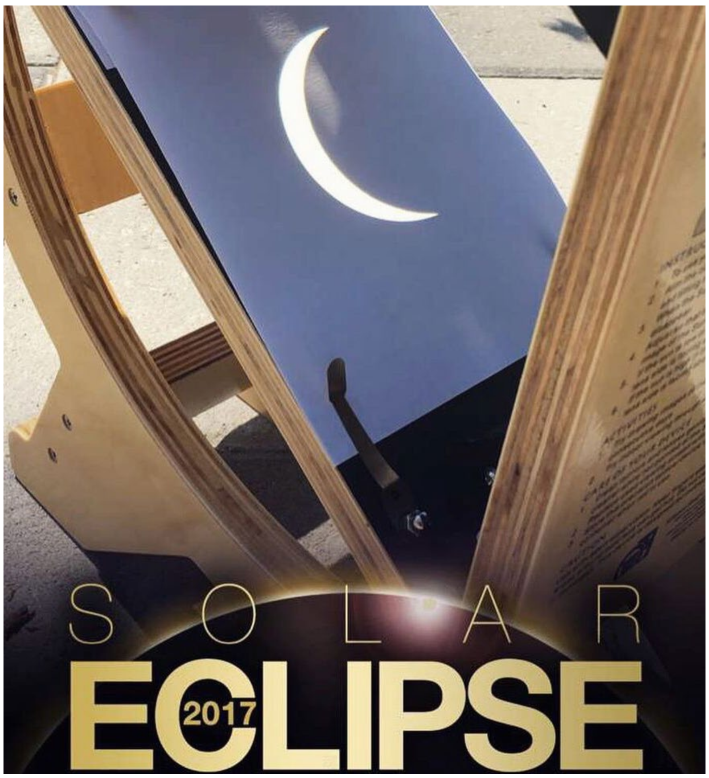
Quantum Leap

University of South Carolina
Department of Physics and Astronomy

2017



Total Eclipse Weekend at the University of South Carolina (August 18-21, 2017).

Totality. Awesome.

By Varsha Kulkarni, Steven Rodney, and Sam Beals

The total eclipse season officially kicked off in April as the University of South Carolina was selected as a venue for the American Astronomical Society's 5th and final eclipse planning and training workshop, which was held in Amoco Hall of the Swearingen Engineering Center. Professional and amateur astronomers alike from across the country gathered to connect, collaborate, and enjoy a full day of presentations and activities on campus. The AAS also held a second meeting at the South Carolina State Museum during the same weekend. This event was an excellent eclipse preview for USC and sparked early interest in a popular topic that would only manifest in the weeks to come.

The peculiar dimness crept in slowly. It was subtle enough that a distracted viewer might not realize at first (and there were plenty of distractions). In the final minutes, though, it became unmistakable. The penumbra was deepening, and a strange twilight was enveloping Columbia as the much-anticipated moment of totality came closer. Then -- at last -- at 2:41:52 pm on August 21, 2017 the Moon moved ever-so-predictably through its orbit to precisely cover the Sun. With the dark umbral shadow falling right over the USC campus, thousands of excited eclipse-viewers were plunged into two and half minutes of awe-inspiring totality.

This was the culminating event that capped off a spectacular weekend of public events all around Columbia, SC. Leading up to that instant, our department had been working for over a year to prepare and organize USC for the first transcontinental total eclipse in 100 years. Our many months of planning and preparation paid off, as the whole weekend came together as a smooth and successful showcase of the USC community. This event was a true representation of campus community in every way as the university came together for this historic occurrence like never before.

The weekend began on Friday, August 18 with a public lecture by Dr. Sarbani Basu, a distinguished solar astrophysicist and chair of the Department of Astronomy at Yale University. More than 500 visitors came to see Dr. Basu's presentation, titled "Solar Eclipses: the Dread and the Fascination." This crowd exceeded the capacity of one of the largest lecture halls on campus, as people were standing in the aisles and sitting on the steps of the W. W. Hootie Johnson Performance Hall at the Darla Moore School of Business.

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Members of the American Astronomical Society enjoy a full day of lectures at the Swearingen Engineering Center for the "5th Conference and Workshop for the All-American Total Solar Eclipse." The organization chose both the University of South Carolina and the South Carolina State Museum as venues for their final eclipse planning meetings in April 2017. Photo courtesy of Mike Kentrianakis with the AAS.

