates to the experimental parts of the physics major. Our yearlong intermediate lab sequence has been re-designed as a single course that will be offered in both spring and fall semesters to improve scheduling flexibility. The learning objectives will be the same, but the faster pace may be a challenge. We are very interested to see how student experiences with this new course compare to the old sequence.

Our upper-level lab courses (Solid State Physics, Optics, and Electronics) are being reorganized into two courses labeled Advanced Experimental Physics I and II (AEPI and AEPII). The intention of these courses is to expose students to the design/execute/iterate process that occurs naturally in an investigation. They will also have the opportunity to choose modules of study

in a larger range of experimental physics than was normally available as scheduled courses.

These types of changes to our experimental program are intended to give our students better preparation for a larger range of professions. The Joint Task Force on Undergraduate Physics Programs commissioned by the American Physical Society and the American Association of Physics Teachers has concluded that undergraduate physics programs need to broaden the skills and knowledge they are imparting to their students so that they can continue to be highly competitive in today's technical workplace. In addition to the standard physics-specific knowledge that is the major component of most undergraduate physics programs, we need to teach more scientific and technical skills, communication skills, and professional and workplace related skills.

You are invited to read their report at *http://www.compadre.org/JTUPP*. The re-design of our lab courses will take a few steps down this path.

Undergraduate Awards

By Jeffrey Wilson

Two undergraduate physics students received major awards during last spring's University Awards Ceremony: Karl Schober received the Nina and Frank Avignone Fellowship for achievement in physics and Edward Dunton received the Lovelace Family Endowed Scholarship, which rotates between physics and mathematics. In addition to the physics awards, we had several physics students who were double majors and received awards from other departments: Karl Schober received the Jeong S. Yang Award for Excellence in Undergraduate Mathematics; Travis S. Dore received the Department of Philosophy Edna W. and Foster E. Tait Scholarship; Katherine Driscoll received an Erasmus Mundus Scholarship. Congratulations to our outstanding undergraduate physics students! We are very proud of you all!

MAJOR ACADEMIC AND RESEARCH GROUPS

Astronomy

By Varsha Kulkarni

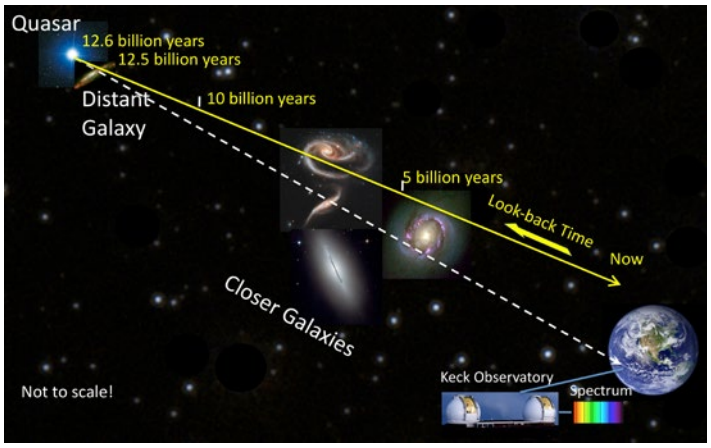
The past year has been filled with wonderful discoveries in the field of astronomy, ranging from detections of gravitational waves to the discovery of a potentially terrestrial planet around the nearest star, Proxima Centauri, only 4.2 light years away! USC astronomers Varsha Kulkarni, Steven Rodney, and their students and collaborators continued to explore the wonders of distant astronomical objects using both space-based and ground-based telescopes.

Prof. Kulkarni and her team worked on various aspects of the evolution of galaxies and the material in between galaxies. Research assistant Sean Morrison, Prof. Kulkarni, former graduate student Debopam Som (now a post-doctoral researcher at the Laboratoire d'Astrophysique de Marseille),

Research assistant Sean Morrison and graduate student Suraj Poudel in front of the Magellan telescopes in Chile during an observing run in April 2016.

and others made an exciting discovery of unusual chemical composition and internal chemical variations within a distant galaxy. This galaxy is so far away that the light we receive from it now left it about 12.5 billion years ago. Their analysis of the chemical composition of this galaxy suggests leftover signatures from element production in early generations of massive stars. Kulkarni and collaborators have recently been observing multiple images of gravitationally lensed quasars to measure the small-scale spatial variations within the foreground lensing galaxies, using optical and UV spectra obtained with the Magellan II telescope (located near La Serena, Chile) and the Hubble Space Telescope. Kulkarni, former graduate student Lorrie Straka (now a post-doctoral researcher at Leiden Observatory), and collaborators have also been using the Hubble Space Telescope to obtain UV observations of the gas in the inner regions of some low-redshift galaxies. Using the Very Large Telescope (also in Chile), Kulkarni, collaborator Celine Peroux, and others have mapped out the internal variation of metallicity and star formation rates in some distant galaxies. Kulkarni, former post-doctoral researcher Monique Aller (now an assistant professor at Georgia Southern University), and collaborators studied the chemistry of interstellar dust grains in gas-rich galaxies using optical and infrared observations.

Sean Morrison completed his M.S. thesis research on searches for molecules in distant galaxies using observations obtained with the Herschel Space Observatory. Sean continues to work with our team as a research assistant, and also as the director of the Melton Memorial Observatory. Graduate student Francie Cashman is working on improvements to the atomic data needed for astrophysical spectroscopy and the associated modeling of the spectra of distant galaxies. Sean and graduate



An illustration showing the journey of a light beam from a distant quasar studied by Sean Morrison, Prof. Kulkarni, Debopam Som, and collaborators. The light left the quasar about 12.6 billion years ago, passed through a distant galaxy 12.5 billion years ago as well as many other galaxies along the way. The light was finally recorded at the Keck Observatory on the Earth. A spectrograph at Keck divided the light into its numerous constituent colors producing a high-resolution spectrum. Morrison et al. analyzed this spectrum to discover the peculiar chemical composition of the material surrounding the distant galaxy as of 12.5 billion years ago, possibly suggestive of the influence of early generations of stars.

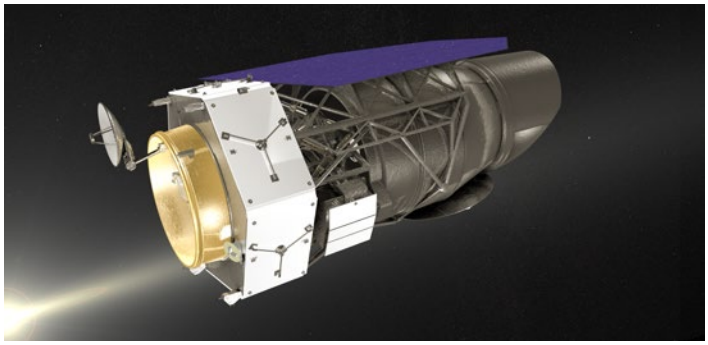
Photo courtesy of NASA.

student Suraj Poudel carried out observations of distant galaxies at the Magellan II telescope in order to measure the chemical compositions in the first 1 billion years, i.e. more than 90% back in the history of the universe. New graduate student Kyle Lackey (a USC Honors College graduate) worked on infrared images of polar ring galaxies - peculiar galaxies with rings of star formation perpendicular to the galaxy major axis, possibly resulting from an earlier collision with another galaxy. Undergraduates Alex Kirby and Jo Lynn Tyner worked with our team in Summer 2016 as NSF REU (Research Experiences for Undergraduates) interns on projects related to the gas in and around galaxies near and far.

Astronomy Research in 2016

By Steven Rodney

As the 2015-2016 academic year closed, Dr. Steven Rodney had completed his first year on the job as the newest Assistant Professor in the department. In that first year, he helped to revise the structure of the USC Astronomy Minor, spearheaded a new Distinguished Lecture Series (see page 17), and developed a new undergraduate astronomy course (ASTR 201: The Dark



"W-FIRST Bright-Right" (NASA / Washington, D.C / 2014). Artist's conception of the planned WFIRST observatory, to launch in the mid-2020's. The WFIRST mission will search for supernova explosions, distant galaxies and extrasolar planets, addressing essential questions in the areas of dark energy, extraterrestrial life, and the evolution of the universe.

For more information, see http://wfirst.gsfc.nasa.gov

Universe). Dr. Rodney had also opened up some new avenues of research, as he secured a 5-year contract from NASA as a co-investigator on the Science Investigation Team for the forthcoming Wide Field Infrared Survey Telescope (WFIRST). This advanced space observatory will launch in the mid-2020's, and Dr. Rodney's team is working now to define the science requirements for the supernova survey that will be one of the key functions of the WFIRST mission. Dr. Rodney has already been using the Hubble Space Telescope (HST) to study distant supernovae, but HST can only find a relatively small sample of these rare stellar explosions. WFIRST will be much like HST, but will cover a much wider swath of the sky with each image, allowing it to discover hundreds or thousands of very distant supernovae over its 5-year mission. As the Fall 2016 semester began, Dr. Rodney welcomed a small group of students into his research group, each launching new research projects to find and study the far-off supernovae that only space telescopes can spot.

Belle2 Program

By Milind Purohit

The Belle2 program, led by Prof. Purohit, is getting closer to starting up. This project aims to unravel the mysteries of CP violation in B-meson decays and related b-quark physics. At South Carolina, we completed testing of over 8,000 channels of high-speed (4 GHz) readout, enabling precision timing of photon arrival. Graduate student Alyssa Loos and undergraduate Eric Rohm learned a lot while testing reached a fever pitch smack during the Great Flood of 2015! Our postdoc, Dr. Vishal Bhardwaj, left at the end of 2015 for a faculty position in India, and we are joined by a new postdoc, Dr. Hulya Atmacan. Hulya is out at KEK in Japan, actively participating in the commissioning of our particle ID (TOP) detector on Belle II. The SuperKEKB accelerator is delivering beam-beam collisions already, and the rest of the Belle II detector is only months away from completion. We are waiting excitedly for our first data!

Research in Timir Datta's Group

By Timir Datta

Physical properties can be sensitive to geometry and topology. We are developing strategies to affect an electronic response of a system through changes in its geometry and topology. In reduced dimensional space, these effects can be considerable. In addition, the Nobel-winning (NP 2004) two-dimensional system, graphene, discovered by Andre Geim and Konstantin Novoselo, has quasi-particles that follow an analogue of the Dirac equation. The peculiar quantum mechanics of massless (zero band gap) spin–half and charged particles in single sheets of pure graphite have attracted a lot of attention, including ours.

