Quantum Leap
University of South Carolina
Department of Physics and Astronomy
2015

UNIVERSITY OF SOUTH CAROLINA

A New Face

Steve Rodney received his Ph.D. from the University of Hawaii at the Institute for Astronomy and moved on to a postdoctoral position at Johns Hopkins University in Baltimore, MD. His graduate work was aimed at wide-field surveys using ground-based telescopes situated in Hawaii and Chile. These observatories are opening up new areas of study in time domain astronomy by rapidly surveying large swaths of the sky every few days. As a Hubble postdoctoral research fellow at JHU, Steve finally got his eyes above the atmosphere, as he became a leader in several multi-year surveys using the Hubble Space Telescope to search for distant stellar explosions.

When a white dwarf star explodes, it can be seen across the cosmos as a Type la supernova, rising in brightness over a few weeks to reach a well-calibrated peak luminosity. Astronomers use these "standard candles" to measure cosmic distances from nearby galaxies to many billions of light-years away. With those distance measurements, we can then test cosmological models and constrain the nature of the "dark energy" that is driving the accelerating expansion of the universe. Steve has used the Hubble Space Telescope (HST) to find many of the most distant Type la supernovae known, including some that exploded just a few billion years after the Big Bang. He is now working with collaborators at Johns Hopkins and the University of Chicago, using these supernovae from the early universe to test for evolution of dark energy, and to examine whether the supernovae themselves are consistent from the early Universe to today.

In recent years, Steve has turned his attention to new searches for supernova explosions that appear behind massive galaxy clusters. These clusters of galaxies are the most massive gravitationally bound structures in the universe, containing dozens to hundreds of galaxies, but most of their mass is in the form of unseen and poorly understood dark matter. The gravitational potential from the cluster's dark matter halo is strong enough to bend the light from distant stars that happen to be aligned along our line of sight directly behind the cluster. This leads to the remarkable and beautiful phenomenon of *strong gravitational lensing*, in which the cluster acts very much like an optical lens, magnifying and distorting the images of background galaxies. Steve is one of the leaders on a joint team of supernova searchers and lensing experts that discovered a unique object in 2014: the first ever strongly-lensed supernova resolved into four separate images. The object, nicknamed "SN Refsdal," is projected to reappear in the next year with a fifth image, offering an unprecedented opportunity to test gravitational lensing models. Steve and his colleagues will be watching for the return of Refsdal with ongoing HST observations, and are launching new initiatives this year that aim to find more of these strongly lensed explosions.

Steve and his wife Megan, both originally from Cleveland, Ohio, are not terribly sorry to be leaving those cold northern winters behind. They have two children, ages 3 and 6, whose artwork adorns Dr. Rodney's office on the 7th floor of the Jones Physical Science Center.

More on Distant Type Ia Supernovae:
http://www.nasa.gov/mission_pages/hubble/science/exploding-star.html

More on SN Refsdal and Gravitational Lensing:
http://hub.jhu.edu/2015/03/11/split-supernova-exploding-star

Message From The Chair

This year I'm delighted to introduce to you our newest faculty member who has had a distinguished career in the short few years since his Ph.D. from the University of Hawaii at Manoa. Steve Rodney, an astronomer, comes to us from the Department of Physics and Astronomy at Johns Hopkins University where he was until recently a Hubble Postdoctoral Research Fellow. At Johns Hopkins, Steve led the execution of the CANDELS and CLASH Supernova programs, using the Hubble Space Telescope (HST) to study Type Ia Supernovae (SN Ia) at high redshifts. These surveys have discovered many of the most distant supernovae yet seen. Steve is now expanding this work as PI of the Frontier Field Supernova search, a 3-year HST survey that uses massive galaxy clusters as cosmic telescopes, magnifying the light of distant SN to reach even farther back into the early universe and studying dark energy, dark matter, and supernovae. We are lucky indeed that Steve is also an excellent teacher. Teaching since his graduate student days, he has also led two short-term instructional programs and mentored graduate students at Johns Hopkins. Steve gave an excellent talk earlier this year and explained everything from gravitational lensing, SMBH's, AGN's, standard candles, and more. Steve's teaching interest extends from using clickers in classrooms to loaning out Galilean telescopes to students and trying out "flipped classrooms". Great physics departments are built by the accretion of great people, and I have confidence that the addition of this latest star brings us closer to critical mass.

Other news from the last academic year include hosting of the meeting of the South Eastern Section of the APS (SESAPS) here in Columbia with Profs. Crawford and Schindler leading the big effort required. Generous support was provided by our Nanoscale Physics program, and I would like to thank Prof. Webb for that. Prof. Kunchur was awarded the George B. Pegram Medal from SESAPS for Excellence in Physics Education in the Southeast U.S. Around the same time he was also honored as a state winner of the U.S. Professors of the Year Awards Program, and we're very proud of his accomplishments. Two graduate students, Anton Kravchenko and Bochen Zhong won the Graduate Student Research and Teaching awards, respectively. Congratulations also to our Administrative Coordinator, Ms. Beth Powell, who was one of only three people across the college winning the Classified Staff Excellence Award this year. I thank her for years of diligent and selfless work for our department; as the Dean rightly quoted one of Beth's nominators, she is the heart and soul of this department! Last, but not least, I would also like to take this opportunity to welcome two new staff members, Kelly Gibson and Sam Beals, to our office this year.

Carolina Connections To The 2015 Nobel Prize In Physics

By Timir Datta

The Royal Swedish Academy of Sciences has announced the 2015 Physics Nobel Prize winners: Professors Takaaki Kajita and Arthur B. McDonald were awarded "for the discovery of neutrino oscillations, which shows that neutrinos have mass." We are very proud to recognize the fundamental contribution of our own Professors Vladimir Gudkov and Kuniharu Kubodera to the study of neutrino oscillations. Profs. Gudkov and Kubodera provided values of the total and differential cross sections that were essential in the analyses of the experimental data by Dr. McDonald's group at the Sudbury Neutrino Observatory (SNO). In particular, the Physical Review C article [S. Nakamura, T. Sato, V. Gudkov and K. Kubodera, Phys. Rev. C, 63, 034617 (2001)] was directly cited in the SNO collaboration's discovery announcement.

The impact of USC physicists on the studies of neutrinos has a long history. For instance, Prof. Frank T. Avignone's contributions to the detection of neutrinos were acknowledged in a 1980 publication of Dr. Frederick Reines; Dr. Reines was a pioneer in the field and a co-winner of the Physics Nobel Prize in 1995.

Currently, our Department's exciting research in theoretical and experimental neutrino physics is carried out by Profs. Sanjib Mishra, Fred Myhrer, Roberto Petti, and Carl Rosenfeld.

We congratulate all of our "neutrino" colleagues for the recognition of their field by the Nobel Prize Committee and we wish them lots of success in their endeavors!

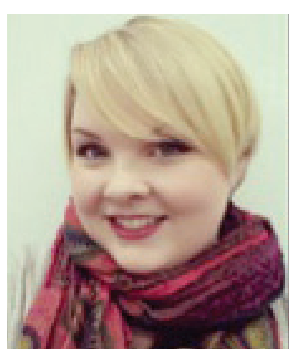
Staff News

It's hard to believe another year has already passed since our last newsletter. The staff has seen some big changes in the past year. Our biggest news is the goings and comings of staff members.

Mandy Davis left at the end of June to begin her studies in osteopathic medicine at the Edward Via College of Osteopathic Medicine (Carolinas Campus). We wish her all the best and know she'll do great!

At the beginning of July, Evelyn Wong transferred to the School of Visual Art and Design to be their Graduate Student Services Coordinator. We really hated to see Evelyn leave our department, but certainly couldn't argue with her doing something involving her love of art.

Along with the rest of the department, the staff was excited to welcome Kelly Gibson as the new Student Services Coordinator and Sam Beals as the new Administrative Assistant. They have both jumped right in to their new positions and have proven to be quick learners. This has come in very handy since they had the advantage (or maybe disadvantage) of coming in at the busiest time of year!