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On Sunday, August 20 we followed up with a series of short talks in the eclipse preview "mini-lectures," another free public event in Amoco Hall at the Swearingen Engineering Center. Once again, there was standing room only in the lecture hall, as more than 330 visitors flocked in to hear four 20-minute talks by astrophysicists visiting USC and Columbia to witness the eclipse. Our guest speakers included Dr. Ramesh Kapoor from the Indian Institute of Astrophysics, Dr. Gerardo Vazquez of Salisbury University, Dr. James Overduin from Towson University, and Dr. Kristin Simunac from St. Petersburg College. Their engaging and diverse talks covered the myths, history, and science of eclipses, with a range of anecdotes from past experiences of totality and insights into the cutting edge of modern astrophysics.

On the day of the eclipse itself, the campus was buzzing with activity. Canopies and tables were set up at ten locations scattered across the campus. These "eclipse viewing stations" were stocked with eclipse glasses, equipped with Sunspotter solar telescopes, and staffed by a small army of volunteers. Some of our helpers were aspiring physicists while others were simply along for the ride, which is what made the day so much fun. Each station featured a unique astronomy-themed activity. Down by the Colonial Life Arena, visitors could toss frisbees for "Stellar Collision Disc Golf" or play with a scale model of the Earth and moon, making a miniature eclipse demo on a yardstick. At the other end of campus, our faculty and students showed off angular momentum demos and managed a steady queue with scores of people viewing the sun through solar telescopes. Thousands of people walked along Greene Street, sprawled out on picnic blankets on the Horseshoe or relaxed on lawn chairs behind the Melton Observatory. As totality approached, others could be seen setting up their cameras and tripods near the Thomas Cooper Library as they prepared to capture once-in-a-lifetime images to share with the world. Eclipse-watchers could get a break from the heat by ducking inside a handful of lecture halls to see live streaming of the NASA Eclipse Megacast, or listen to short public talks from USC faculty. But everyone was out in the open air by 2:30 pm for the main event -- and no one was disappointed.

More than 100 volunteers helped with all of these campus events. They were the greeters and guides at public lectures, the set-up and clean-up crews, and the enthusiastic and cheerful staff at our eclipse-day viewing stations. Many had never taken a class in physics or astronomy, had never attended a public lecture, or even participated in a USC public outreach event. The excitement of the eclipse brought them out to join us, and our events could never have succeeded without this groundswell of support from the USC community. We owe a tremendous amount of gratitude to these amazing people.

A third public lecture event on Monday evening rounded out our 4-day eclipse weekend. Dr. Craig Roberts from Argonne National Laboratory presented a talk on "Laying the God Particle to Rest." Dr. Roberts was a participant in the NSTAR 2017 conference hosted by Ralf Gothe here at USC, which was perfectly timed to coincide with the complete line-up of events during Total Eclipse Weekend. More than 250 attendees joined for this event, which closed with a special moment to deliver a very well-deserved recognition to Mr. Sam Beals, our department's administrative assistant and special events coordinator par excellence. Sam put in many long hours in preparation for the eclipse weekend and the NSTAR conference. His tireless dedication and unfailing enthusiasm made the whole process better for everyone involved.

Generous financial support for the department's programming was provided by the Offices of the Provost and the Vice President for Research. These funds were used to purchase solar telescopes and filters, printing and supplies for the info stations, and travel costs for visiting speakers. The university community came together under the leadership of the Office of Student Affairs and Academic Support, who provided substantial logistical support. The USC security, parking, housing, food and events staff members were all outstanding partners in this enormous effort. A special and critical gift came in at the last minute, in the form of sponsored catering from the new campus food service provider, Aramark. Their Horseshoe Catering service stepped up to provide a pre-eclipse lunch and a post-eclipse reception for our deserving volunteers. There are countless on-campus groups and individuals that were active participants in our success, and we are so thankful for all who contributed to this unforgettable weekend!

During an eclipse, the Moon's shadow races across the surface of the Earth at a speed of about 1,500 miles per hour. This means that totality is fleeting, and the precious few minutes were gone all too quickly this August. For all of us that were lucky enough to witness the brief and awesome moment of totality that afternoon, it was an experience we will never forget.

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UPDATES FROM THE CHAIR AND DIRECTORS

Message from the Chair

By Milind Purohit

Welcome to another year of Quantum Leap, and we hope we will make a Leap to a higher state this year! This brief welcome message is to introduce you to some highlights of this year and upcoming events.