In our collaboration with Prof. Ming Yin's DOE-sponsored supported materials program, graduate student Lei Wang has been continuing his doctoral research on the magneto transport matrix, especially the Gxx and Gxy components of conductance in graphene at the National High Magnetic Field Laboratory (NHMFL) in Tallahassee, FL. At NHMFL, we were awarded times on the 35 Tesla DC resistive magnet facility as well as several of the 20 T superconducting systems. In the high magnetic field regime, Wang observes dominant Shubnikov-de Haas (see Figure 1) oscillations associated with the Fermi surface in momentum space.

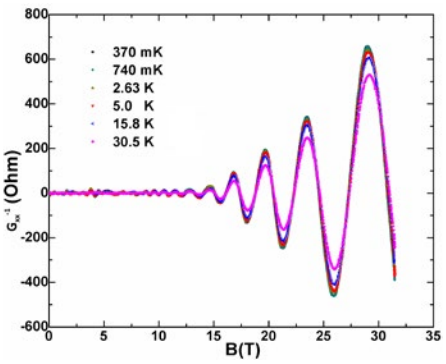


Figure 1: Temperature dependence of Shubnikov-de Haas oscillations in a sheet of graphene excised with an array of anti-dots. The isotherms are periodic in inverse magnetic fields and contain information about the Fermi-surface as well as quasi particle excitations.

Also, Wang is beginning to resolve the low field Aharonov-Bohm phase contribution that is commensurate with the real space area (~ 104 nm2) of the anti-dot features excised in the carbon grid. A graphene sheet can be freestanding, but, typically, as in our case, the sheet is supported on a non-conducting substrate. We are finding that the substrate may be more than a silent partner in graphene electronics. This adds to the complexity and richness of this exciting new system.

As in the past, our former group members, Yeuncheol Jeong (Sejong University, Seoul, South Korea) and Erdogan Ozel (Balikesir University, Turkey), visited over the summer (see Figure 2). As participants in the Newton's constant experiment, both remain involved in the current effort with super resolving, forbidden imaging with topological and edge state optics.

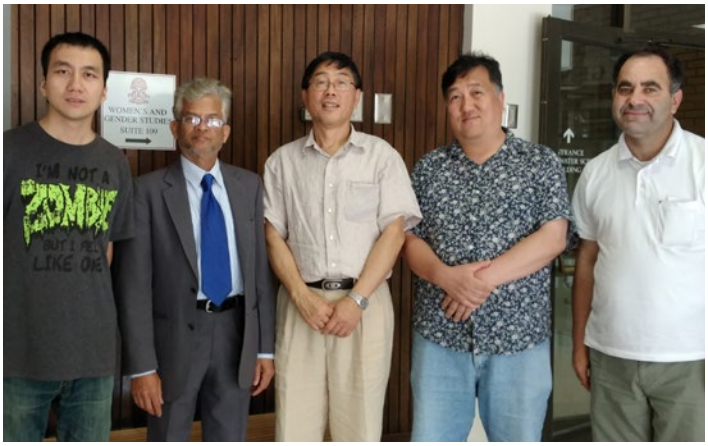


Figure 2: Timir Datta's research group (Wang, Datta, Yin, Jeong and Ozel). Photo taken in July 2016.

Research in Milind Kunchur's Group

By Milind Kunchur

Professor Milind Kunchur's research group works in two areas: superconductivity, thin-films, and nanofabrication; and psychoacoustics, auditory-neurophysiology, and high-end audio. Ongoing experiments probe current-induced depairing and vortex explosion phenomena in superconductors. Recently the new phenomenon of oscillatory magnetoresistance in superconducting transitions was discovered. The theory for this effect is at present a mystery. Dr. Kunchur has reported this discovery at invited talks at international conferences including the Energy-Materials-Nanotechnology meeting in Prague, Czech Republic, and the DAE Solid State Physics Symposium in Bhubaneswar, India. He currently has three graduate students—Charles Dean, Nahid Shayesteh, and Stacy Varner. Three undergraduate students—Keiko Bridwell, Andrew Lyons, and Akhila Padi—worked in Dr. Kunchur's group during 2016. Andrew Lyons graduated in May of 2016, with Prof. Kunchur as the director of his senior honors thesis entitled "Beyond the Classroom."

Experimental Nuclear Physics Group

By Steffen Strauch

Figure 1 shows members of the experimental nuclear physics group. Our group includes faculty members Ralf Gothe, Yordanka Ilieva, and Steffen Strauch, and graduate students Colin Gleason, Gary Hollis, Hao Jiang, Lin Li, Chris McLauchlin, Aneta Net, Evan Phelps, Nicholas Recalde, Iuliia Skorodumina, Ye Tian, Arjun Trivedi, and Nick Tyler. Also, many undergraduate students join our group for various research projects. 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), and at the Paul Scherrer Institute (PSI) in Switzerland. We have also engaged in collaborative research at the J-PARC proton accelerator in Japan and the electron accelerator, MAMI, in Germany and are 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. Our research helps to address basic questions such as: what is the origin of 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.

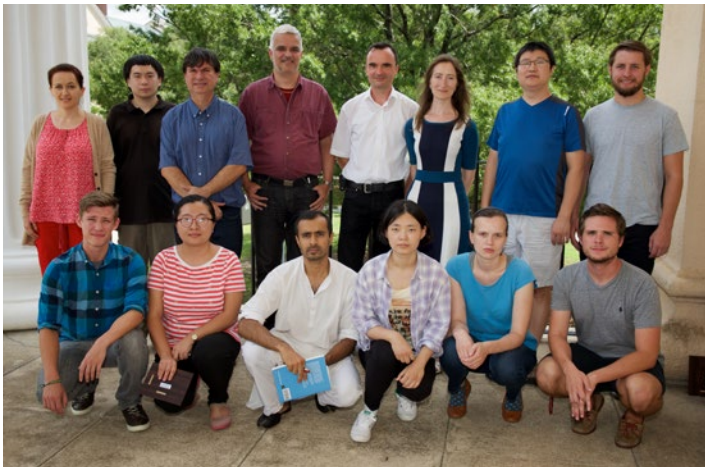


Figure 1: The USC Experimental Nuclear Physics Group. Front (from left): Chris McLauchlin, Ye Tian, Arjun Trivedi, Lin Li, Iuliia Skorodumina, Nick Tyler. Back (from left): Aneta Net, Hao Jiang, Nicholas Recalde, Ralf Gothe, Steffen Strauch, Yordanka Ilieva, Tongtong Cao, Colin Gleason. Not pictured: Gary Hollis.

In the past year, members of our group presented our research and findings in about 30 invited and contributed talks at national and international meetings and published more than a dozen articles on our collaborative research. We are very proud to announce that Tongtong Cao successfully obtained his Ph.D. degree in May 2016. Tongtong's Ph.D. research, Determination of the Polarization Observables C_x, C_z, and P_y for Final-State Interactions in the Reaction, was carried out under the supervision of Yordanka Ilieva. He is currently a postdoctoral fellow at Hampton University, where he will continue his research in hadronic physics and will undertake projects searching for physics beyond the Standard Model. Another outstanding achievement is that Ye Tian has been invited to this year's "Rising Stars in Physics" workshop taking place at MIT in Cambridge, MA. In recognition of the outstanding quality of their research, Ye and Tongtong were awarded the 2016 Graduate Student Research Award of the Department of Physics and Astronomy (see Figure 2).

Five different photo-production experiments at Jefferson Lab study the excited states of the proton with polarized beam and polarized frozen-spin target (FROST program). Our group is leading two of these experiments, in which we determine polarization observables in single- and double-pion-nucleon final states. The goal of these measurements is to obtain a better understanding of the structure of protons. In an analysis of our recent data, a group of theorists from Bonn University found, in fact, new evidence for a previously poorly known excited proton state. This past summer, we received funding recommendations for the full construction project for our Muon Scattering Experiment (MUSE) at PSI (S. Strauch). MUSE is a scattering experiment of electrons and muons off a cryogenic liquid-hydrogen target and aims to compare the extracted proton-charge radii for these two leptonic probes to study the Proton Radius Puzzle. Figure 3 gives an impression of the planned detector setup. Our group is going to build the time-of-flight, veto, and beam-monitor scintillator detectors for the experiment. Together with graduate and three undergraduate students, we built six prototype detectors and shipped them to PSI for testing under beam conditions.

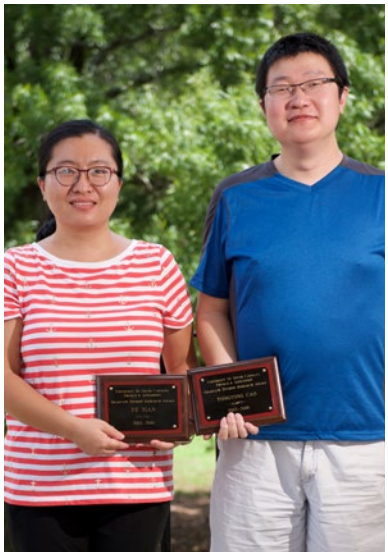


Figure 2: Ye Tian (left) and Tongtong Cao (right) shared the 2016 Graduate Student Research Award of the Department of Physics and Astronomy. Both of them use the deuteron as a lab and extract observables for elementary processes taking place on one of the bound nucleons. Ye and Tongtong made substantial contributions to solving the problem of nuclear effects on the observables of interest.

We have advanced forward our hardware projects. Our group plays a major role in the 12-GeV JLab upgrade project with the development and construction of a new addition to the Time-of-Flight (TOF12) spectrometer for the CLAS detector in Hall B and now four approved experiments on the electro-excitation of nucleons. Ralf Gothe is leading these efforts. During his sabbatical next year, he will stay at JLab and take part in the final commissioning of the CLAS12 detector. These are milestone achievements of our group that involved efforts over many years, not only of senior personnel, but also with assistance from a large number of graduate and undergraduate students.

As part of the JLab R&D efforts related to building an Electron Ion Collider (EIC), we are 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 T. We have secured funding to continue this activity in 2016-2017 through the collaborative proposal, EIC PID Consortium (Y. Ilieva). We will plan more measurements in Summer 2017. We also plan to begin implementing the sensor structure in Geant4 simulations to support the design optimization work of the manufacturers. Graduate student Colin Gleason and undergraduate student Corinne Barber contributed to this project.