Kelly Gibson came to us in August from right here in Columbia, by way of South Korea. She was born and raised here and got her degree in Theater from USC. After college she decided to embark on an adventure, and went to teach English in South Korea for a year or two; that ended up turning into five. While living there, she taught English in Private Kindergartens and Public Elementary and Middle Schools. She was also able to travel to many countries in South East Asia. And yes, she speaks Korean. Kelly returned from her travels in March of this year, back to her hometown, and is so happy to be working for her Alma Mater. Feel free to pop by her desk to see her pictures from Asia, sit in her cozy chair, and chat about Korea or Hello Kitty.

Sam Beals arrived in September and graduated with honors from Anderson University (SC) in 2010 with a Bachelor of Arts in History. While he has numerous historical and research interests, his main areas of study are Medieval Europe and the Protestant Reformation during the sixteenth century. Over the past few years, he managed a local The UPS Store franchise and quickly discovered how much he enjoyed working with people and developing specific solutions to fulfill their personal and business needs. He also previously worked at the South Caroliniana Library and Thomas Cooper Library when he took summer courses during his undergraduate years. In his free time away from the office, he enjoys spending time with family and friends, serving at his church, volunteering in the community, music, and writing. Sam is excited to be back on campus and learning the detail-oriented work of his new position!

Beth Powell was one of three recipients of the College of Arts and Sciences Classified Staff Excellence Award for 2014-2015. She was truly honored to receive the recognition.

Lisa Saxon, James Clawson, and Robert Sproul have remained as busy as ever keeping the department going. We are grateful to have such a wonderful team!

News From The Graduate Director

New Students:

The Physics Department welcomes students from Turkey and Nepal as well as the U.S. We now have two Ph.D. students from Nepal and are happy to report that both their families were unharmed in the recent earthquake there.

Nicolas Recalde has returned to physics after working in the field of medical physics for several years. He is studying the newest generation of therapeutic radiation sources under the guidance of Professor Steffen Strauch.

Ph.D.:

Anton Kravchenko (Prof. Purohit) completed his Ph.D. during the last year.

Scholarships And Awards:

Anton Kravchenko, who is working with Professor Purohit, received the "Graduate Research Award" and Katia Gasperi received the "Graduate Teaching Award" for 2014-2015.

Hongyue Duyang received the "University Research Association Award" to support his research at Fermilab. Ye Tian was awarded a Jefferson Lab Graduate fellowship for 2014-2015. Dheyaa Alameri has a fellowship sponsored by the government of Iraq.

Five students are supported with GAANN (Graduate Assistance in Areas of National Need) fellowships funded by the Department of Education.

News From The Director Of Undergraduate Studies

The major challenge we faced this past year was the management of the significantly increased student population in our introductory classes. The undergraduate enrollment at the University has skyrocketed in the last 8 years, going from 19,000 in 2007 to 25,000 this year - a 31% increase. While this has brought many advantages to USC, it has also placed a huge burden on various departments and schools. For us, that meant keeping up with the demand for our courses. Fortunately, we received help. This year, the College of Arts and Sciences, along with the Evening College, agreed to fund a new instructor position in our Department, which we filled by hiring Dr. John Cook. Our request for larger classrooms for the main sections of our 200-level courses was granted. With these two changes this fall, we finally had a semester that started with seats still available in our classes so that we didn't have to turn anyone away. Unfortunately, to get the lecture halls in the sizes we needed, some of our courses had to be moved to other locations on the Columbia campus. We will no longer have the comfortable situation of teaching all of our courses in our own building – this has been an adjustment for everyone.

In addition to these changes in our Physics courses, we discontinued the Astronomy Center in the Fall of 2014. As every ending turns out to be a new beginning, this created a new and exciting opportunity for our faculty and students. Professor David Tedeschi created a new course – Astronomy 101: "Introduction to Astronomy," which was taught starting in the Fall of 2014, after a small test run during the summer of that year. It was very popular with non-science majors. Next spring, our new colleague, Professor Steven Rodney, will teach a second freshly-minted introductory course - Astronomy 201. Professor Rodney has also done an outstanding job to adapt our Astronomy minor program to these changes.

On the Physics-major front, we had 11 graduates last year and another record-setting number of declared physics majors (115 at last count). In the Spring of 2016, Professor Scott Crittenden will be teaching his Biophysics lab course for the second time – a nice addition to our standard course cycle involving optics, condensed matter, and nuclear physics.

Undergraduate Awards

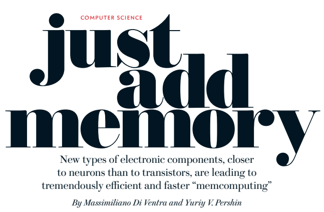
The undergraduate Physics award winner in the 2014-2015 academic year is **Nolan Miller**, who won the Nina and Frank Avignone Fellowship.

In addition to the Physics awards, several physics students received awards from other departments: **Elizabeth Yankovsky** received the Joseph R. Leconte Outstanding Senior Award in Earth and Ocean Sciences; **Karl Schober** received the James Bruce Coleman Mathematics Scholarship; **Tanner Pearson** received the Lovelace Family Endowed Scholarship; **Nolan Miller** received the Thomas Markham Mathematics Scholarship; **Kyle Lackey** received the Jeong S. Yang Award for Excellence in Undergraduate Mathematics; **Travis S. Dore** received the Department of Philosophy Rising Senior Award.

Congratulations to our outstanding undergraduate physics students! We are very proud of you all!

Experimental Nanoscale Physics: The Smart State Center

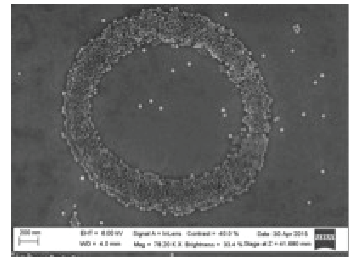
The Smart State Center for Experimental Nanoscale Physics has had another exciting year. In November 2014, the Center sponsored the Annual Meeting of the Southeastern Section of the American Physical Society (SESAPS) (Center member Thomas M. Crawford was the local organizer together with the Department's Prof. Matthias Schindler). 231 physicists attended the meeting (74 full members, 50 graduate students, 7 retired members, 13 non-members, and 87 undergraduates), which received 168 abstracts (34 invited, 70 contributed oral, 64 contributed posters). The conference sessions covered topics on nanotechnology, solid-state physics, and bio-magnetism (convened by Crawford).



Frontpiece from Prof. Pershin's article on memcomputing

During the past year, Center faculty wrote a number of review articles suggesting that the Center is having broad impact, both within and outside South Carolina. Prof. Crawford was invited to author an article on magnetic field-directed self-assembly to be published in the Springer Encyclopedia of Nanotechnology (publication imminent as proofs have been returned), as well as a book chapter on magnetic patterning for a forthcoming CRC book on Biomagnetism. Prof. Crittenden co-authored a review article in Modern Physics Letters on dielectric measurements at the nanoscale using Atomic Force Microscopy. Prof. Pershin wrote an article on novel memory systems for future computers that were published in Scientific American (see front page at left).

In addition, Center faculty mentored 27 students and 2 postdoctoral associates over the past year: 14 Physics graduate students as well as one Chemistry student and one in Electrical Engineering, 8 undergraduate students, and 3 high school students. One of Crawford's undergraduates, Tanner Pearson, entered the Physics Ph.D. program at Cornell University in Fall 2015. During the coming year, the Center intends to recruit both a full-time Technician and a Research Assistant Professor in Low Temperature Physics.



2.5 micrometer diameter toroidal magnet assembled from 30 nm diameter magnetic nanoparticles using perpendicular recording medium (Crawford group)

With the Helium liquefier operational together with a high pressure Helium recovery system, the Webb group (Webb plus graduate students Bochen Zhong, Ning Liu, Ken Stephenson, and Shawn Draper) are performing low temperature transport studies of tunnel junctions, graphene films, and semiconductor materials for photovoltaic applications.

Professor Yanwen Wu has 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 has assembled a group studying ultrafast optical properties of quantum dots and other plasmonic nanostructures.

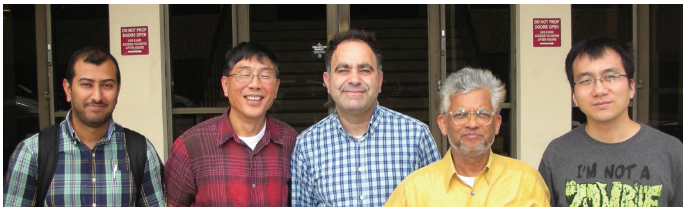
With a new NSF-funded collaboration in-place with the Andrew group in the Materials Science Department at the University of Florida, Professor Crawford's group has been aligning ferrite nanofibers using external magnetic fields and immobilizing them into polymer nanocomposites. In addition, Crawford continues to work with the Mefford group at Clemson, most recently assembling magnetic nanoparticles into micrometer-sized structures (see SEM image at right of a toroidal micromagnet self-assembled from individual 30 nm magnetic nanoparticles).