While last year had a long shadow cast over it from the deficit in the college budget, we hear that in the remarkably short period of a single year, the College has climbed out of the fiscal red and we can hope for further improvement. At the same time, due to a new "Excellence Initiative" at the university, we will on the one hand again face severe financial restrictions while on the other we might benefit from the resulting university-level accumulation of funds if some of those become available to us. While we hope that this materializes as a good opportunity for our department, I encourage you to think of donating to the Physics Fund as well! At the college level, graduate students will be supported by a renewed number of Dean's fellowships. Our university as a whole is seeing more students enter, and indeed the prestigious Capstone and Honors College programs

The 2017 Graduate Award winners (April 2017). From left to right: Krishna Neupane, Saba Arash, Dr. Rick Creswick, Chatura Kuruppu, Hao Jiang.

are doing even better in terms of enrollment and interest in our college.

This summer, we lost a valuable staff member when Kelly Gibson moved on to a career in teaching. We wish her the best in Tennessee, and remain hopeful of filling her position soon. Kelly was a student coordinator and worked tirelessly in the interests of our graduate and undergraduate students. She is greatly missed already.

The summer of 2017 saw an important conference, NSTAR 2017, hosted by our department and chaired by Prof. Ralf Gothe. The conference was a smashing success, and the renowned SLAC theorist Prof. Stan Brodsky called it the "best conference he's ever been to." Coincident with the conference was a once-in-a-lifetime event, the Great Solar Eclipse of 2017 right here putting us in the dark for a full 2½ minutes! Our astronomy faculty (Profs. Kulkarni and Rodney) and our indefatigable staff member, Sam Beals, worked tirelessly for months to make this event a big success. People from near and far sent appreciative emails and other intimations, and we feel we reached out to the wide community rather effectively.

Recently gravitational waves have been in the news, as have discoveries in the field of neutrinos. We are looking forward this year to some excellent talks by giants in these two fields: Nobel Laureates Prof. Barry Barish (CalTech) and Prof. Art McDonald (Queen's University).

News from the Graduate Director

By Richard Creswick

New and Current Students

The Physics Department welcomes Harry Oslislo to the graduate program. After retiring from a successful career with Merck, Mr. Oslislo attended Rutgers University as a non-traditional undergraduate student and is now pursuing his Ph.D. at USC. Mr. Oslislo is interested in astrophysics and currently working with Dr. Varsha Kulkarni.

It was with some trepidation that we saw two of our graduate students travel home this past summer. Rahman Mohtasebzadeh traveled to India and Afghanistan and Saba Arash to Iran. We are happy to say that both have returned to USC successfully and are diligently working toward their doctoral degrees.

Graduate Awards

Each year, the department recognizes graduate students who have excelled in research, teaching, and service. This year's recipients of the Graduate Awards are Hao Jiang (research), Saba Arash (teaching), Chatura Kuruppu (teaching), and Krishna Neupane (service).

PhD

During the past year, a record ten students received their doctorates. They are Nicholas Chott (Avignone), Colin Gleason (Ilieva), Hao Jiang (Strauch), Rasha Kamand (Schindler), Leila Net (Strauch), Evan Phelps (Gothe), Camilo Posada-Aguirre (Mazur), Ye Tian (Gothe), Arjun Trivedi (Gothe), and Lei Wang (Datta).

Astronomy Club president Alex Kirby (left) and SPS president Eric Rohm (right) demonstrate induced eddy currents and the concept of magnetic braking to a captive audience at Midway Physics Day at the South Carolina State Fair.

Scholarships and Awards

Iulia Skorodumina (Gothe) has been awarded a JSA/JLab Graduate Fellowship. Francie Cashman (Kulkarni) is now in the second of a three-year NASA/South Carolina Space Grant Consortium graduate fellowship. Alyssa Loos has been awarded a one-year U.S. Department of Energy (DOE) Office of Science Graduate Student Research (SCGSR) Fellowship and is currently working at Pacific Northwest National Laboratory (PNNL). Clint Wiseman was recently stationed at Los Alamos National Laboratory (LANL) after receiving a DOE Office of Science Graduate Student Research Program award.

Justin Roberts-Pierel is PI on a Hubble Space Telescope Research Grant entitled "Turning Gravitationally-Lensed Supernovae into Cosmological Probes," and is co-Pi with Dr. Steven Rodney on a grant from the South Carolina Space Grant Consortium, "Rare and Peculiar Stellar Explosions with the Next Generation of Space Telescopes."