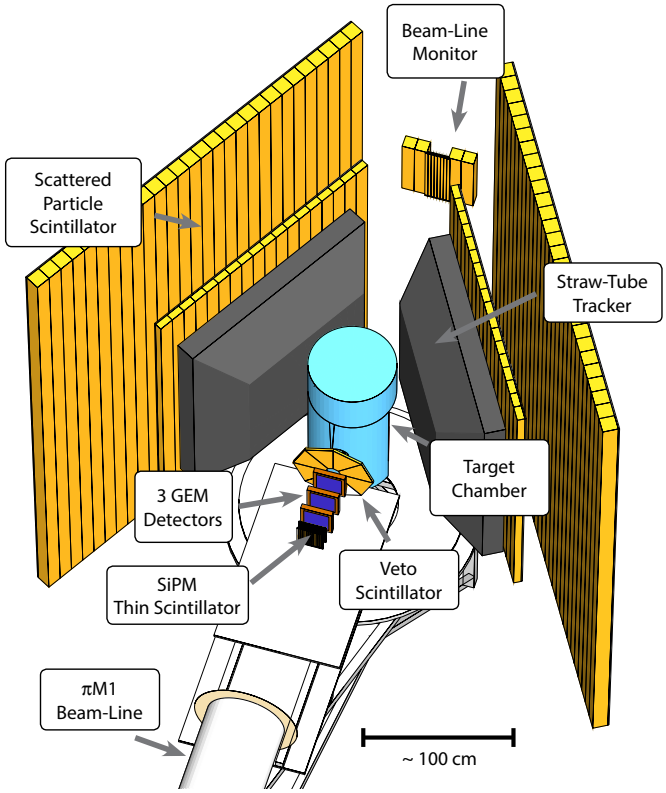


Figure 3: Rendering of the planned MUSE detector setup. The cartoon shows the setup as it is implemented in the MUSE simulation code, which our group has been developing. Our group is building the scintillation detectors (yellow) for the experiment at USC.

We have continued to invest significant efforts into mentoring and training of our junior personnel. Through regular weekly meetings and rigorous sessions throughout each year, we not only ensure that each student is progressing well in their research, but also provide training in preparation and delivery of oral and poster presentations, in preparation of job applications, as well as in writing competitive funding proposals. We have encouraged and supported our students to participate in conferences appropriate for their level where they can network with other professionals in the field, promote their work, and enhance their visibility. In the past year, our students have presented at meetings, such as USC Graduate Student Day, collaboration meetings, the semi-annual meetings of the Division of Nuclear Physics of the American Physical Society, the HUGS Summer School, Baryons 2016, The Gordon Conference on Photonuclear Reactions, and The Frontiers and Careers in Nuclear and Particle Physics.

High Energy Neutrino Group

By Sanjib Mishra and Roberto Petti

The focuses of the Carolina Neutrino Group are the NOvA and DUNE experiments. The group currently comprises two faculties, Prof. Sanjib. R. Mishra and Assoc. Prof. Roberto Petti; one postdoctoral fellow, Dr. Hongue Duyang; one graduate student, Bing Guo; and three talented undergraduate research assistants, Travis Dore, Edward Dunton, and Avery Freeman. Postdoctoral fellow Dr. Xinchun Tian got a new job in April 2016. Graduate student Libo Jiang graduated in May 2015, and, in November 2015, she begun a postdoctoral position at the University of Pittsburgh. Undergraduate student Tyler Alion worked at Fermilab (Batavia, IL) until the end of Summer 2016 and is now starting graduate school at the University of Sussex in the United Kingdom. We will also be acquiring a new graduate student in the near future.

NOvA Experiment

The NOvA experiment is designed to measure the oscillation of muon to electron neutrinos by comparing the electron neutrino event rate measured by a Near Detector (ND) located on the Fermilab site with that measured by a Far Detector (FD) located 810 kilometers away from Fermilab. The FD will see the appearance of electrons in the muon neutrino beam produced at Fermilab and the concurrent disappearance of muon neutrinos. The data analysis consists of comparing the measured event rates of different neutrino flavors in the 222 metric-ton ND and in the 15 metric-kiloton FD. An accurate measurement of the oscillation parameters in NOvA could shed light on the ordering of the neutrino mass states and on the mechanisms responsible for the matter/anti-matter asymmetry in our universe.

Carolina has been a founding member of NOvA. After a decade's worth of work, NOvA has been collecting data since 2014, and, in 2016, published the first measurements of neutrino oscillations using both the electron appearance and the muon disappearance channels. Even as the accuracy of the NOvA measurements is expected to increase substantially with the collection of larger statistics, the initial results already provided tantalizing insights on the oscillation parameters (Fig. 1). In addition, the NOvA experiment also measured some of the fundamental properties of neutrino interactions and cross-sections. The Carolina group's responsibilities on NOvA include Monte Carlo simulation, beam studies, data-acquisition system, and data analysis. Mishra, Petti, Duyang, and Guo work on NOvA.

In parallel with the major efforts in data analysis culminating with the first NOvA publications, we built a duplicate of the NOvA control room and installed it in our Physics Department at USC (Fig. 2). The Carolina control room, which was approved by the NOvA collaboration, is connected remotely to Fermilab and is used to monitor in real time the actual data taking of the experiment. The NOvA remote control room offers an invaluable learning experience for both undergraduate and graduate students, since it places them in direct contact with the core activity of a frontier research in High Energy Physics. They can interact with scientists, personnel, and students at Fermilab and follow in real time how neutrino interactions are selected, recorded, and reconstructed in the NOvA detectors.

DUNE Experiment

The Deep Underground Neutrino Experiment (DUNE) is a next-generation oscillation experiment with greatly increased physics sensitivity with respect to NOvA. The unique capabilities and accelerator infrastructure at Fermilab joined with a far

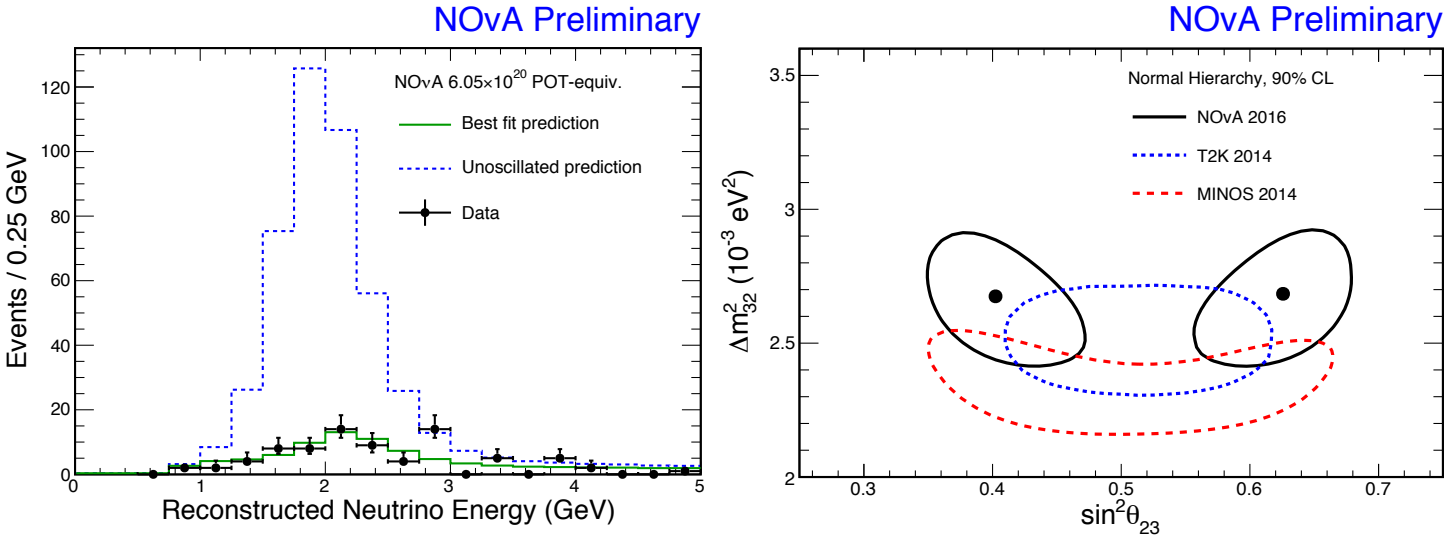


Figure 1: Preliminary results from the muon-neutrino disappearance analysis in the NOvA experiment at Fermilab. Left panel: measured neutrino energy spectrum (full circles) compared with the expected spectrum in the absence of neutrino oscillations (dashed histogram) and the best fit including neutrino oscillations (solid histogram). Right panel: allowed regions at 90% CL for the oscillation parameters consistent with the new NOvA measurement (solid line) compared with previous measurements from other experiments (dashed lines).

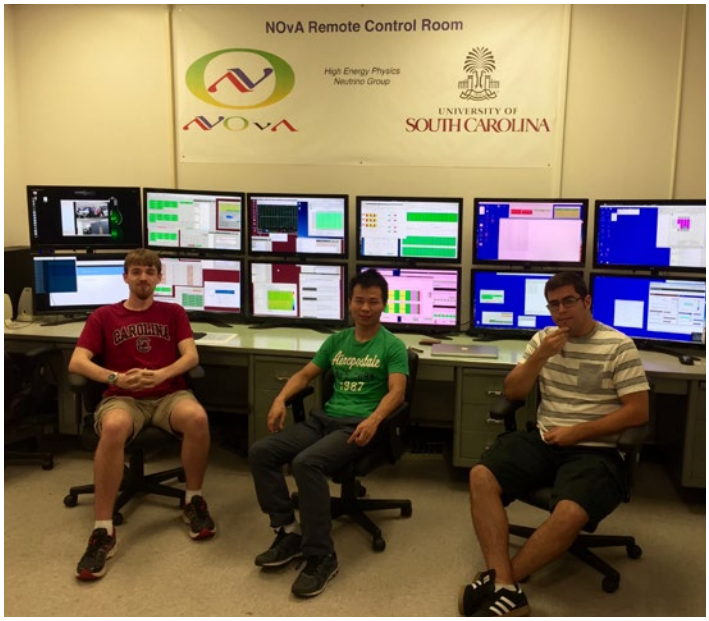


Figure 2: Graduate student Bing Guo (center) and undergraduate students Edward Dunton (left) and Travis Dore (right) monitoring, in real time, the data taking of the NOvA experiment at Fermilab from the remote control room operational at the Department of Physics and Astronomy at USC.

detector of 40 metric-kilotons located 1,300 km away at the Sanford Underground Research Facility (SURF) in Lead, South Dakota, present an extraordinary opportunity to develop a world-leading program of long-baseline neutrino science. This baseline distance, between near and far neutrino measurements, is optimal for oscillation studies and not currently available at any existing facility. The DUNE experiment plans to take physics data starting in 2023 - initially with a 1.2 MW beam, but later with a 2.3 MW upgraded beam. Since 2015, the DUNE evolved into a leading-edge international collaboration, including 890 scientists from 160 institutions and 29 countries. The Carolina group's commitment to the DUNE program has been deep and critical to its progress and success in achieving the various milestones during the preparation of the Conceptual Design Report (CDR) and the following external reviews.