MagAssemble LLC company logo. The first start-up to commercialize center research received a NSF SBIR phase 1 award that began on July 1, 2014, as well as matching funds from SC Launch and a SBIR Phase 1B award from NSF.

During the past year, Center's first start-up company, MagAssemble LLC, commercializing Crawford group's nanomanufacturing technology, with two USC graduates as employees (Crawford group Ph.D. graduate Dr. Longfei Ye, and one of our B.S. recipients, Cameron Nickle), in addition to $150,000 from NSF-SBIR received $50,000 in matching funds from the South Carolina Research Authority (SCRA) through SC Launch, and a NSF SBIR Phase 1B award for an additional $25,000, for a total of $225,000 awarded during the past year. As part of their Phase 1/Phase 1B project, MagAssemble successfully demonstrated an 80% efficient phase diffraction grating based on Crawford's nanomanufacturing research, and booked its first official sale, to OpTek Systems, Inc., a Greenville based optical fiber machining company. MagAssemble demonstrated a prototype fiber-based optical splitter at the 2015 Optical Fibers Conference, attracting interest from telecommunication companies such as Finisar and Furukawa Electric, as well as with Spectrometer manufacturer Ocean Optics, Inc.

Condensed-Matter Research Brings New Solutions to Old Problems

Faculty: Dr. Timir Datta, Graduate Students: Lei Wang and Dheyaa Alameri



Group photo taken in August: Present (Left to Right) are Dheyaa Alameri, Ming Yin, Erdogan Ozel, Timir Datta, and Lei Wang.

The spatial resolution that can be achieved using any kind of waves is limited by diffraction. This limit is specific to the details, but can be loosely related to wavelength (λ) through Ernst Abbe's famous formula of 1873. Remarkably, by incorporating quantum mechanical processes such as fluorescence, this limit was surpassed in the atomic-resolution microscopy technique that won the 2014 Chemistry Nobel Prize.

We are working on a non-fluorescent alternative optical strategy for 'super resolution.' Super-resolving techniques can be extremely useful in our gravitational experiments, which we carry out in collaboration with David Tanner's group at the University of Florida. In summer 2015, Erdogan Ozel, a former graduate, was a visiting researcher in our group on this project. He was at USC with funds from the Turkish government and has since returned to teaching at the University of Balikesir in Turkey.

Physics Nobel Prizes for 1914 and 1915 were awarded to Max von Laue and Lawrence Bragg and William Bragg in recognition of their work on X-ray diffraction. In a recent paper, Timir Datta showed that Laue's three-dimensional diffraction and Bragg's 2-D reflection represent the exact same physics. Bragg's eponymous law mathematically follows from an invariance of Laue's equations. This article appeared in a March (2015) issue of Physica Scripta, and the publisher, Institute of Physics (IOP), recognized this article as the 'paper of the week.'

Energy, and how to harvest useful forms of energy, is a perennial physics topic. On account of the fracking boom, currently there is a petroleum glut and oil prices are at record low. But in the energy equation, dollar cost is just one parameter; impacts of energy usage and power generation on the environment and sustainability are huge factors. The laws of thermodynamics demand that about two-thirds of the total used energy (~65%) is released back into the environment. Just imagine the positive impact, if say 15-20% of this wasted thermal energy can be clawed back!

Because the lost energy escapes only in the form of heat, recovery by direct conversion, such as thermoelectricity, is optimal. Thermoelectricity is also the only long-term option for spacecrafts that venture deep into the solar system and beyond. Coincidentally, Datta was an associate of George Cody, co-inventor of radioactive SiGe generators that power the Voyager space probes. Exhaust heat from conventional electro-mechanical generators at power stations and especially cars is suitable for thermoelectric recovery.

Recent calculations by the theorist David Singh, who visited us from the Oak Ridge National Laboratory last fall (2014), show novel thermoelectric properties in some special compositions of phase-change materials (PCM). PCM substances undergo Martensitic transformation. These materials have shape memory so they may be important in designing 'self deploying space umbrellas.' Sometimes there is a large latent heat of transition and thence can be used for heat storage. Many PCM alloys containing germanium have atomic structural bi-stability; that is, one form is crystalline and the other form is amorphous or non-crystalline.

Before his recent passing, the late American inventor Stanford R. Ovshinsky has been a guest in our group. Stan was the first to discover that in some PCM systems, the transformation relates to changes in the atomic order. Furthermore, the electrical properties of the crystalline phase may be significantly different from those of the amorphous form. In addition, the two states can be switched back and forth by passing currents, leading to the invention of non-volatile, all-electric memory devices or flash memory, also known as 'Thumb drives.' Unlike many information storage devices, such as computer hard drives, flash memories save energy because power is turned completely off when not in the 'read or write process'. In comparison, a magnetic hard drive contributes about a third of the energy usage of a 'sleeping' computer.

Dheyaa Alameri is a new member of our group. He is studying on an Iraqi Government Fellowship, and, for his doctoral project, Dheyaa is interested in energy materials including thermoelectrics, photovoltaics, and PCMs. Even though he is now preparing for the 'A to C exam', he has already assembled and calibrated an apparatus for thermoelectric measurements. He has begun learning how to solve thermal and thermoelectric equations with the finite-element software 'COMSOL.'

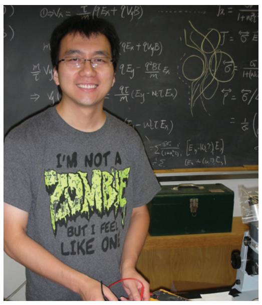
Our present era is often termed the 'Silicon age.' More mobile phones have been sold than there are people on this planet. A smart phone is sine qua non for the trendy digital fashionista; but it has a big problem – silicon technology is not green!

Most processes in silicon technology require either high energy (temperature) and/or chemicals that are extremely dangerous – these are in addition to challenges that loom ahead as one approaches the proverbial limits of Moore's Law of Miniaturization.

The element carbon, the building block of living matter, and silicon are members of the same group (four) of the periodic table. As was pointed out by Dresselhaus and others, similar to silicon, carbon also has physical properties that may be chemically modified or gated electrically, that is, properties that may be controlled by applying electrical fields. Furthermore, carbon comes in several allotropic forms that vary from the hardest substance in nature diamond, the extremely slippery graphite, to the tiniest nanotubes and Buckyballs, which are monster single molecules of pure carbon atoms. It is reasoned that green processes can produce carbon-based devices.

There has been a number of recent Nobel Prizes that recognized the importance of carbon. For instance, the 2010 Physics Prize was given for the discovery of graphene, a single layer of carbon atoms in an ordered array of benzene rings. Physics of such systems is remarkable! Existence of charged spin-half particles with photon-like linear-dispersion (energy–momentum) relations plus meeting of the 'hole and electron bands' at a single Euclidean point on the Fermi surface, the zero excitation Dirac point, exponential decay-less Klein tunneling and Klein transistors, are examples of many-body quantum mechanical exotica of such two-dimensional space.

A fantastic range of theoretical and technological ideas can be explored in these materials. Recently, using the low-temperature and high-magnetic-field facility that our collaborator Prof. Ming Yin has established at Benedict College, we have discovered an unexpected electro-magnetic response in a three-dimensional carbon nanostructure; the conventional wisdom has been that charge flow is affected only when the magnetic field (B) is perpendicular to current and resistance should go up as square of the strength of the field. However, in this structure magneto-resistance increases linearly and is independent of the field orientation. A proposal to the National High Magnetic Field Laboratory (NHMFL) for extending this novel observation has been successful; we will be travelling to the NHMFL facility in Florida for studies over a much higher field-temperature phase space. This work will be important in extremely high-field ('MegaTesla') metrology and other applications.



Lei Wang in the lab getting specimens ready for a trip to the National High Magnetic Field lab in Florida.