Alumni News

Nicholas Chott is now a post-doc at LNGS in Italy working on the CUORE project. Dawei Li is a software engineer at SIOS Technology Corporation in Lexington, SC and Lelia Net is now a Data Scientist at Biodesix, Inc. in Boulder, CO. Colin Gleason (Ilieva) is a postdoc at Indiana University working on a project in Hall D at Jefferson Lab.

Undergraduate News

By Jeff Wilson

As a continuing theme to my undergraduate updates in recent years, I again focus on the department's response to our rapidly expanding student body.

Last year, we were able to hire an instructor to teach extra Honors courses. We chose Albert Dearden, who received his Ph.D. from Rensselaer Polytechnic Institute in 2014. He was a postdoctoral fellow at Florida State University in 2014-2015 and helped to develop a theory modeling oxygen reduction reactions in CO and CO_2. Dr. Dearden then followed that with a teaching stint at Berea College in 2015-2016 where he developed and taught courses in introductory physics. He brings experience teaching small classes using interactive teaching methods, which was just what we were looking for.

With the hiring of our second instructor, we feel that we have reached a critical mass in our introductory physics program. We have a collection of faculty and instructors who have become interested in the craft of teaching physics. We have been using input from physics education research to help us modernize our physics teaching. As part of this process, we have begun using some standard assessment tools to measure our student's

Energetic undergraduate Jane Vista uses a turntable to show an interested high schooler how angular momentum is generated at Midway Physics Day. This exhibit helps students better understand the rotations that they experience on amusement rides.

performance starting with pre/post testing using the physics force-concept inventory test. We look forward to having some information on our progress with that project next year.

Our major outreach event of the year, the R. L. Childers Midway Physics Day at the South Carolina State Fair, was a huge success this year. After two years of decreased attendance due to disastrous weather events (the "thousand-year flood" in 2015 and Hurricane Matthew in 2016) we finally had a normal year. A full roster of 2,500 students from 65 schools was able to attend and we had over 20 departmental faculty, staff, and students serving as mentors. Local television station WLTX News 19 obtained some great footage of our undergraduate mentors interacting with some of the high school participants.

Undergraduate Awards

By Jeff Wilson

In a very unusual award season, we had only one awardee in physics. Edward C. Dunton received the Nina and Frank Avignone Fellowship for achievement in Physics and he also received the Jeong S. Yang Award for Excellence in Undergraduate Mathematics.

Congratulations to Edward Dunton for a very productive year!

NEW IN 2017

NSTAR 2017

The nuclear physics group hosted the 11th International Workshop on the Physics of Excited Nucleons that took place from August 20-23, 2017 at the University of South Carolina in Columbia. 116 nuclear and particle physicists from 62 different institutions all around the world came here to present and discuss their latest results and achievements. The aim of the conference was to develop and push our understanding of the strong force as it confines quarks and how it creates nucleons and their excitations from these fundamental building blocks. The public lecture, "Laying the God Particle to Rest," by Craig Roberts from the Argonne National Laboratory in Chicago addressed the directly corresponding topic of how nuclear matter and hence mass is generated in our world.