Mishra and Petti proposed a high resolution near detector, the Fine Grained Tracker (FGT), as a generational advance in the investigation of systematic errors affecting the neutrino oscillation and mass measurements in the precision neutrino-interactions made possible by the unprecedented neutrino fluxes foreseen in DUNE. The DUNE collaboration has chosen FGT as the reference ND design and passed the Department of Energy CD1 approval stage in July 2015. The FGT detector (Fig. 3) comprises a 7 metric-tons high-resolution, low-density (0.1 gm/cm^3) straw-tube tracker (STT), surrounded by a fine-grained electromagnetic-calorimeter (ECAL) and embedded within a 0.4 T dipole magnetic field. Muon-detectors instrument the magnet and two stations downstream of the STT. The Carolina group along with Fermilab has been working with a consortium of Indian institutions, which proposed to the Indian funding agencies to design, R&D, and fabricate the FGT detector in India, which would then be shipped to Fermilab and installed in the DUNE near-detector hall. For the first time, the FGT detector would combine an accurate reconstruction of the momentum and energy of the particles produced in neutrino interactions, together with an increase in statistics by two orders of magnitude over past experiments. This detector would perform over 100 new measurements and searches, each surpassing the best previous result, and, in the course of a ten year operation, would result in over 300 publications and many potential physics discoveries. The Carolina group is expected to play a leading role in the R&D phase in preparation for the CD2 approval, which will last until 2018.

Mishra and Petti are leading the ND detector and physics groups in the DUNE collaboration. Duyang, Guo, Dore, Dunton, and Freeman are participating in the DUNE-related research.

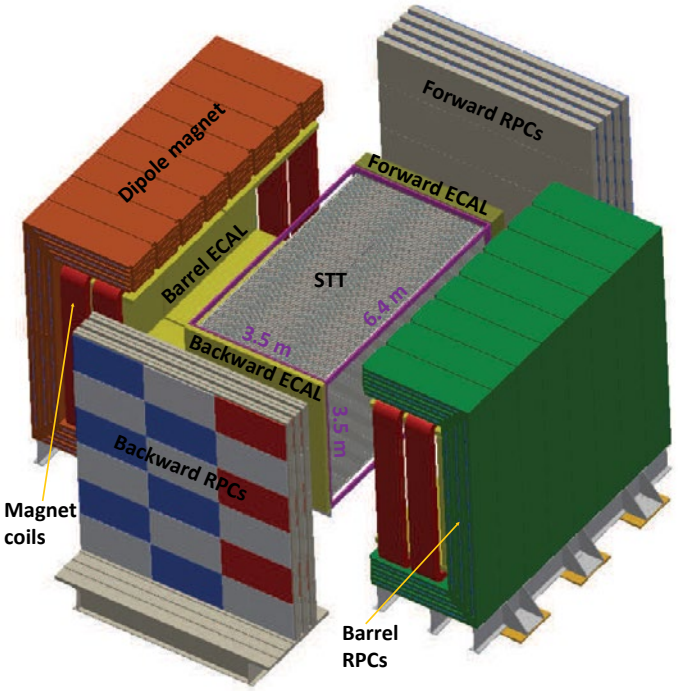


Figure 3: Schematic of the reference Near Detector of the DUNE experiment. The central Straw Tube Tracker (STT) is surrounded by a 4pi electromagnetic calorimeter (ECAL) placed inside a large aperture dipole magnet. Muon identification is provided by RPC located inside the iron yoke of the magnet and in the forward and backward regions.

Particle Astrophysics Group

Faculty: Frank Avignone, Richard Creswick, Vincente Guiseppe, Carl Rosenfeld, David Tedeschi and Jeffrey Wilson; Graduate Students: Christopher Alduino, Nicholas Chott, Clint Wiseman and Kevin Wilson, (Recent 2016 graduate Dawei Li).

Particle Astrophysics focuses on the study of phenomena in astrophysics and cosmology associated with the properties of elementary particles including neutrinos, axions and Weakly Interacting Massive Particles (WIMPS), a candidate 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 has been well established by Galactic Rotation Curves. The USC group was a pioneer in particle astrophysics when, in 1985, it led the first terrestrial search for CDM in the Homestake goldmine in Lead, South Dakota. This experiment used a unique detector developed in collaboration with the Pacific Northwest National Laboratory (PNNL). The results eliminated heavy Dirac neutrinos as the major component of CDM over a very large range of neutrino masses. Several Ph.D.'s from the particle astrophysics group have joined the PNNL staff.

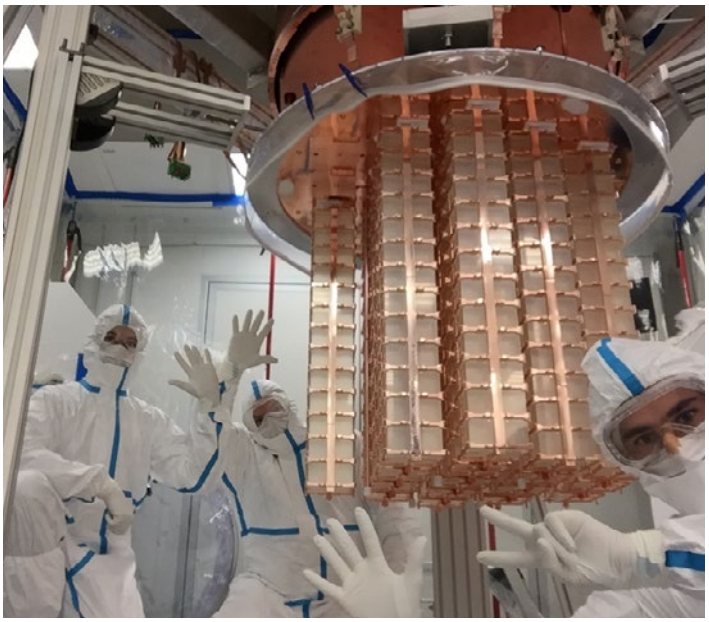
The Silver Jubilee of the publication of the seminal paper resulting from this experiment was celebrated in an international conference at the Pacific Northwest National Laboratory in June 2012. Following the publication of these results, a multitude of dark matter searches have been carried out all around the world, with vast improvements in detector technology. In 1994, Dr. Avignone was awarded the Jesse Beams Medal of the American Physical Society for his leadership in the experiment.

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 an international collaboration led by Rick Creswick. It uses the coherent Bragg conversion of axions to photons in single crystals to predict a characteristic time-dependent event rate. Other groups used this technique worldwide for solar axion searches. 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) nearing completion in the Gran Sasso Laboratory in Assergi, Italy. The USC group is leading a new search for solar axions produced by the atomic transitions in the core of the sun.

Our group is currently concentrating on two searches for the exotic zero-neutrino nuclear double-beta decay (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 decay would determine the absolute masses of all three neutrino-mass eigenstates.

The USC group was heavily involved in the CUORICINO double-beta decay experiment in the Gran Sasso laboratory from the very beginning until it was discontinued in July 2008. CUORICINO was an array of ~42 kg of TeO_2 cryogenic detectors operating at ~0.008-K. It set a lower limit on the half-life for the decay of ^{130}Te. A new experiment, CUORE-0 was completed in July 2015. Currently, the group is involved in the construction of CUORE, a 760-kg detector using the same low-temperature technique. The group's main responsibility was the fabrication of the electronic system led by Carl Rosenfeld. The USC group has maintained a presence at the Gran Sasso Laboratory year-round since 2002.

Our group is also playing a leading role in the Majorana Demonstrator, a 21-million dollar research and development project designed to establish the feasibility of building and operating a ton-scale ^{76}Ge double-beta decay experiment. The principal technology being used in Majorana is a vastly improved version of the IGEX experiment, which was led by the USC group in the 1990s. Funding for the ton-scale experiment will depend on the level of success of the Demonstrator project. In the last year, the collaboration has fully loaded the second of two detector modules and has begun operating the full detector mass of 45 kg (30 kg enriched in ^{76}Ge within a low background



The recently completed CUORE bolometer array shown earlier with two towers left to install.

shield). Physics Ph.D. student Clint Wiseman has spent significant time on-site preparing the detectors for their final deployment in the shield. He assisted in the careful loading and installation of the strings of Ge detectors that form the detector array inside the vacuum cryostat module. Clint plays a major role in the commissioning of the detectors in order to fine-tune the detector electronics and optimize their performance. Prof. David Tedeschi contributes to the commissioning activities, as well as leading the data production where he maintains a smooth transfer of the new data collected to off-site locations

for processing, as well as tracking the run status in real time through his custom run database. Asst. Professor Vincente Guiseppe leads the Majorana group at USC while managing the construction of the experiment's shield, which is now in its final stages of completion around the recently deployed modules.

MAJORANA Module #2 entering the shield where Module #1 is visible in the background.

Clint Wiseman is leading the analysis of the muon detector data and documenting its performance. He is building muon analysis codes in order to tag the rare muon-induced events we expect deep underground and couple the results with the analysis of the ^{76}Ge detectors. Clint is also studying the low energy response of the detectors to understand the sensitivity to new physics through the detection of dark matter interactions or the presence of solar axions. Clint will be presenting his work at an upcoming APS Division of Nuclear Physics annual meeting.

In 2012, Jeffrey Wilson joined the USC Particle Astrophysics Group bringing computational expertise in Monte Carlo simulations using GEANT and the most up-to-date data analysis techniques. He most recently worked on data analysis for the BaBar experiment at the Stanford Linear Accelerator Collider (SLAC) facility. Jeff is guiding Christopher Alduino and Nick Chott in their orientation to the CUORE computational tools.