Lei Wang, the lead author of our recent publications in Applied Physics Letters, is a doctoral candidate and a prolific researcher. He has a number of refereed articles in print, plus Lei Wang already refereed several manuscripts submitted for publication in the journals of American Institute of Physics! In November of last year (2014), Lei gave an oral presentation at the SESAPS in Columbia, and another this year (March 2015) at the APS National meeting in San Antonio, Texas.

Many processes are stochastic, the best-known example being Brownian motion. Albert Einstein in one of his papers of annus mirabilis (1905) related this type of random walks with Fick's Law of Diffusion. Since then, these processes are shown to be universal and to follow the central limit theorem or Donsker's invariance. Hence, probability density is a Gaussian with only two parameters, mean and variance. However, a number of important physical, biological, and social random phenomena show anomalous diffusion. The dynamics of such processes is also interesting. We are doing a non-analytic study of anomalous random walk including Levy walks and flights, Michael Wescott and Erdogan Ozel are both involved in this.

Theoretical Physics Group

Faculty members: Brett Altschul, Vladimir Gudkov, Satoru Inoue, Rasha Kamand, Pawel Mazur, Camilo Posada-Aguirre, Matthias Schindler

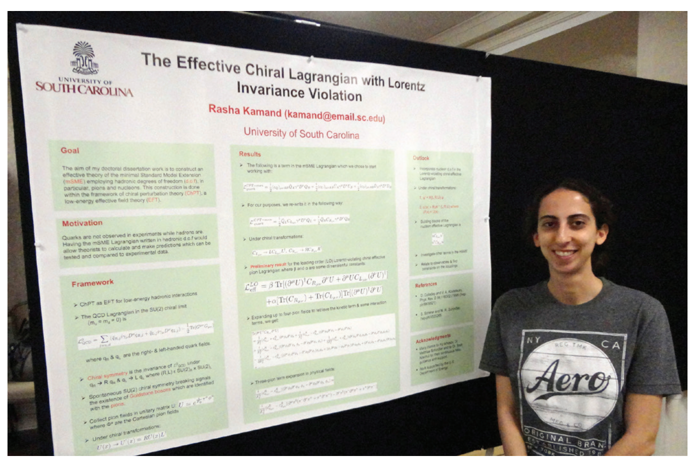
We are excited to welcome postdoctoral researcher Satoru Inoue as a new member of the Theoretical Physics Group. Satoru joins us from the University of Massachusetts, where he held a postdoctoral position after receiving his Ph.D. from UC Berkeley in 2012. We are looking forward to exciting collaborations.

In June, graduate student Rasha Kamand attended the Second IUCSS Summer School on the Standard-Model Extension (SME) at Indiana University. The week-long program was filled with lectures by experts in the field, including Theory Group member Dr. Altschul. In addition, Rasha presented her own research on "The Effective Chiral Lagrangian with Lorentz-Invariance Violation" at a poster session.

Dr. Altschul has been part of the Space-Time Explorer and Quantum Equivalence Principle Space Test (STE-QUEST) collaboration; STE-QUEST was a proposal for a satellite containing a high-precision atomic clock and atom interferometer, which would have performed the most precise tests ever of the universality of free fall. The proposal was not selected for the European Space Agency's 2025 launch window, but the collaboration published a paper describing the experimental possibilities for space-based atom interferometry in January and is continuing to update the proposal for new launch openings.

Dr. Gudkov and Dr. Schindler joined two collaborations that study Time Reversal Invariance Violation (TRIV) in compound nuclei: the TREX international collaboration at Oak Ridge National Laboratory, and the NOPTREX US-Japan collaboration. These collaborations are pursuing a test of TRIV by measuring the transmission of polarized neutrons through polarized targets. This experimental opportunity is not only complementary to neutron Electric Dipole Moment experiments, but could even provide increased sensitivity for TRIV interactions. Dr. Gudkov was a member of the organizing committees for the inaugural meetings of these collaborations at Indiana University and Nagoya University (Japan), where he presented a theoretical overview of TRIV in nuclei and discussed future research plans of our group in relation to these experimental programs.

Dr. Mazur and Mr. Camilo Posada-Aguirre continue to work on the theory of spinning ultra-compact objects of astrophysical importance. In February, Camilo presented a talk "Electrovacuum solutions to the Einstein-Maxwell system via the Ernst potentials" at the 8th Gulf Coast Gravity Meeting at the University of Florida, Gainesville. Dr. Mazur gave two lectures at the Marian von Smoluchowski Institute of Physics, Jagiellonian University, Krakow, Poland in May and June on "The Issue of the Final State of Gravitational Collapse." He also presented a lecture entitled "Model independent constraints on correlation functions in CMB and on the early galaxy distribution from CFT" at the "Quantum Vacuum and Gravitation" workshop at the Mainz Institute for Theoretical Physics, Johannes Gutenberg University, in Mainz, Germany.



Graduate student Rasha Kamand presenting a poster at the Second IUCSS Summer School on the Standard-Model Extension.

Particle Astrophysics Group

Faculty: Frank Avignone, Richard Creswick, Vincente Guiseppe, Carl Rosenfeld, David Tedeschi and Jeffrey Wilson
Graduate Students: Christopher Alduino, Nicholas Chott, Dawei Li, Clint Weisman and Kevin Wilson.

The USC Particle Astrophysics Group. Front Row, Left to Right: Clint Wiseman, Frank Avignone, David Tedeschi, Chris Alduino. Second Row, Left to Right: Vince Guiseppe, Carl Rosenfeld, Nick Chott, Dawei Li. Top Row: Kevin Wilson, Jeff Wilson, Rick Creswick.

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. The collaboration between USC and PNNL remains active today and 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, dozens of dark matter searches have been carried out all around the world, with vast improvements in detector technology. In 1994, Avignone was awarded the Jesse Beams Medal of the American Physical Society for his role 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 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 ($0\nu\beta\beta$–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 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 $0\nu\beta\beta$–decay of ^{130}Te. A new experiment, CUORE-0, was completed in July of 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 been maintaining 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. Vince Guiseppe is now leading the MAJORANA DEMONSTRATOR effort. He was in charge of the design and construction of the complex DEMONSTRATOR shield, which was completed over the summer of 2014. He is joined by David Tedeschi, Clint Weisman, and Frank Avignone. David brings significant experience from his years doing accelerator nuclear physics at the Jefferson Laboratory.

In 2012, Jeff 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 inner detectors of 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 eliminate a large part of the background. Jeff 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 Rosenfeld and Avignone; he played a major role in the fabrication of the CUORE electronics.

Experimental Nuclear Physics Group

The experimental intermediate-energy nuclear physics group consists of three faculty members: Ralf Gothe, Yordanka Ilieva, and Steffen Strauch. Other members of our group include postdoctoral researcher Gleb Fedotov and graduate students Tongtong Cao, Colin Gleason, Gary Hollis, Hao Jiang, Lin Li, Chris McLauchlin, Aneta Net, Evan Phelps, Nicholas Recalde, Ye Tian, Arjun Trivedi, Nick Tyler, Iulia Skorodumina, and many undergraduate students (see Fig. 1).

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

The study of the atom's nucleus and its constituents on the quark level is 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. We are also engaged in collaborative research at the J-PARC proton accelerator in Japan, the electron accelerator MAMI in Mainz, Germany, and the Paul Scherrer Institute (PSI) in Switzerland. Our studies focus on Quantum ChromoDynamics (QCD) and nuclei and are recognized as U.S. nuclear science frontiers. Our research helps to address the following basic questions: what is the origin of the visible mass in the universe, what is the nature of neutron stars, and what are the properties of dense nuclear matter?

The past year was full of exciting developments and achievements. Members of our group presented our research and findings in more than 30 invited and contributed talks at national and international meetings, and published more than a dozen articles on our collaborative research. We are happy to share that all of our submitted funding proposals have been approved. The funds will support our major research efforts at Jefferson Lab, as well as the hardware development we perform for the MUSE experiment at PSI and for the DIRC detector at JLab. We are very proud to announce that Yuqing Mao successfully obtained his Ph.D. degree last December. Yuqing's Ph.D. research, Measurement of polarization observables Pz, Pzs and Pzc in double-pion photoproduction off the proton, was carried out under the supervision of Steffen Strauch. Our postdoctoral fellow, Dr. Nick Zachariou, got a research assistant position with the University of Edinburgh, where he will continue to study the properties of the strong force between the strange and the up and down quarks.