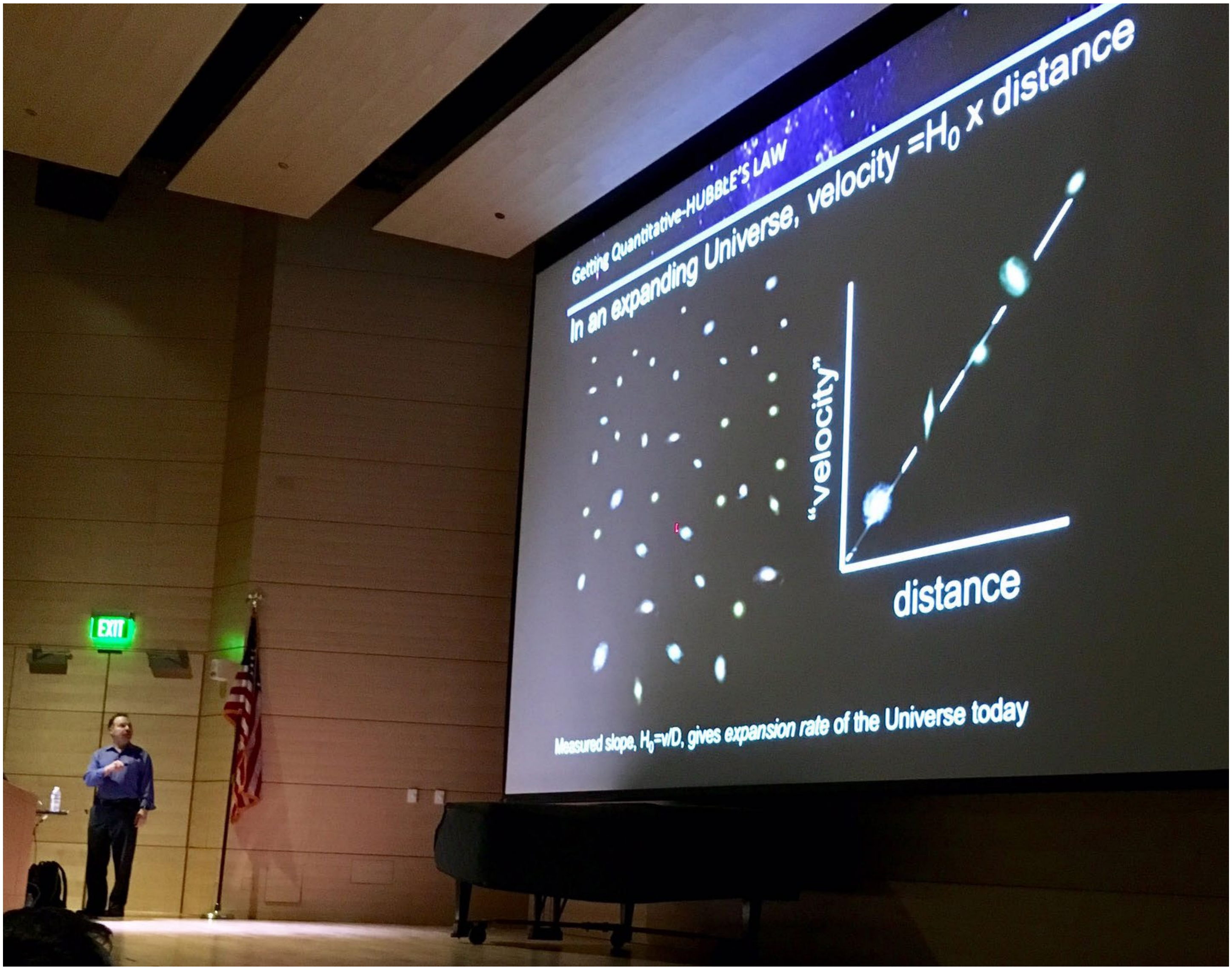
Organizing the NSTAR workshop around the total eclipse was evidently a bigger challenge than we anticipated four years ago as the idea was born, but at the end it was such a special highlight that touched everyone who could experience it in a very profound manner.

Craig Roberts (right) in the W.W. Hootie Johnson Performance Hall of the Darla Moore School of Business just before he was introduced by Ralf Gothe (left) to give his public lecture as part of the Total Eclipse Weekend in Columbia.

Excited nuclear physicists from across the globe gather together on the rooftop of the Darla Moore School of Business to experience the total solar eclipse during the NSTAR 2017 conference at USC.

Courtesy of Lothar Tiator, participant of the NSTAR 2017 workshop in Columbia.

Conference participants and guests alike enjoyed gazing into the sun, clearly not without the proper ISO 12312-2 protection.



Nobel laureate Dr. Adam Riess shares his findings on the expansion of the universe with an audience of over 500 attendees at the W.W. Hootie Johnson Performance Hall (January 2017). Photo taken by Dana Woodward with the USC Office of Communications and Public Affairs.

Supernovae and the Discovery of the Accelerating Universe

By Steven Rodney and Sam Beals

Distinguished Lecture Series continues with visit from Nobel Laureate Adam Riess

As young physics students, most of us would have told you that the universe is full of surprises. After all, that's why we got into this business: for the excitement of making one of those inspirational and paradigm-shifting discoveries–the unforeseen breakthrough that rewrites textbooks and changes the way we think about the world. And while in truth unraveling the mysteries of the physical world is to a large part achieved by incremental steps, those leaps do come about from time to time. And sometimes they are indeed true surprises. The 2011 Nobel Prize in Physics was awarded for one such unexpected advance–the discovery of the accelerating expansion of the universe. Dr. Adam Riess, a Bloomberg Distinguished Professor of Astronomy and Physics at Johns Hopkins University, was one of the three recipients of that prize, and he visited Columbia as the second speaker in the USC Distinguished Lecture Series in Physics and Astronomy earlier this year.