For the past few years, the USC Group has been deeply involved in the major construction issues for CUORE-0, CUORE, and Majorana. Upon their commissioning, the role of the group will transition to mainly running shifts and analyzing data. In addition, the group is introducing a new concept of using the CUORE array to study the 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 essentially eliminate the background. Jeffrey Wilson is leading the team of Alduino, Chott, and Avignone in carrying out the complex simulations needed to compute the efficiencies of the many possible gamma-ray interaction scenarios and the design of the associated data analysis codes. Kevin Wilson recently joined the group. Kevin worked with Drs. Rosenfeld and Avignone; he played a major role in the fabrication of the CUORE electronics.

SmartState
SC Centers of Economic Excellence

Smart State Center

By Thomas Crawford

This past year, the Department of Physics and Astronomy and the Smart State Center for Experimental Nanoscale Physics suffered a terrible loss, with the passing of Smart State and John M. Palms Chair Professor of Physics, Richard A. Webb (1946-2016). Rich was at Carolina for 12 years, from 2004 until January 2016. During his time here, he designed, built, and oversaw a top-quality facility for nanoelectronics research, while simultaneously recruiting five current faculty members to Physics and his Center: Crawford, 2005, Bazaliy, 2006, Crittenden, 2007, Pershin, 2009, and Wu, 2012. He helped enable their success in building nanoscience research programs in diverse areas ranging from magnetism, to surface science, to photonics, to memristors, both experimental and theoretical. Over the past year, 33 personnel, 18 graduate students and postdoctoral fellows, 13 undergraduates, and two high-school researchers, conducted research within the Center, as well as five faculty associates from other departments and universities.

Rich received his B.A. from Berkeley in 1968, and his M.S. and Ph.D. degrees from UC San Diego, all in Physics. After a postdoctoral position at UCSD, and three years as a research physicist at Argonne National Laboratory, Rich joined the technical staff at the IBM T. J. Watson Research Center in Yorktown Heights in 1978, where he stayed until 1993. During his time at IBM, he won three Outstanding Technical Contribution awards, one for macroscopic quantum tunneling in single Josephson junctions, one for 1-d Mott variable range hopping in Si transistors, and, finally, for observing the Aharonov-Bohm effect in disordered metallic rings. For these discoveries, he received the American Physical Society's Oliver Buckley Prize for Condensed Matter Physics, the Simon Memorial Prize, and was nominated for the Nobel Prize in Physics. He was elected a Fellow of the APS in 1986, a Fellow of the AAAS in 1998, and was elected a member of the National Academy of Sciences in 1996. After leaving IBM, he was the Alford E. Ward Chair of Semiconductor Physics at the University of Maryland, from

1993 until 2004, when he came to South Carolina. The Center is planning a memorial symposium on low-temperature physics to commemorate Webb's contributions to condensed matter and nanoscale physics and begin the process of seeking a new chair to continue Rich's work here at Carolina.

During the 2015-2016 school year, Dr. Crawford was promoted to Full Professor, and Dr. Crittenden received tenure and was promoted to Associate Professor. Associate Professors Bazaliy and Pershin were on yearlong sabbaticals, Bazaliy at Institut Paul Sabatier, in Toulouse, France, and Pershin (supported by the Smart State Center) visited Dr. Franco Nori's group at RIKEN, Japan. Dr. Nori is the Group Director of the Quantum Condensed Matter Research Group (QCMRG), at the Center for Emergent Matter Science (CEMS), in RIKEN, which is the flagship research institute in Japan ranked among the top Japanese research institutions. RIKEN conducts research in many areas of science, including physics, chemistry, biology, medical science, engineering, high performance computing and computational science, and ranging from basic research to practical applications.

Assistant Professor Yanwen Wu helped revive USC's chapter of the Society of Physics Students, and under Wu's tutelage, these undergraduates participated in trebuchet and Rube Goldberg machine-building competitions during the past year. In addition, she assembled a group studying ultrafast optical properties of quantum dots and other plasmonic nanostructures.

Associate Professor Crittenden graduated his first Ph.D. student, Dr. Fiona Oberbeck-Oxsher (Ph.D. in Chemistry), this past May, for her work on a novel method of modifying the magnetic properties of nanoscale thin metal films, pioneered by a previous student of Crawford's. The Crittenden group also continued its work on the nanoscale measurement of surface-solvent forces.

With a NSF-funded collaboration in-place with the Andrew group in the Materials Science Department at the University of Florida, Professor Crawford's group has been aligning ferrite nanofibers using external magnetic fields and immobilizing them into polymer nanocomposites. In addition, Crawford continues to work with the Mefford group at Clemson, publishing articles in Advanced Functional Materials and (Nature) Scientific Reports in 2016.

MagAssemble™ LLC

MagAssemble, LLC company logo. The first start-up to commercialize center research received a NSF Phase 2 SBIR award that began on March 1, 2016. This 2-year, $735,000 award supports two full-time employees, both graduates of USC Physics and Astronomy.

The Center continues to partner with MagAssemble, LLC, its first start-up company, during 2015-2016, commercializing Crawford group nanomanufacturing technology. MagAssemble currently employs two USC graduates, Crawford group Ph.D. graduate Dr. Longfei Ye (chief scientist), and one of our B.S. recipients, Adam Fisher. Prior MagAssemble employee and USC Physics graduate Cameron Nickle is now working on his Ph.D. in Physics at the University of Central Florida. MagAssemble was awarded a NSF Phase 2 SBIR award, for $735,000 over two years, and continued to provide two full-time jobs during 2015-2016. In early 2017, MagAssemble will have funds to hire a second optical engineer to assist Ye and Fisher. In addition, MagAssemble is subcontracting several scientific investigations to Dr. Crawford, supporting two graduate students for two years. The Center continues to provide MagAssemble with imaging time on the Zeiss field-emission SEM in the USC Electron Microscopy Center, as well as use of the cleanroom and other Center facilities. To date, MagAssemble has raised almost $1,000,000 in external funds for operations in Columbia, South Carolina.

Theoretical Physics Group

Faculty Members: Brett Altschul, Vladimir Gudkov, Pawel Mazur, Matthias Schindler
Research Associate: Satoru Inoue
Graduate Students: Rasha Kamand, Camilo Posada-Aguirre

The Theoretical Physics Group has been quite active in 2016.

Working with her dissertation advisor, Dr. Schindler, and also with Dr. Altschul, Rasha Kamand finished up her research of Lorentz symmetry violation (LV) in chiral perturbation theory. Lorentz symmetry is the basic symmetry of special relativity, but it is ultimately an experimental question whether the symmetry actually holds exactly in nature. There are many excellent tests of Lorentz symmetry being done, but it can be difficult to interpret their results, particularly when the experimental observations are made on protons, neutrons, or other hadrons, because these are complicated composite particles, made up of smaller quarks and gluons. Chiral perturbation theory provides a way of studying the relationships between the coupling constants that govern LV for different types of hadrons, and, as a result of Rasha's recent work, some bounds of LV for pions have been improved by as much as ten orders of magnitude!

Dr. Altschul also spent the 2015-2016 academic year working with an undergraduate student from the South Carolina Honors College, Karl Schober. Karl was also working on a topic related to LV, studying the behavior of electric and magnetic fields in the presence of a new Lorentz- and CPT-violating magnetic self-interaction. This work formed the basis for Karl's Honors

College thesis, but it also led to two papers published in refereed journals, with him as the first author.

The postdoctoral researcher in the group, Satoru Inoue, who received his Ph.D. from the University of California at Berkeley in 2012, has also been working on fundamental symmetry problems. In collaboration with Dr. Gudkov and Dr. Schindler, Satoru has been looking at time-reversal invariance violation (TRIV) in nuclear systems. TRIV is an observed effect, but it is very small and has only been seen in a handful of systems. One manifestation of TRIV that attracts a lot of interest is the possible existence of electric dipole moments (EDMs) for fundamental particles, and Satoru has worked on understanding the possible EDM of the deuterium nucleus.

Dr. Gudkov and Dr. Schindler are also part of two collaborations studying TRIV in nuclei: the TREX international collaboration, located at Oak Ridge National Laboratory, and the NOPTREX US-Japan collaboration. These collaborations are pursuing tests of TRIV by measuring the transmission of polarized neutrons through polarized targets. These experiments will complement the results of ongoing EDM measurements and will increase sensitivity to TRIV.

Dr. Mazur and graduate student Camilo Posada-Aguirre are continuing their study of the theory of ultra-compact astrophysical objects carrying large amounts of rotational angular momentum. Such bodies are important test systems for modified theories of gravitation. A small, dense, rapidly-spinning astrophysical object will have strong gravity—meaning extensive curvature of space and spacetime—which is sourced not just by the mass density of the object but also by the angular momentum. These properties make them useful test environments for General Relativity and other, more exotic, gravitational theories.

SPECIAL ARTICLES

In Memoriam

With Contributions by Ron Edge and Horacio Farach

Over the past year, we mourned the loss of four distinguished faculty members who greatly contributed to the successes of our department through their combined expertise in both condensed matter physics and particle astrophysics. These included Dr. Jasper D. Memory, Dr. Charles P. Poole, Jr., Dr. John L. Safko, Sr., and Dr. Richard Webb.

Dr. Memory (December 10, 1936 – December 23, 2015) was the son of Jasper Livingston Memory and Margaret Durham Memory as well as a faculty member in the department at USC. During his time in Columbia, Dr. Ron Edge (Distinguished Professor Emeritus) connected with Dr. Memory on a number of occasions, including frequent collaborations with world-renowned physicist, Dr. Anthony P. French, who was department chairman during the 1950's. Dr. Edge recounts, "Jap's favorite game was squash. He and Tony French used to play when the NGB building was under construction." Years later, Dr. Memory transitioned to Raleigh, NC and was a professor of physics at North Carolina State University in addition to later serving as the Vice President for Research of the UNC System from 1986 to 1998.

Dr. Poole (June 7, 1927 – November 1, 2015) was the son of Charles Patton Poole, Sr. and Irene Hackett Poole. Prior to serving as a physics professor at USC, he obtained both a B.S. in Pre-Medicine and a M.S. in Physics from Fordham University (Bronx, NY). Shortly after, he also acquired his Ph.D. in Solid State Physics from the University of Maryland. His career not only spanned years in academia, but professional experience with Westinghouse designing microwave components for radar in addition to involvement with nuclear magnetic resonance (NMR) at the Gulf Oil Research Center in Pittsburgh, PA. Throughout the course of his life, Dr. Poole also published over 150 research articles and numerous books on a wide variety of condensed matter topics. Distinguished Professor Emeritus and close friend Dr. Horacio Farach remembers Dr. Poole as an incredibly diligent worker with a vast memory and wholly dedicated to his students and their long-term success.