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 one of these experiments in which we determine polarization observables in pion-nucleon final states. This summer, we published the first results of the FROST program in Physics Letters B.

We have continued the preparation for the Muon Scattering Experiment (MUSE) at PSI (S. Strauch). At USC, we are going to build the time-of-flight, veto, and beam-monitor scintillator detectors for the experiment. With funding from the U.S. National Science Foundation, we built a first prototype element of the time-of-flight detector and reached the required time resolution in tests at USC. We are going to build additional elements for more extensive in-beam tests at PSI. We are also in charge for the development of a full Geant4 simulation of the experiment. This past summer Heather Garland and Clay Robinette (see Fig. 2) joined our group on Research Experiences for Undergraduates (REU) projects on this MUSE project. Heather studied the effect of multiple scattering in detector elements and Clay worked on the optimization of the MUSE veto detector.

Figure 2: REU students Heather Garland (left) and Clay Robinette (right) presenting the results of their research with our group at the University's Summer Research Symposium.

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. R. Gothe is leading this effort. In the past year the detector has been connected to the read-out electronics and is now fully implemented and pre-commissioned. This is a milestone achievement of our group that involved efforts over many years not only of senior personnel but also of 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 2015-2016 through the collaborative proposal EIC PID Consortium (Y. Ilieva). This past year has been very exciting as we measured and analyzed data from 2014 and 2015 runs and sat together with the manufacturing companies to discuss how to change the design of the sensors in order to optimize their performance in magnetic fields and experienced

science-drives-technology first hand! Our results were presented at several detector-physics conferences, where they attracted significant interest. We plan more measurements in Summer 2016. We also plan to begin implementing the sensor structure in Geant4 simulations to support the design optimization work of the manufacturers. Graduate student Tongtong Cao and undergraduate Corinne Barber contributed to this project (see Fig. 3).

Figure 3: USC undergraduate student Corinne Barber working on the high-magnetic field sensor test facility at Jefferson Lab.

We have continued to invest a significant amount of 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 alone, our students have presented at meetings, such as USC Graduate Student Day (see Fig. 4), USC Discovery Day, collaboration meetings, the semi-annual meetings of the Division of Nuclear Physics of the American Physical Society, and the 21st International Conference on Few-Body Problems in Nuclear Physics.

With Jefferson Lab's approval to start initial 12-GeV operations (CD-4a) and the successful extraction of the first 12 GeV beam on target in Spring 2014, our commitment to publishing the 6-GeV physics results and developing future JLab12 experiments, as well as our involvement in several non-JLab projects, we are looking forward to another productive year.

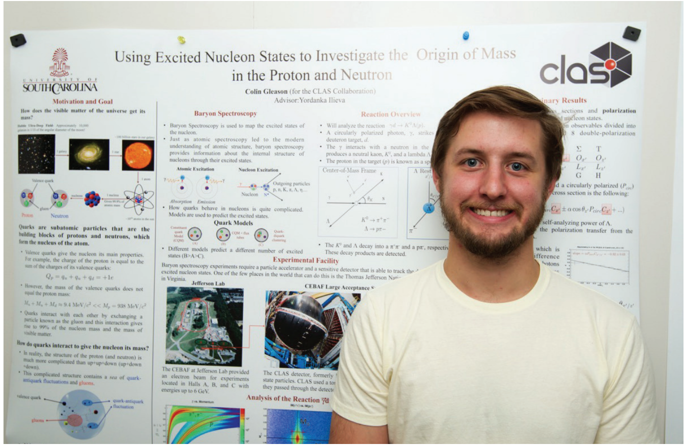
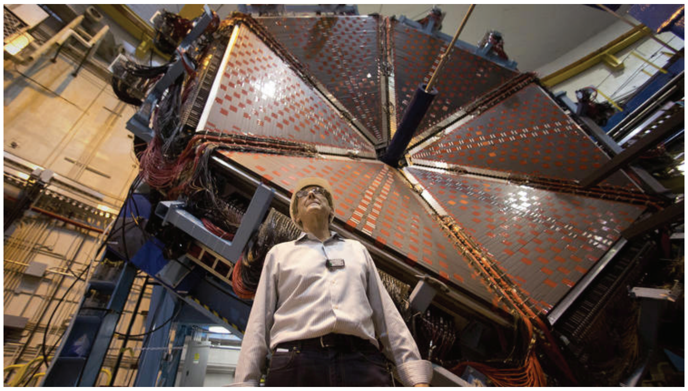


Figure 4: Graduate student Colin Gleason gave a poster presentation of his research at the 2015 USC Graduate Student Day. Colin won 2nd place in his section.

Research Program And Particle Identification Detector Of The Medium Energy Group Featured In News Article About Jefferson Lab

By Ralf Gothe



"The CEBAF Accelerator" (Kaitlin McKeown / Daily Press / Newport News, Virginia / October 2015).

The leader of Experimental Hall B at Jefferson Lab, Volker Burkert, poses in front of the Forward Time-Of-Flight Detector that was designed and built here at USC under the lead of Prof. Ralf Gothe. The picture shows the detector installed in the hall.

The research program carried out by our own Nuclear Physics Group and the time-of-flight detector built by the group here at USC have recently been in the News! The article was inspired by the just-announced Nuclear Science Advisory Committee (NSAC) recommendations. The Committee recommends priorities in Nuclear Science research to the federal government for the next five to seven years. The first topic in the first recommendation of the new 2015 NSAC Long Range Plan (LPR) for Nuclear Physics and, hence the absolute highest, is to capitalize on the investments made at the Thomas Jefferson National Lab (JLab) in Newport News, VA. The LPR states, "With the imminent completion of the CEBAF 12-GeV Upgrade, its forefront program of using electrons to unfold the quark and gluon structure of hadrons and nuclei and to probe the Standard Model must be realized." This highest recommendation is followed by the construction of the Facility for Rare Isotope Beams (FRIB), the fundamental symmetries and neutrino research, and the upgrade of the Relativistic Heavy Ion Collider (RHIC). For the long term future of the field the LPR lays out "We recommend a high-energy high-luminosity polarized EIC as the highest priority for new facility construction following the completion of FRIB." The facts that JLab has the highest priority for operation and is a main competitor for the new Electron Ion Collider (EIC) project were picked up by the Newport News Daily Press and were published with the headline picture that features the CLAS12 detector at JLab and shows the time-of-flight detector built by the Nuclear Physics Group here at USC.

Astronomy

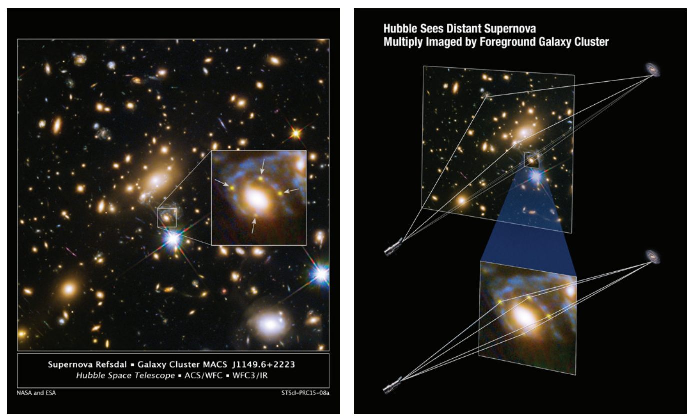
The USC astronomy team is pleased to welcome Prof. Steven Rodney as our new member. Profs. Rodney and Kulkarni, along with their students and collaborators, are working on some of the most fascinating and fundamental questions about our universe—What is the structure of the universe on the largest scales? How has the expansion of the universe proceeded? How have galaxies evolved with time? How did our Galaxy (including our solar system) reach the current composition of different chemical elements? To address these questions, we use state-of-the-art telescopes around the world, such as the Gemini and Keck telescopes in Hawaii, the Large Binocular Telescope in Arizona, the Magellan Clay telescope and the European Southern Observatory's Very Large Telescope in Chile. We have also been using NASA's Hubble, Spitzer, and Chandra Space Telescopes, and the Herschel Space Telescope operated by the European Space Agency and NASA. Our work is funded by the NSF and NASA.