Dr. Riess presented a public talk in early January, as the Spring 2017 semester was just getting underway. His talk attracted a near-capacity crowd to the Darla Moore School of Business, with visitors attending from across the university, the Midlands region, and even other states. The audience was given an inside look at the process that led Adam and his collaborators to their remarkable discovery in 1998. In addition to explaining the scientific background–how stellar explosions are used to measure distances across the cosmos–he also shared the internal discussions between his co-investigators as they wrestled with the surprising results of their measurements. The supernova distances were suggesting that the expansion of the universe was not slowing down under the inexorable pull of gravity, but was actually speeding up–accelerated by the mysterious negative pressure of dark energy. Could the universe really be so strange?

Professor emeritus Dr. Kuniharu Kubodera (front row, far left) receives the Totsuka Prize at the University of Tokyo (Tokyo, Japan) on March 20, 2017.

The answer, of course, turned out to be a resounding "yes." The universe does appear to be that strange. The existence of dark energy is now supported by two decades of corroborating evidence, but we are not much closer to understanding the nature of this mysterious stuff that makes up more than two thirds of the mass-energy budget of the universe. Dr. Riess continues to work at the forefront of astrophysical observations to improve our constraints on dark energy. As part of his visit at USC, he also presented a special colloquium talk describing his ongoing efforts to measure the Hubble constant, H0, the current expansion rate of the universe. As Dr. Riess explained, improving the precision of our local measurement of H_0 is one of the most effective ways to advance our knowledge of cosmic acceleration and the physics of the universe.

Dr. Kubodera is Awarded the Totsuka Prize

By Kuniharu Kubodera

Dr. Kuniharu Kubodera is a recipient of the Totsuka Prize, a prestigious Japanese physics prize awarded by the Heisei Foundation for Basic Science, which was founded by Dr. Masatoshi Koshiba, a 2002 Nobel Prize winner. The citation recognizes Dr. Kubodera's contribution to neutrino physics through his high-precision calculation of the neutrino-deuteron reaction cross sections. This calculation, done in collaboration with Drs. T. Sato and S. Nakamura (both at Osaka University) and Dr. V. Gudkov (USC), provided an important theoretical input needed when the Sudbury Neutrino Observatory (SNO) experiment established the discovery of solar neutrino oscillations, a discovery for which the SNO leader, Dr. A.B. McDonald, received the 2015 Nobel Prize.

RESEARCH GROUPS AND STUDENTS

Advanced Solutions Group (ASG)

By Joe Johnson

ASG is the R&D group led by Professor Johnson who has been PI for over $14M in multidisciplinary grants and contracts since 1993. His primary interests are in problems involving Lie algebras and groups, Markov processes, network theory, cluster analysis, artificial intelligence, mathematical physics, foundations of quantum theory, and most recently general relativity with programing in Python, Sage, SymPy, and other Python modules. ASG has just completed three new grants, partnering with 18 USC faculty and 22 students from various disciplines. Six new proposals are underway with research and development currently continuing in the following domains:

1. **An Optimal Numerical Data Standardization Algorithm:** Johnson has developed an algorithm for attaching the units of measurement, level of uncertainty, and exactly defining metadata to numerical values with automatic dimensional analysis and error processing with full tracking of all metadata & meaning. This constitutes a new data standard that can support automated data exchange, IoT, and artificial intelligence on new levels. It totally eliminates the problems of adapting the metric (SI) standard as all units are equal (with metric default). In this standard, called MetaNumber (MN), every single numerical value has a unique name defined by the Internet path to retrieve and process it. Machines can process such information without any human intervention allowing a new level of automation and machine communication. (www.metanumber.com)

2. **Network Analytics Based upon Lie algebras and Markov transformations:** He has developed a method of mathematically analyzing any network by proving that every network is isomorphic to a continuous Markov transformation that models network flows. The eigenvalues and eigenvectors of that transformation provide an innovative cluster analysis for the network, which, along with its Renyi' and Shannon entropies, allow for extensive classification, comparison, and analytics. The importance of this rests on the fact that networks are ubiquitous in living systems. This work rests on his novel decomposition of the general linear group GL(n,R).

3. **Cluster Analysis of Tabular Numerical Data:** Imagine a numerical data table with various entities in rows and with their properties in columns (such as the chemical elements or personal health data). He devised a method of converting such data into two networks: a property network and an entity network thus allowing the cluster and entropy analysis above to be invoked. This cluster analysis can outperform existing cluster analyses. This process is now automated and can classify clusters in all tabular data tables with rank

order of the degree of "tightness." This is important since cluster analysis is fundamental for both human & artificial intelligence. The algorithm can be deployed on standardized data to intelligently find relationships and patterns and thus to "learn." We are now working on constructing an advanced user interface.