Further details regarding the lives and legacies of Dr. Safko and Dr. Webb can be found on pages 18 and 12 respectively. Our thoughts go out to the families and friends of these colleagues who made very positive impacts on both the department, the University of South Carolina, and in their own communities over the last few decades.

Sources

Charles Poole Obituary. Dignity Memorial, 2015, www.legacy.com/obituaries/name/charles-poole-obituary?pid=1000000176301825. Accessed 21 Sept. 2016.

Jasper Memory Obituary. The News and Observer, 2015, www.legacy.com/obituaries/newsobserver/obituary.aspx?pid=177020420. Accessed 21 Sept. 2016.

Going Deep with the Majorana Demonstrator

By Clint Wiseman

For the last three years, I've been living under a rock, with neutrinos on my mind.

More accurately, I've been traveling out to the Sanford Underground Research Facility (SURF) in Lead, South Dakota, to work in one of the most unique laboratories on the planet: a class-100 clean room in a former gold mine, at a depth of nearly a mile. The mine used to be called Homestake, and for over 100 years, it sustained a community of gold miners in the Black Hills. Now, the mine has been closed and the tunnels host a variety of experiments, including a 20-million-dollar R&D project called the Majorana Demonstrator.

This morning, I walked onto a cage about the size of two normal elevators with 30 other people, all decked out in hard hats, cap lamps, boots, and coveralls over our clothes. Packed like sardines, shoulder to shoulder, we joked and talked on the 11-minute ride down to the lab. I watched the timber of the mineshaft go by, steel beams and wood, some almost 70 years old. The "shaft guys" maintain sprinklers in the shaft that spray water onto the wood so it doesn't rot. This can make the cage a very wet place when standing in the wrong spot. Most days, we don't give the cage ride a second thought. All the same, if you're not one to look down when you're on a high-dive, don't look up when you're in a mine. 4,850 feet is the equivalent of five Empire State Buildings. At the end of the ride and after a quick morning safety meeting, three of us walked through a tunnel over sixty years old into our new, brightly lit, modern lab space. Over the summer, we all put in overtime to bring a complex and expensive array of high-purity germanium radiation detectors online and operate them inside a multi-layered cosmic-ray shield.

The author testing a string of HPGe detectors. The electroformed copper making up the detector mountings was grown and machined underground at the Davis Campus of SURF.

Our corner of the 4850-foot level of SURF bears the

name Davis Campus. Ray Davis won the 2002 Nobel Prize in Physics for a neutrino experiment he began more than forty years earlier in the late 1960s. His "Homestake experiment" was an enormous tank of chlorine shielded from cosmic rays using the mile of rock above it. It counted the number of neutrinos emitted from the sun by utilizing a chemical reaction where an incident neutrino converts a chlorine atom into an argon atom. The result was provocative - he found only a fraction of the solar neutrinos expected from predictions. The discrepancy between theory and experiment lasted decades, and the resolution of the problem led to more Nobel Prizes and a series of new questions. Why do neutrinos have mass? Why do they oscillate between three flavor states? Could the neutrino be its own antiparticle?

The Majorana Demonstrator's goal is to pave the way to an answer to that last question. If the neutrino is its own antiparticle, then it is possible to observe an extremely rare nuclear decay process known as "neutrinoless double-beta decay." In double beta decay, an atom emits two electrons and two electron antineutrinos as it transitions to a lower energy state. The energy spectrum of beta decay is well-known for being very wide, as the energy in the decay is split between the electron and the neutrino. The elusive neutrinos escape the detector, and the scientists measure a wide range of electron energies. In the "neutrinoless" process, all the energy available in the decay is given to the electrons, which are detectable. The signature of this process is a very small peak at the end of the energy spectrum, which would tell us something new and fundamental about the neutrino despite never actually detecting one.

The Module 2 cryostat and 15,000-pound lead monolith (foreground) on its way from the assembly glovebox to its home in the main shield (background).

Unfortunately, the rarity of this process makes it an enormous challenge to observe. One has to start with the largest possible quantity of an isotope, which is known to double-beta decay. Majorana chose germanium-76, and a significant effort was led by Prof. Frank Avignone, his colleagues, and several contractors to enrich the raw germanium material and turn it into high-performing, high-purity germanium radiation detectors. Our detector array has 44 kg of active material, 29 kg of which has been enriched to 88% germanium-76. They are assembled in a nitrogen-filled glove box and are so sensitive that the radioactivity of a single human fingerprint on a detector would be a devastating source of unwanted background signals to the entire array. The detectors are crystals roughly the size of hockey pucks and cost around $200,000 a piece.

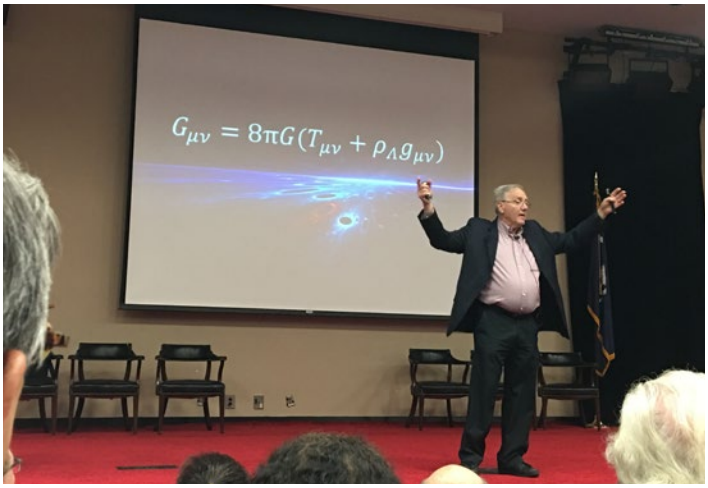
This is the fascinating aspect of double-beta decay experiments like Majorana. The source is the detector itself. The detectors are highly sensitive to outside influences and painstaking care must be taken to make their environment as radio-pure as possible. Only by taking the most sensitive radiation detector we can produce, surrounding it with ultra-clean materials, putting it in a lead shield the weight of a Boeing 737 aircraft, and burying the detector under a mile of rock, will we begin to get to the "background-free" environment we need to observe this process.

The lab's unique location and history have brought a host of guests down to the 4850. Reporters from Harper's and Symmetry magazines, NPR's Radiolab, CNN's Great Big Story and many others have all produced pieces on Majorana. The researchers underground often double as science tour guides to groups ranging from high school science classes and their teachers to Chamber of Commerce members, South Dakota state politicians, professional scientists, and, on one memorable occasion, Apollo 11 moonwalker Buzz Aldrin himself.

Over the years we've found many ways to have fun in the Black Hills after the novelty of Mount Rushmore and Devil's Tower wore off. We've played "open mic" nights, organized an impromptu concert in an abandoned school gymnasium, hiked up the aptly named Hill Street in the middle of a blizzard and four feet of snow to respond to an emergency underground, made friends with the locals, given public science talks, closed out the local brewery, eaten uncountably many breakfast burritos, and made friends from across the country and around the world.

It's been quite a ride.

For more information on the Majorana experiment, contact USC Professor Vincente Guiseppe.



Dr. Livio shares some of his own "brilliant blunders" with an audience of nearly 300 attendees at the public lecture event in the School of Law Auditorium (September 2016). Photo taken by Mr. Alex Mowery with the Midlands Astronomy Club.

The Distinguished Lecture Series in Physics and Astronomy

By Steven Rodney and Sam Beals

The fields of physics and astronomy have always provided fertile ground for the great luminaries of modern science. Ask anyone to name the most famous scientists in history and, invariably, you will get a list full of physicists and astronomers: Albert Einstein, Marie Curie, Isaac Newton. This remains true today, as advances in physics dominate the scientific headlines in the popular media, from the Higgs boson to gravitational waves to extrasolar planets. The faculty of the USC Physics and Astronomy department are closely connected with many esteemed researchers who are leading these world-changing advances and communicating their results to the public. In the Fall of 2016, our department launched a new "Distinguished Lecture Series" to bring such renowned scholars to the Columbia campus.

These new lectures will be a valuable tool for recruitment, will showcase our department to the community, and provide opportunities for cross-disciplinary interaction. Each speaker will present both a colloquium and public lecture to members of the university and broader Columbia communities. Colloquia will be given at a level approachable by undergraduates and the public lectures are targeted toward general audiences. The effort to establish this lecture series was led by Dr. Rodney, with key assistance from Department Chair Dr. Milind Purohit and Dr. Varsha Kulkarni. To launch the series this year, they secured financial support from the Office of the Provost and the Vice President for Research. Over the summer, Dr. Rodney and administrative assistant Sam Beals organized a broad campaign to promote the upcoming series on campus and across the Greater Columbia area.

The first lecturer was Dr. Mario Livio, an internationally renowned best-selling author, popular speaker, and a Fellow of the American Association for the Advancement of Science. From 1991 to 2015, he served as an astrophysicist at the Space Telescope Science Institute, which manages science operations for the famous Hubble Space Telescope. Dr. Livio's most well-known books include The Golden Ratio (2002), Is God a Mathematician? (2009), and Brilliant Blunders (2013). During his visit, Dr. Livio enjoyed a luncheon with undergraduate students in the South Carolina Honors College, tours of the USC campus and surroundings, and collaborations with departmental faculty, staff, and students. The public lecture event in the School of Law Auditorium even featured a book signing, which was sponsored by the USC Bookstore and Barnes & Noble College.

A book display positioned in the Ernest F. Hollings Special Collections Library (USC) showing some of Dr. Livio's most well-known works. Ms. Elizabeth Sudduth and Ms. Christine Nicol-Morris at Hollings were instrumental in creating the display.

In January 2017, the department will welcome Dr. Adam Riess for the second installment of the series. Dr. Riess is a Professor of Physics and Astronomy at Johns Hopkins University and shared the 2011 Nobel Prize in Physics for the discovery of the accelerating expansion of the Universe through observations of distant supernovae. He is continuing to make profound scientific contributions, with ongoing work to measure the current expansion rate of the universe (the Hubble constant) with 2% precision. Among his numerous accolades, Dr. Riess has been elected as a Fellow of the American Physical Society and the National Academy of Sciences. He is highly regarded for his classroom presence, public lectures, and commitment to community outreach.