New Assistant Professor Dr. Steve Rodney joined the department in 2015, bringing with him an exciting astronomical investigation that is still in progress. Late in 2014, Rodney and collaborators discovered a unique event: the appearance of a supernova -- an exploding star -- appearing simultaneously as four distinct points of light on the sky. This is the first ever example of a supernova being gravitationally lensed into multiple images, a spectacular example of Einstein's theory of general relativity in action. Rodney and colleagues are still watching that patch of sky with the Hubble Space Telescope, as they now expect a fifth image of the supernova to appear within the next year or two.

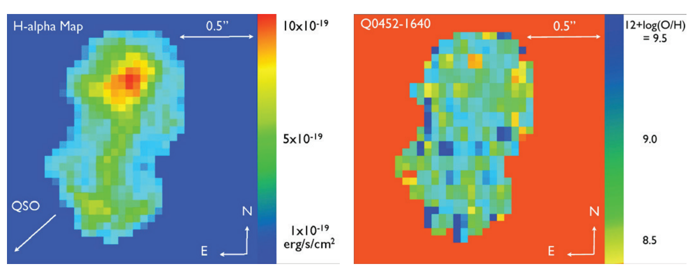
More details on this discovery can be found at:
http://hubblesite.org/newscenter/archive/releases/2015/08/
http://hub.jhu.edu/2015/03/11/split-supernova-exploding-star
https://www.spacetelescope.org/news/heic1505/

Professor Kulkarni's work focuses on the evolution of galaxies and the material in between galaxies, and the chemical evolution of the universe. In the past year, using the Hubble Space Telescope, Kulkarni, postdoctoral researcher Debopam Som, and collaborators discovered several distant galaxies with higher abundances than in our Sun for most elements heavier than Helium, yet with surprisingly low Nitrogen abundances, suggestive of an interesting formation mechanism for Nitrogen. Kulkarni, former graduate student Lorrie Straka (now a post-doctoral researcher at Leiden Observatory, The Netherlands) and collaborators have discovered some metal-rich, star-forming galaxies that appear to have no significant variation in metallicity from the inner parts of the galaxies to their outskirts. Using the Very Large Telescope in Chile, Kulkarni, collaborator Celine Peroux and others have mapped out the internal variation of metallicity and star formation rates in some distant galaxies and find a mixture of trends, with the metallicity decreasing from the center out in some galaxies, and increasing from the center out in some others! Kulkarni and collaborator George Chartas also obtained deep X-ray images of the fields of quasars with the Chandra telescope to study proto-galaxies associated with quasar absorbers. Kulkarni and former post-doctoral researcher Monique Aller (now an assistant professor at Georgia Southern University) continued to study the chemistry of interstellar silicate dust grains in distant galaxies using optical and infrared observations. Graduate student Sean Morrison analyzed far-infrared spectra of distant galaxies obtained with the Herschel Space Observatory to search for molecules. Graduate student Francie Cashman has been working on improvements to the atomic data needed for astrophysical spectroscopy, and the associated modeling of the spectra of distant galaxies. Postdoctroral researcher Som and graduate students Sean Morrison, Suraj Poudel, and Nassim Beiranvand worked on the measurements of element abundances in distant galaxies. Undergraduates Jacob Lee and Anya Rogers started working with our team in Summer 2015 as NSF REU (Research Experiences for Undergraduates) interns. Undergraduates Franco Godoy and Kyle Lackey also continued work on various aspects of quasar spectroscopy and on polar ring galaxies.

In other news, postdoctoral researcher (and former USC graduate student) Debopam Som left the university in Fall 2015 to start a post-doctoral researcher position at the Laboratoire d'Astrophysique de Marseille. We are sorry to see Debopam leave, but wish him the best in his new appointment at this prestigious institution in beautiful southern France. Recent USC graduates Bryan DeMarcy (BS, 2014) and Kyle Lackey (BS, 2015) are working with the new observatory and planetarium at the SC State Museum, and continue to do research work with us. Our staff and students continued outreach efforts at the Melton Memorial Observatory, where public nights are held on all clear Monday nights. Bryan DeMarcy is doing an excellent job as the new observatory instructor. Our other outreach activities in the past year included sessions at local area elementary schools, popular talks at local organizations such as the Midlands Astronomy Club and the Mensa Club, as well as interviews with local newspapers and TV stations. Dr. Soheila Gharanfoli continues her excellent undergraduate teaching work.



Supernova Refsdal, split into four images, and the galaxy cluster MACS J1149.6+2223, imaged by the Hubble Space Telescope Advanced Camera for Surveys and Wide Field



Map of the H-alpha line emission and metallicity (O/H) made for a galaxy at redshift 1.01 with the SINFONI integral field spectrograph at the Very Large Telescope, Chile (C. Peroux et al.)

High Energy Physics Group

Neutrino Group: *HIRESMNU as the Reference Near-Detector for DUNE*

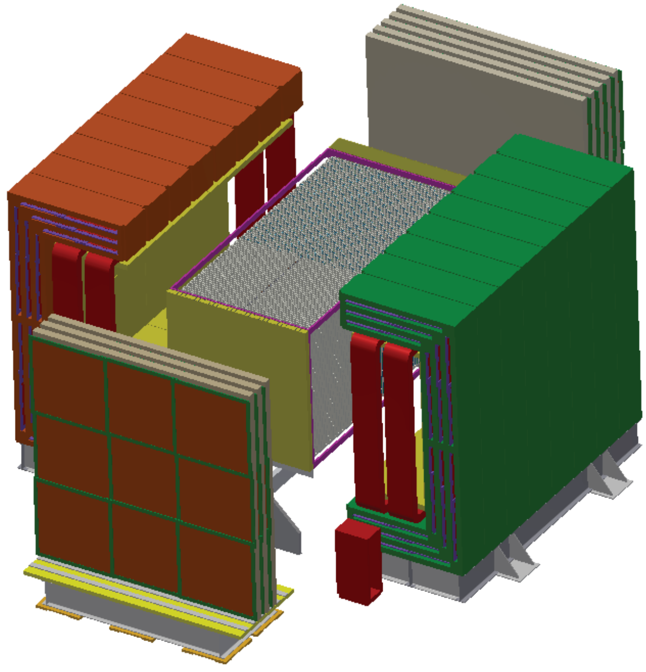


Figure [Hiresmnu-fig]

The unique capabilities and accelerator infrastructure at Fermilab combined with a far detector 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 facilities. The proposed Deep Underground Neutrino Experiment (DUNE) aims to measure three out of the four parameters that characterize three-flavor neutrino oscillations; it will be the only oscillation experiment to simultaneously measure the CP-violation phenomenon, which may help explain the matter-antimatter imbalance, and determine the relative ordering of neutrino masses. 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 beam introduced by Project X. The core scientific capability of DUNE will be significantly enhanced by a high-resolution near neutrino detector.

Professors Sanjib Mishra and Roberto Petti proposed a high-resolution near detector, HiResMν, as a generational advance in the investigation of systematic errors affecting the neutrino oscillation and mass measurements in the precision neutrino-interactions. The latter are made possible by the unprecedented neutrino fluxes foreseen in DUNE. The DUNE collaboration has chosen HiResMν as the reference Near-Detector (ND) design. The design passed the Department of Energy CD1 approval stage in July 2015. The HiResMν detector shown in Figure [Hiresmnu-fig], comprises a high-resolution, low-density (0.1 gm/cm^3) straw-tube tracker (STT), surrounded by a fine-grained electromagnetic-calorimeter (ECAL) and is embedded in a 0.4-T dipole magnetic field Muon-detectors instrument the magnet and two stations downstream of the STT. The HiResMν detector would combine for the first time an accurate reconstruction of the momentum and energy of the particles produced in neutrino interactions, and 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 along with Fermilab has been working with a consortium of Indian institutions to establish their collaboration with the neutrino experiments at Fermilab, especially with DUNE. In particular, the Indo-US nu-collaboration has proposed to the Indian funding agencies to design, R&D, and fabricate the HiResMν detector in India, which would then be shipped to Fermilab and installed in the DUNE near-detector hall. Carolina and Fermilab are the lead U.S. institutions in this collaboration. The Indo-US proposal, requesting ~$75M for equipment and associated personnel, is a decade long commitment, and is currently under review. In summer 2014 a funding of about $10M was allocated by the Indian funding agency to support the R&D activities in preparation for the construction of the HiResMν detector. 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.