4. **An Integration of General Relativity (GR) with Quantum Theory (QT) and the Standard Model (SM):** QT and the SM are built upon a Lie algebra foundation with representations on a Hilbert space. But GR is built with nonlinear differential equations for the metric of space-time as determined by the Einstein equation in terms of the energy momentum tensor. Thus QT and the SM are fundamentally incompatible with GR and their integration is one of the most challenging problems in physics. Johnson previously proposed an extension of the 10 parameter Poincare Algebra to include four-vector position operators giving a 15-parameter Lie algebra that includes a covariant Heisenberg Lie algebra (HA). He now proposes to generalize the HA structure constants from the flat Minkowsky metric to be the Riemann metric as determined in GR. The representations of this algebra are shown to convert the Christoffel symbols, and the Ricci and Riemann tensors from differential equations into commutator equations for operators thus giving GR and Einstein's equations a solid foundation in Lie algebras of operators. The resulting representations also very naturally allow for the SM strong and electroweak vector boson terms to appear in parallel with the Riemann metric (for either a classical or quantized gravitational force as a graviton) and optionally with a scalar field. The constants "c", h, and "G" now all reside in the structure constants supporting Plank units. More recently, he has rebuilt the basis of Riemannian geometry in terms of Lie algebras and groups in order to apply that mathematics here. Available at http://arxiv.org/abs/1606.00701.

5. **A Phone App Useful for Public Safety, Emergency Management, and Telemedicine:** A novel phone application has been designed and prototyped by ASG and with faculty in Computer Science. It has extensive applications.

Joseph E. Johnson, Ph.D., is a Distinguished Professor Emeritus in the Department of Physics and Astronomy, University of South Carolina, Columbia, SC, 29208 and an Affiliate in the USC Department of Mechanical Engineering.

Astronomy

By Varsha Kulkarni

The past year has been filled with wonderful events in the field of astronomy, ranging from more detections of gravitational waves to the great American total solar eclipse of August 2017! USC astronomers, students, and collaborators continued to explore the wonders of the cosmos 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 around them. Former graduate student Sean Morrison and Prof. Kulkarni, along with another former graduate student Debopam Som (now a post-doctoral researcher at the Laboratoire d'Astrophysique de Marseille) 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 (i.e. more than 90% back in the history of the universe). The analysis of the chemical composition of this galaxy suggests leftover signatures from element production in early generations of massive stars. Graduate student Suraj Poudel, Kulkarni, and others extended this work to study more galaxies in the first 1 billion years of cosmic history, and completed a paper about the early results from this survey. This work is providing new measurements of the rate at which galaxies got enriched with the heavier elements in the young universe.

Graduate student Frances Cashman led the publication of a large compilation of key atomic data needed for astrophysical spectroscopy. This compilation, the first of its kind in 14 years, provides an important improvement in the tools available for determining the chemical composition in a wide variety of astronomical objects. Kulkarni, Cashman, and collaborators also continued to work on analyses of 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 Péroux, 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. Along with an international team of collaborators, Kulkarni is also involved in a large survey

Francie Cashman standing outside the twin Magellan telescopes.

of atomic and molecular absorption in distant galaxies to be carried out with the MeerKAT radio telescope array in South Africa, a precursor to the Square Kilometer Array.

Former graduate student Sean Morrison completed his M.S. from the University of South Carolina and joined the Ph.D. program at the Laboratoire d'Astrophysique de Marseille in France. Graduate students Poudel and Cashman carried out spectroscopic observations of some distant galaxies at the Magellan II telescope. Graduate student Kyle Lackey continued the analysis of infrared images of polar ring galaxies – peculiar galaxies with rings of star formation perpendicular to the galaxy major axis, possibly resulting from earlier collisions with other galaxies. New graduate student Harry Oslislo has just joined our team and is assisting with some of the computational aspects of quasar spectral analysis. Undergraduate Alex Kirby won a Magellan Scholarship to work on the nature of extinction of light caused by interstellar dust in nearby and distant galaxies. Several other undergraduate students such as Andrew Re, Joshua Rapoport, and others have also been participating in various astronomical research projects with our team.

Two rising high-school seniors worked with our team in Summer 2017 on projects related to the gas and dust in and around galaxies. Ishrat Singh from the Governor's School for Science and Mathematics worked on spectra of quasars obtained with the high-resolution optical spectrograph on the Keck telescope to determine the chemical compositions of some dusty galaxies. Matthew Hawkins of Dutch Fork High School assisted with the sample construction for the determination of dust extinction curves in distant galaxies. Both students enjoyed the research experience and were a pleasure to work with!