Future lectureships are already being considered for the 2017-2018 academic year and all are welcome to attend these exciting events. More details can be found at *physics.sc.edu/lectureseries.*

Remembering John Safko

By Frank Avignone

In June 2016, we lost John Safko, one of the true pioneers of our department. John completed his Ph.D. degree at the Field Theory Institute at the University of North Carolina in 1964, and came directly to USC as an assistant professor. He studied general relativity under Bryce De Witt, who was in fact a student of Julian Schwinger. In those early days, theory in our department consisted of three theoretical physicists: Ed Lerner, John, and a year later, Jim Knight. In the summer of 1965, Mike Schuette, our department head, nominated John and I for Oak Ridge Institute for Nuclear Science (ORINS) fellowships, and we both were selected. We took our wives and children and moved to Aiken to work and study at the Savannah River Laboratory, where we shared an office for almost three months. There, I got my first real introduction to astronomy and cosmology. I can say first-hand that he was a natural teacher, and I was one of his early students. All of his students would agree that he was a great teacher.

In the Fall of 1965, John took over the astronomy teaching program with Colgate Darden and immediately began to conceive a method to gain a broader audience. He began to write a series of lectures that would soon become a self-paced astronomy teaching program. Writing the lectures, although itself a great challenge, was only the beginning. He had to publish a detailed study guide, set up a large volume computerized laboratory and an organization to support it. This course built the teaching FTE level that allowed us to build a modern Ph.D. granting research department. John ran the course like a Swiss watch; students had to perform their work at a continuous rate, so as not to cause a scheduling crisis during the last weeks. This took great management skill.

John Safko was indeed a scholar. He studied astronomy and cosmology and his outlet was teaching it. In the 1970s, he collaborated with Lou Witten (father of Ed Witten), and brought professor Witten to USC a number of times. This was very important to the intellectual growth of the department in those early days. A later example occurred when the Deep Supernova Search claimed discovery of the acceleration of the expansion of the universe. John was immediately ready to explain these findings in detail and to discuss the scientific impact. His clear explanations showed that he had delved deeply into the subject with his usual vigor.

John made a number of other scholarly contributions, among them were: Senior Editor, Classical Mechanics, McGraw-Hill Encyclopedia of Science and Technology, 2006 Edition, Instructor's Manual for W.K. Hartmann's Astronomy: The Cosmic Journey, wrote the Self-Paced Study Guide and Laboratory Exercises in Astronomy used in our astronomy program, wrote and published the Student Study Guide for Jones' and Childers' Contemporary College Physics, collaborated with Charles Poole in the latest edition of Goldstein's Classical Mechanics for Addison Wesley in 2002, and collaborated with his colleague, Jeeva Anandan, in editing Quantum Coherence and Reality, the proceedings of a conference by that name held at USC.

John was a Fellow of the American Physical Society, a Fellow of the American Association for the Advancement of Science, a Distinguished Professor from 2001-2002, and a Distinguished Professor Emeritus of our department. Such a pioneer and plank owner of this department will certainly be missed. He will be remembered for his many contributions and will be warmly remembered by all who knew him.

Melton Memorial Observatory

By Bryan DeMarcy

It was a fun and productive year at the Melton Memorial Observatory! We were able to get the main telescope (16-inch Cassegrain) working again after help from USC Alumni Alex Mowery, Heath Smith, and Jeffrey Stokes. We also had help from the USC maintenance department. This year was the first time we have used the telescope in over four years.

USC undergraduates enjoying food and good company at the dark site observing trip. This trip is held once per semester in Bethune, SC.

Once the equipment was working properly, our next step was to increase public night attendance. Sam Beals and Kelly Gibson have been instrumental with regards to advertising. The observatory now advertises our weekly public nights on social media, the Russell House Movie Theater hosted by Carolina Productions, the UofSC weekly newsletter, and the radio station 98.5 WOMG-FM. We also had an ABC Columbia camera crew visit in May to broadcast our public night on the 11 o'clock news. Public night attendance has increased significantly due to the additional advertisements. We went from having an average of 15 people per night to about 60 per night. In fact, we probably need to cut back on the advertising because public nights are starting to become too crowded for our small building.

The shaded region with the orange borders represents the path of totality. The entire US will see a partial solar eclipse; however, only the people inside this region will witness a total solar eclipse. The blue line signifies the path of longest totality. The time of totality increases as you approach the blue line.

Photo courtesy of Astrobites.org.

The spike in attendance would not be manageable without our wonderful student volunteers. USC undergraduate students Jeremy Day, Alexander Kirby, Will Mitchell, and Krystal Rolon attend almost every public night to educate guests on the beauty of astronomy. The success of our public nights relies heavily on the presence of these volunteers.

The light pollution from Columbia greatly restricts our view of the cosmos, though. For this reason, the department now puts together a trip every semester for students to observe under dark skies. The observing site is about 60 miles northeast of Columbia. It is not the darkest site on the continent, but we were able to see the Milky Way last year. These trips are open to members of SPS, the USC Astronomy Club, and Dr. Kulkarni's Honors College astronomy class. Our trip for the spring semester consisted of 44 USC undergraduate students. Along with our dark-site trips, we also take the above-mentioned groups to the South Carolina State Museum every semester. The museum visit consists of a private tour from curator Tom Falvey, a visit to the Boeing Observatory, and one planetarium show in the new BlueCross BlueShield of South Carolina Planetarium. These trips are a great way for students to learn about astronomy and physics outside of the typical classroom setting.

Astronomy has been in the news several times this past year. The detection of gravitational waves, Juno's arrival to Jupiter, SpaceX successfully landing the first stage of a Falcon 9 rocket, and the search for Planet X have been some of the biggest headlines. We also had a Mercury transit on May 9, 2016. The sky was covered in a light haze for most of the transit, so we weren't able to get any good images, but it was still great to witness this rare event. The next Mercury transit will occur on November 11, 2019.

Typically, summer vacation is a time to catch up on research and prepare for the upcoming fall semester; however, that won't be the case for us next summer. The astronomy group will be busy finalizing plans for the August 21, 2017 total solar eclipse. This eclipse has been nicknamed the "Great American Eclipse" because the path of totality starts in Oregon, stretches across the continental US, and finishes in South Carolina. Columbia lies very close to the center of totality, so we will have a great view, assuming the weather cooperates. The plans are still being worked out now, but Columbia could see many thousands or tens of thousands of visitors during the weekend of the eclipse. The eclipse also occurs during the USC Welcome Week events, so we should expect to see a large amount of the student body in attendance. This is the perfect outreach opportunity to teach students about physics and astronomy!

I was accepted as a transfer student to the Penn State Astrophysics program back in early May, so I will be shivering in the northeast winter. Recent M.S. graduate, Sean Morrison, will take over operations of the Melton Memorial Observatory and teach the observatory labs. I know he will do an excellent job. I wish everyone in the department all the best and I appreciate the help and guidance you have provided me over the years.

Astronomy Club

By Dakota Jones

The Astronomy Club at USC is a club devoted to all things astronomy and astrophysics. We aim to use the club to educate people on both the fields of astronomy and physics. We also seek to develop more interest in the study of astronomy and in the observation of astronomical events. We also work to raise awareness for upcoming astronomical events and use such events as platforms for educating.

The club is a member and a participation-focused group. Discussion around the presented topics or objects observed is encouraged. While we put emphasis on entertainment and interest, we put a large effort in making sure our members leave being more aware and informed about the science of astronomy. We also provide a safe and comfortable atmosphere for people

Astronomy Club members enjoy learning about the universe at a recent meeting on campus. The Astronomy Club became an official campus organization during the Spring 2016 semester and continues to promote an awareness of astronomy topics to students through a wide variety of programming.

to ask questions and learn more about various astronomy topics. We believe this is key to educating our members.

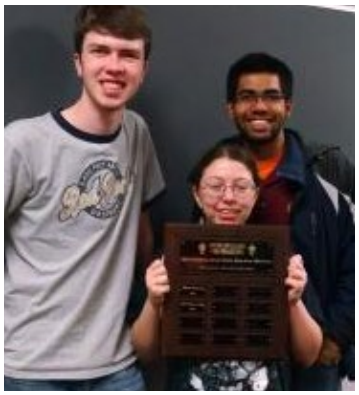
As a club, we hold three distinct kinds of meetings regularly. The first is a standard presentation and discussion meeting. In these meetings, an officer (usually the president) will present on a topic or a couple of short topics on recent astronomy news. The second kinds of meetings we hold are observatory nights. For observatory nights, we visit the Melton Memorial Observatory on the Columbia campus. We then use the telescopes available to show planets, the moon, or any available bright objects in the night sky. Our third kinds of meetings are dark site trips. A dark site is an area with significantly less light pollution. At dark sites, the night sky has greater visibility and is much clearer. In addition to clearer skies, there are usually many high-quality telescopes, and, often times, there are researchers attending with a high level of expertise.

Going beyond our general purpose, we are focused on making the club more entertaining while still maintaining our commitment to educate students in astronomy. We also wish to acquire external speakers to present topics and research that is about or related to astronomy. We also desire to further establish our club and increase our range of influence at USC. Ultimately, we seek to serve as a campus organization that provides reliable information on the universe around us, and, at least slightly, reduce the ignorance of those willing to learn.

News from the Society of Physics Students (SPS)

By Krystal Rolon

The Society of Physics Students (SPS) began the new academic year with high expectations. Upon reviving the chapter last year, students have enjoyed interacting with their fellow peers through participating in events, attending conferences, and studying together in the new student lounges. Dr. Yanwen Wu is currently the advisor for the organization and has encouraged students, especially those interested in physics, to use SPS as a way to better transition into college and challenging coursework. Many intimidating aspects of the shift include learning how to approach professors, becoming involved in undergraduate research, and developing professional skills needed for future careers. The group hopes to offer weekly presentations by students and faculty regarding how to navigate some of college's more difficult aspects that many have questions about, but are not always sure about who or how to ask.



From left to right are SPS members Tyler Strampp, Krystal Rolon, and Nabil Khan. They proudly present the first place award achieved for their Rube Goldberg machine at the annual Veeblefetzer Challenge hosted by the Theta Tau Zeta Delta engineering fraternity at USC.