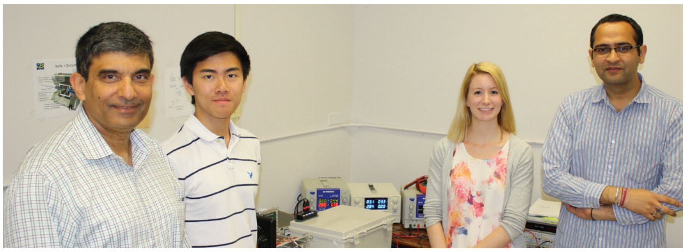
Professors Mishra and Petti are leading the ND detector and physics groups in the DUNE collaboration. Post-doctoral fellows Dr. X.Tian and H. Duyang, graduate student Ms. L. Jiang, and undergraduates Mr. T. Alion, K. Wood, and E. Dunton are participating in the DUNE related research.

NOvA Experiment:

NOvA, a second-generation oscillation experiment, is under construction and is scheduled to begin operation in 2014. The Carolina group's responsibilities for NOvA include Monte Carlo simulation, beam studies, data-acquisition system, and data analysis. Mishra, Petti, Tian, Duyang, and graduate student B. Guo work on NOvA.

Belle2 Program

The Belle2 program, led by Prof. Purohit, is in an exciting phase for students. This project aims to unravel the mysteries of CP violation in B-meson decays and related b-quark physics. We are testing electronics where high-speed digitization of waveforms, at up to 4 GHz, is to be done with the Belle2 detector for over 8,000 channels. In turn, this will lead to precision timing of photon arrival at the MCP-PMTs, of order 50 ps or better. Graduate student Alyssa Loos and summer students Madison Baker and Jeffrey Chen from South Carolina high schools enjoyed this learning experience in electronics and the building of a physics detector. The main engine of this work is Dr. Vishal Bhardwaj, a post-doctorate, who has dedicated his time to this work and is turning it into a success story. Prof. Rosenfeld is also contributing to this project, and we all enjoyed summer conferences and summer schools this year.



The Belle II pico-second electronics testing setup. From left to right are Prof. Milind Purohit, summer student Jeffrey Chen, graduate student Alyssa Loos, and postdoc Dr. Vishal Bhardwaj. The testing setup is in the background with the board being tested partially visible near the fans and between the students.

Special Articles

Deep In The Heart Of CUORE

By Chris Alduino

Coming from the relatively flat plains of Texas and having only moved to South Carolina for college, I am constantly surprised by the way my eyes are drawn magnetically to mountains. Anyone can become accustomed to anything with enough time. This past summer, I had the honor of traveling to the Laboratori Nazional del Gran Sasso (LNGS) for the fifth time to work on the Cryogenic Underground Observatory for Rare Events (CUORE). While traveling underground for my internship has quickly become old hat, every time the bus leaves the tunnel my eyes are instantly drawn to these snow capped pieces of the earth's crust sticking up in stark contrast to the small office building nestled at its base. Once completed, CUORE will be a staggeringly large cryostat able to cool 741 kg of TeO^2 down to 10 mK, and, in the process, it will hold the record for largest contiguous volume cooled down to the lowest temperature (Just Google "Coldest Cubic Meter"). All of this in an effort to probe further than the Standard Model by observing one of nature's most elusive particle, the neutrino. Since neutrinos only interact with matter by way of the Weak Nuclear force, much is still unknown about them. CUORE solves this problem by using bolometer technology, which is essentially a crystal that has a heat capacitance such that an energy deposit left by a single nuclear decay can be seen as a temperature rise in the detector. CUORE will be using bolometers to try to observe a very rare theoretical process, neutrinoless double beta decay. Simply put, if two beta decays occur simultaneously and we observe an energy signal that indicates a lack of neutrinos, it would mean that the neutrinos have annihilated each other during the reaction. If observed, it would mean that the neutrino is a majorana particle, which is a fancy way of saying that the neutrino is its own anti-particle. Such a discovery would have wide-ranging consequences for the fields in physics, the two biggest would be a much better understanding of the neutrino mass and possibly a window into learning why there's so much matter instead of anti-matter in our universe.

The Particle Astrophysics Group at The University of South Carolina has given me this opportunity to contribute to CUORE, and, in effect, the scientific community at large. USC has been involved in the production of CUORE even back when the bolometer technology was being demonstrated in CUORICINO. While USC's responsibility for CUORE is primarily providing the electronics, we maintain a graduate student on-site to help with construction of the project. It's one thing to work on the project from the safety of South Carolina, but there's nothing like being sent to Gran Sasso to work directly on one of the biggest cryostats in the world. Since most of the experiments going on at Gran Sasso have to do with detection or neutrinos, the actual laboratory is under the Gran Sasso Mountain. Unlike the ordinary schoolwork where you're left mostly to your own devices trying to imagine how the world works, the physics behind CUORE becomes real. What is acceptable to see the detector? Should I be eating bananas before touching the ultra clean copper? (Definitely not [as it contains trace amounts of radioactive Potassium]) What's causing temperature oscillations in the cryostat when we reach base temperature? Suddenly, everything you've learned in the classroom has to be applied to real-life problem solving. Even better, you're no longer tethered down tightly within the realm of known method and science. With CUORE being the size that it is, a large number of normal techniques that can be used on a smaller cryostat can no longer be used. Even small things like checking for leaks within the detector or calibrating the bolometers require real outside-the-box thinking.

Once data taking for CUORE commences, the focus will shift off the every day challenges of building a sufficiently low background detector and towards the process of data-taking. CUORE will be, if not the first, one of the first ton scale detectors actively looking for neutrinoless double beta decay. This means that while the hands-on fun of construction will end, the task of data analysis is only beginning. As the project moves forward, there are only more opportunities for students and USC as a group to contribute to a further understanding of neutrinos, and, by extension, a further understanding of where to look further in a Post Standard Model environment.

Professor Francesco Terranova (left) of the Dipartimento di Fisica dell'Università di Milano-Bicocca (Department of Physics, University of Milano-Bicocca, Italy) and graduate student Chris Alduino(right) test vacuum seals for helium leaks at the Laboratori Nazional del Gran Sasso near the Gran Sasso Mountain in Italy.

My Medical Physics Career Experience

By Nicolas Recalde

I am currently a Ph.D. student at the Experimental Nuclear Physics Group, working toward a Ph.D. degree. I first came to the Physics department in 1999, and, in 2003, gotzmy Master's degree in Physics under Professor Chaden Djalali's supervision. Soon after, I got a job offer as a clinical medical physicist at Georgetown University Hospital in Washington D.C. Since I needed the money to pay off a debt, I accepted the job and moved to the D.C. area. In my mind, I always had the plan to come back some day to South Carolina and finish my Ph.D. I thought I would work for a couple of years before I came back, but I ended up working 11 years, from 2003 to 2014. When I look over the past years, I see that the job offer was a tremendous opportunity.

The teaching assistant position and education I received from my M.S. graduate studies at USC's Physics Department made a huge difference in my life. I was able to give back to society professionally working with cancer patients as a medical physicist. It was very rewarding and full of experiences. Basically, I was helping others fight against cancer using all the education I received. Medical physicists are the only non-MD specialists who are certified by the American Board of Medical Specialties (ABMS) through the same process, and, in 2009, I got my specialty diploma to serve as a Therapeutic Medical Physicist from the American Board of Radiology (ABR). In 2011, I worked for Inova in the D.C. area as a Chief Physicist. We treated the first breast cancer patient in the State of Virginia by using nanotechnology that uses a miniature electron accelerator to produce photon x-rays at 50 keV. When I left my work in 2014, we had treated more than 80 patients in three years.

Last year, I was given the opportunity to continue my Ph.D. studies at USC and was able to go back to school beginning in Spring 2015, this time, under Professor Strauch's supervision. I am filled with gratitude for this chance to make a new start and I am sure I will also have future opportunities to continue fighting against cancer!

News From The Society Of Physics Students (SPS)

By Yanwen Wu

For many students, leaving home for college can be as daunting as it is exciting. However, this transition doesn't have to be an overwhelming experience if there's a place in the university where students can feel a strong sense of belonging. Therefore, we are happy to announce the re-activation of the University of SC chapter of the Society of Physics Students (SPS) beginning in January 2015.