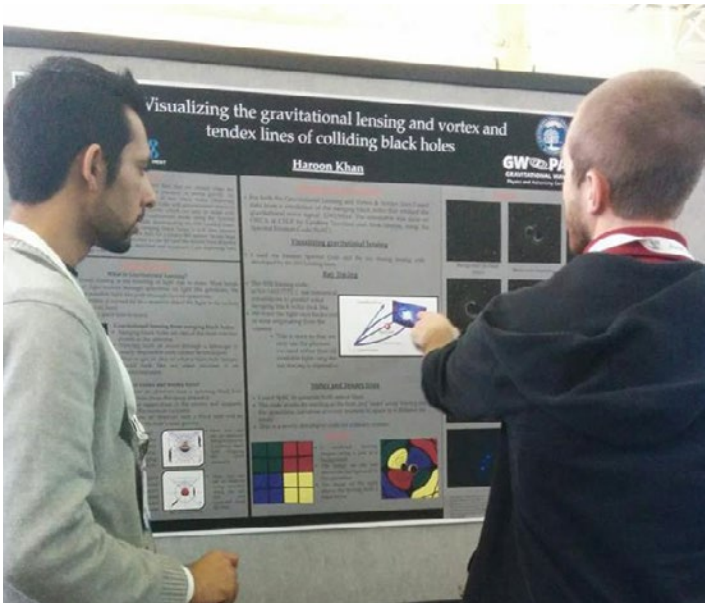
Students were able to attend several events including the American Physical Society conference, which met in Salt Lake City, UT in April 2016. Attendees had the unique opportunity to meet professionals working in various disciplines and sit in on educational presentations. One particular special experience included being able to witness the enthusiasm generated by the discussion of LIGO's announcement earlier in the year concerning gravitational waves. It was certainly an exciting time! Another highlight involved attending a public talk given by Neil deGrasse Tyson in Atlanta, GA, also in April 2016.

This year, there are plans to attend PhysCon, a conference specifically designed for undergraduate physics majors, along with the 229th Meeting of the American Astronomical Society (AAS) in Grapevine, TX. Throughout the year, SPS will encourage students to attend talks that include internship opportunities, information about graduate school, and career advice.

Outside of the classroom and events, the Society of Physics Students plans to engage with our local community through a wide variety of volunteer projects. You will likely see many of our members serving as mentors at the annual R.L. Childers

Midway Physics Day event at the South Carolina State Fair as well as participating in outreach activities that include assisting local Cub Scout groups with a Rube Goldberg machine.

More information regarding the SPS chapter at USC is available on our website, *www.physics.sc.edu/sps.* Also, feel free to follow us on Facebook, *www.facebook.com/UofSCSPS* for updates!

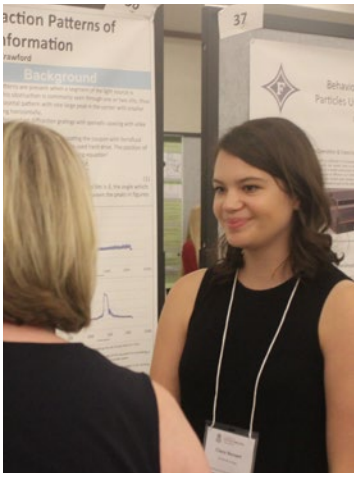


Haroon Khan (left), an undergraduate student at California State University (Long Beach, CA), presents his poster on gravitational lensing to USC student Bryan DeMarcy (right) at the APS April Meeting in Salt Lake City, UT.

News from the Research Experience for Undergraduates Program

By Brett Altschul

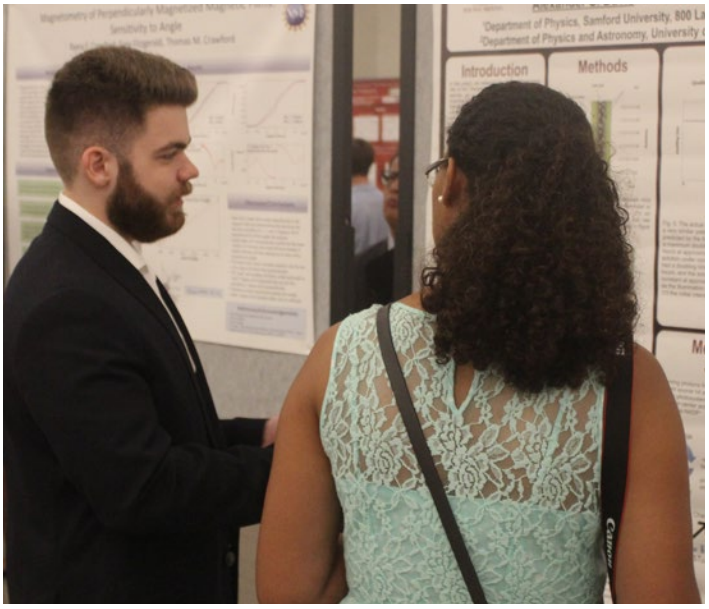
The summer of 2016 marked the third time the department hosted an NSF-funded Research Experience for Undergraduates, organized by Prof. Brett Altschul. This year, there were ten undergraduate participants. Two came from colleges and universities in the Carolinas, and more than half came from the Southeast, but there were participants from all over the United States.



Claire Bernert, a student at Occidental College, explains her work on magnetic materials.

For ten weeks, the cohort of students worked with faculty mentors, on projects dealing with astronomy, surface physics, particle physics, and mathematical physics. More specifically, Claire Bernert (Occidental College) worked with Prof. Crawford on Diffracting Data: Analyzing Diffraction Patterns of Magnetically-Recorded Information, Zachary Carter (Furman University) worked with Prof. Crittenden on Modeling the Behavior of Charged Particles in a Cloud Chamber, Raina Crawford (Bryn Mawr College) worked with Prof. Crawford on Magnetometry of Perpendicularly Magnetized Magnetic Films: Sensitivity to Angle, Alexander Davis (Samford University) worked with Prof. Crittenden on Response of Chlamydomonas Reinhardtii CC-125 Algal Cultures to Flashing Light in Thin-Plate Bioreactors, Phillip Kane (Grinnell College) worked with Prof. Crawford on Optimization of a Simple Projection Photolithography System: Impact of Exposure Parameters on Feature Size, Alexander Kirby (USC) worked with Prof. Kulkarni on Examining the Circumgalactic Medium of Low-Redshift Galaxies, Alexander Layton (University of Illinois at Urbana-Champaign) worked with Prof. Crittenden on The Effects of Temperature Parameters on Cloud Formation in a Tall Diffusion Cloud Chamber, Jo Lynn Tyner (Austin Peay State University) worked with Prof. Kulkarni on Observations of Sub-Damped Lyman-α; Absorber at z = 2.636, and Joseph Kroeger (Wingate University) and Brian Weaver (Pennsylvania State University) both worked with Prof. Altschul on Synchotron Processes with Lorentz Violating Dispersion Relations.

Each student prepared a poster explaining their work, which they presented at USC's university-wide undergraduate research symposium at the end of July.



Alexander Davis, a student at Samford University, presents his research on the biophysics of bacterial growth.

Using a bicycle wheel, undergraduate student Camille Yoke teaches students from Legacy Charter School about the conservation of angular momentum.

The R.L. Childers Midway Physics Day at the S.C. State Fair: Business as Usual in 2016

By Jeffrey Wilson

For the second year in a row, the state of South Carolina was hit by a historic weather event a little more than a week before Midway Physics Day. Hurricane Matthew skirted the coast on October 8 causing major flooding and extensive damage to large areas near the coast. Many Midlands area schools were used as evacuation shelters.

A week later, the Fair opened normally and we hosted our 20th Midway Physics Day event. Five of our registered schools from the lowcountry were unable to attend due to continued issues from the hurricane recovery process, but we still saw attendance by over 2,300 students from 55 schools.

About half of our mentors were freshman physics students and were able to have their first fair experience. Dorian Gothard, Gabby Herrin, Nahid Shayesteh, Heath Smith, and Camille Yoke got to run some of our more popular hands-on demos, which included the rotating table, the vibrating spring/wave demo, and the magnetic braking/induction tube. Chatura Kuruppu (graduate student) was our only repeat student mentor from last year, and, of course, we had our faculty regulars: Dr. Myhrer, Dr. Tedeschi, Dr. Wilson, and Dr. Wu. Also, many thanks to our lab manager, James Clawson, who assembles our

Physics undergraduate Gabby Herrin uses a series of induction tubes to demonstrate the principle of magnetic braking to curious high school students.

demo apparatus every year, and helps ferry it out to the Fair, as well as mentoring one of the demos.

We are happy to have another Physics Day in the books, having furnished another rewarding experience to thousands of high school students and their teachers across the state of South Carolina.

Alumni Notes

By Kenneth Galloway

January 8, 2016

I have just read Quantum Leap 2015, and, reflecting on the passage of time, was prompted to write. Fifty years ago this month, I completed a Ph.D. in physics at USC and moved to a post-doc at Indiana University. I have always looked back at my time in the USC Department of Physics and Astronomy with great affection. I enjoyed the camaraderie of an outstanding group of graduate students and benefited from the dedication of a terrific faculty. In Fall 1967, I joined the IU faculty as an Assistant Professor, and, soon after promotion to Associate Professor, left to work for the U.S. Navy on radiation effects on solid-state devices. I joined NIST (then the National Bureau of Standards) in 1974 and served as a Division Chief in semiconductor electronics from 1980 to 1986. During this period, I also served as a Professor of Electrical Engineering (part-time) at the University of Maryland. In 1986, I was named Professor of Electrical and Computer Engineering at the University of Arizona and Head of the ECE Department. After 10 years in Tucson, I came to Vanderbilt (my UG school) as a Professor of Electrical Engineering and as the Dean of the School of Engineering, serving as Dean until 2012 (16 years). Along the way, I was elected as a Fellow of the IEEE,

the APS, the AAAS, and the ASEE. I am still teaching and active in research, but do have plans to gracefully glide toward retirement. On the personal side, Dot and I have very much enjoyed each of the places we have lived. We love to visit our children and grandchildren in Maryland and Pennsylvania and we enjoy the privilege of travel. All in all, my USC physics Ph.D. has served us well and I will always be grateful for the opportunity and experience of graduate study at USC.

Kenneth F. Galloway
Distinguished Professor of Engineering
Vanderbilt University

Photograph courtesy of the School of Engineering at Vanderbilt University (Nashville, TN).

ATTENTION ALL ALUMNI OF THE DEPARTMENT OF PHYSICS AND ASTRONOMY!

We will continue to include news from our past graduates in future editions of Quantum Leap. In our "Alumni Notes" section, you can let your classmates know what is new with you and find out what is happening with your fellow alumni.

To be listed in our "Alumni Notes," please take a few moments to share with us your educational and professional accomplishments, personal adventures, and more!

Notes can be submitted to us via e-mail at:

alumninews@physics.sc.edu

Looking forward to hearing back from you and best wishes always!

Quantum Leap

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Space Elements imaged by Alex Mowery from the Melton Observatory

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