SPS is a perfect home away from home for undergraduate students in physics. It creates a common hangout for undergraduate physics majors who normally do not interact outside of the classrooms. As a nationally recognized society (**http://www.spsnational.org**), it introduces students to a professional association with ample opportunities for scholarships, fellowships, and internships, as well as national and international conferences. As a university chapter, it enjoys the freedom of a self-governing entity and provides leadership training for students in officer positions. As a student organization, it is eligible for funding from the university's student government for group related activities, such as attending conferences, hosting invited speakers for undergraduate colloquiums, volunteering at outreach events, and participating in physics and engineering competitions.

SPS solar system painting party. The solar system model will be displayed in the Department of Physics and Astronomy display case.

Dr. Yanwen Wu is currently serving as SPS's faculty advisor. Our members consist of students from the physics department as well as those from biology and engineering. Recently, SPS has successfully secured full funding from the student government for three undergraduate students to attend the American Association of Physicists in Medicine (AAPM) conference held in Anaheim, California this July. Since its re-activation, students in SPS have participated in multiple outreach opportunities. We have built trebuchet and Rube Goldberg machine in competitions hosted by the Theta Tau Engineering Fraternity. SPS members have actively sought the opportunity to volunteer as demonstrators for the Astronomy Day at the South Carolina State Museum. We have also hosted a mini-seminar on graduate school preparation where a senior student who had already been accepted to top graduate schools shared his experiences with his younger peers.

Through SPS, we hope to instill a sense of comradery between students throughout their years in the university and provide them with a place to go to for both academic and extracurricular fun. The long-term goal for SPS is a self-governing and engaged group that will attend regular meetings, participate in outreach activities, go to conferences, and host colloquiums and informative mini-seminars geared towards undergraduates. So far, members of the group have bonded through meetings and activities. In the near future, we plan to secure a physical space dedicated to SPS in the department where students can do their homework and peer-to-peer tutoring or simply relax and enjoy each other's company.

Recent SPS activities and group information are available on the department website (**http://www.physics.sc.edu/sps**) and social media outlets such as Facebook (**https://www.facebook.com/UofSCSPS**). We would like to invite you to support us and check out our activities by following us on Facebook.

SPS participating in competitions hosted by the Theta Tau Engineering Fraternity

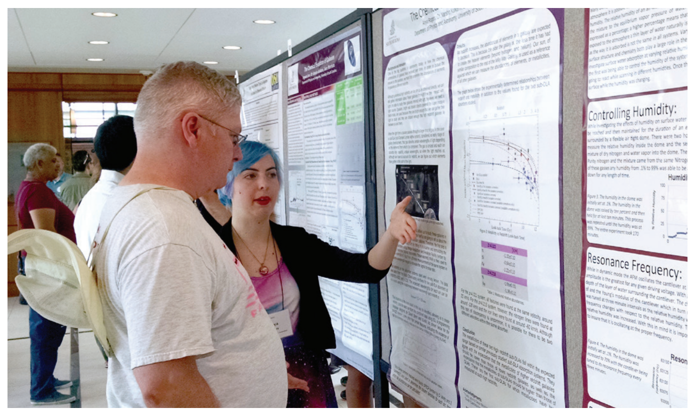
News From The Research Experience For Undergraduates Program

By Brett Altschul

The summer of 2015 marked the second time the department hosted an NSF-funded Research Experience for Undergraduates organized by Prof. Brett Altschul. This year, there were six undergraduate participants, some coming from the Carolinas but others from colleges and universities in South Dakota, Pennsylvania, Indiana, and Georgia.

For ten weeks, the six students worked with faculty mentors on projects dealing with astronomy, surface physics, nuclear physics, and mathematical physics. More specifically, Alexander Cramer (Dakota State University) worked with Prof. Johnson on *Exploration of Markov-Type Lie Algebras as a Basis for Differential Diffusion*, Heather Garland (Gettysburg College) worked with Prof. Strauch on *Mutiple Scattering Caused by Detectors Upstream of the MUSE Target and the Fraction of Primary Particles that Hit the Target*, Clay Robinette (University of North Georgia) worked with Prof. Strauch on *Design and Optimization of the Veto Scintillator for the MUSE Experiment*, Ing-Wan Lee (USC) and Anya Rogers (USC) worked with Prof. Kulkarni on *The Chemical Evolution of Galaxies*, and Harrison Schurr (University of Notre Dame) worked with Prof. Crittenden on *Nanoscale Measurements of Surface Water Adsorption*. Each student prepared a poster explaining their work, which they presented at USC's university-wide undergraduate research symposium at the end of July.

Physics and Astronomy 2015 REU Participants: (Back Row, From Left) Alexander Kramer, Ing-Wan (Jacob) Lee, Clay Robinette, Harrison Schurr; (Front Row) Anya Rogers, Heather Garland.



USC student Anya Rogers explains her work on the chemical evolution of galaxies to Prof. Scott Crittenden at the poster symposium.

Attention All Alumni Of The Department of Physics and Astronomy!

Beginning in next year's (2016) edition of Quantum Leap, we will be including news from our past graduates. In our new section of "Alumni Notes," 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

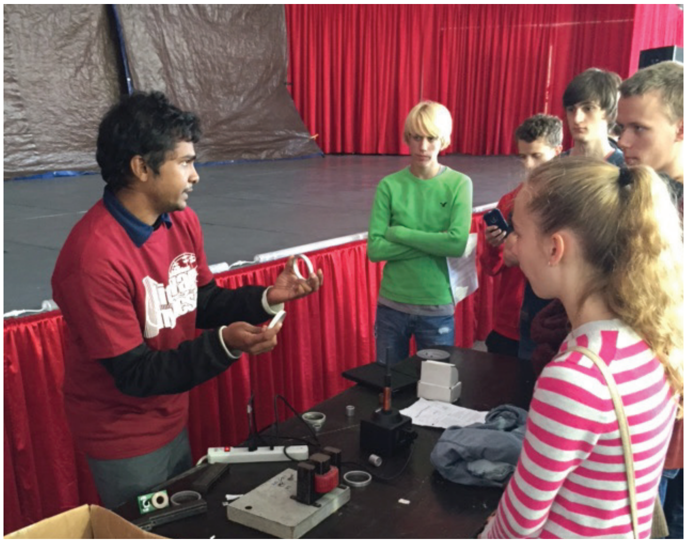
Looking forward to hearing back from you and best wishes always!

The R.L. Childers Midway Physics Day At The S.C. State Fair: A Historic Success In 2015

USC Midway Physics Day 2015 Participants: Front (from Left): Nicholas Chott, Krystal Rolon, Zachary Wallick, Chatura Kuruppu. Back (from Left): Alexander Kirby, Jeff Wilson, David Tedeschi, Sam Beals.

Several things happened to make this year's event historic. On the weekend of October 4, 2015, the Columbia area experienced a rainfall event characterized as "a once in a 1000-year storm." A large part of the Midlands received more than 12 inches of rain. There was severe flooding and many bridges and roads were closed and destroyed, and stayed closed for weeks. Fortunately, the State Fair was on higher ground and was spared from flood damage and was able to open normally two weeks after the storm. Midway Physics Day was in business. Unfortunately, some of our local area schools could not make it for the event. These schools were still under delayed openings due to ongoing transportation issues or had to cancel all of their field trips in an attempt to regain some classroom time. Our own pre-Fair teacher-training event, which was to be held at A.C. Flora High School during the week after the flood, had to be cancelled too; A.C. Flora was still being used as an emergency shelter at the time.

So, we ended up having a slightly smaller Midway Physics Day this year, with about 2,000 students in attendance instead of the expected 3,000, but we had as much fun as ever. The tent activities were a little less crowded and more relaxed, and we got rave reviews from the schools that attended. This year's event was also our 19th Midway Physics Day, with the first one (organized by Richard Childers, of course) in the fall of 1997. Next year, we will have a historic 20th anniversary celebration that will be marked with extra new exciting activities and more!



Curious physics students view a hands-on application of the Principle of Superconductivity utilizing metal rings led by graduate student Chatura Kuruppu.

Professor David Tedeschi displays the magic of polarized filters and teaches an interested student how the process works to make light disappear.

Quantum Leap

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Space Elements imaged by Alex Mowery from the Melton Observatory