Adventures in Chile

By Francie Cashman

I may have screamed when my advisor, Dr. Varsha Kulkarni, asked if I wanted to go to Chile for a 3-night observing run. I can't remember exactly, but I'm fairly certain that my affirmative response was shouting and that I came off as someone who had completely lost her cool. It was after our Astronomy Journal Club meeting and a few of us were still milling about in the room. Serendipitously, I had applied to renew my passport only a week earlier. And now I'd be off to Chile to use one of the most famous telescopes in the world? Unbelievable.

The Las Campanas Observatory, or LCO, is located in the high altitude (~8000 ft) Atacama Desert about 60 miles northeast of La Serena, Chile. Las Campanas means 'the bells' in Spanish. The bluish-green rocks that can be found there have copper in them and when hit together, actually ring! The LCO is home to the twin 6.5 meter Magellan telescopes named for Walter Baade and Landon Clay, and is also home to the 2.5 meter du Pont, the 1 meter Swope, and the 1.3 meter Warsaw telescope. It is also the future site of the 24.5 meter Giant Magellan Telescope, which is to be completed by 2025.

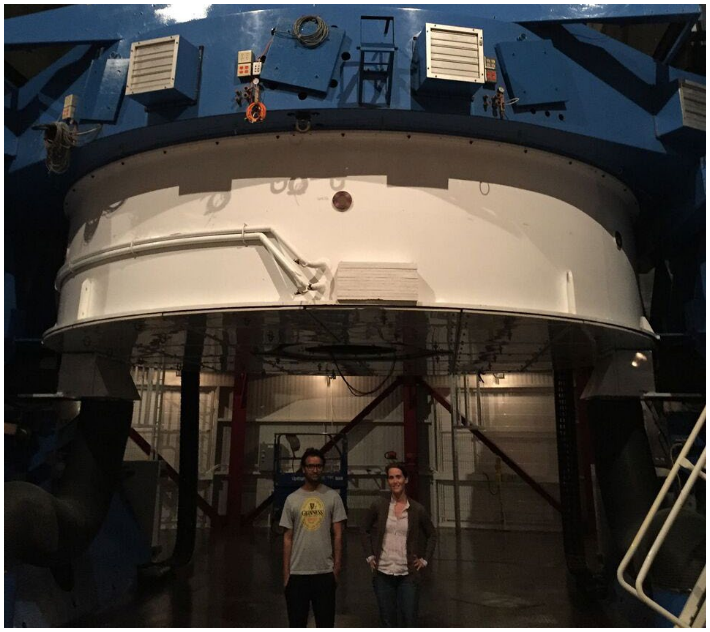
The year before, Dr. Kulkarni had written a proposal to use the 6.5 meter reflecting Magellan telescope along with the Magellan Inamori Kyocera Echelle (or MIKE) spectrograph to capture the spectra of very distant quasars. These spectra would be used to examine the chemical composition of progenitor galaxies along the line of sight to the quasars in order to study the chemical evolution of these galaxies. The data would be part of fellow graduate student Suraj Poudel's thesis, who would be making his second trip to the LCO in Chile. Suraj and I decided we wanted to tack on a few extra days to the trip so that we could enjoy some sights.

We flew out of Columbia to Houston then southward to Santiago, Chile on an overnight flight. One more short flight to La Serena in the morning and we had arrived at the offices of the LCO, where we would stay for two nights before heading "to the mountain", as they say. It's a beautiful facility in the hills looking down upon an expansive view of the city and the Pacific Ocean. As we were arriving, there were exhausted looking astronomers departing, and it was fun to imagine this periodic routine of ebbing and flowing scientists there. We were shown around the building and offered office spaces to work in before we'd make our ascent to the mountain. We spent the next two days mostly preparing for observing, which included finalizing our targets and maximizing our projected signal-to-noise calculations. Fortunately, it wasn't all work and we were able to tour around La Serena on both days. We visited a traditional Chilean market and strolled amongst the early 20th century colonial architecture that comprises the city.

Then it was finally time to go to the observatory itself. We had been well advised to get to the observatory early so that we could visit the telescope, the spectrograph, and the control room. It is also helpful to stay up at least half the night before your first night observing. The LCO operates a shuttle from the observatory to the offices in La Serena and the drive would take about 3 hours. Our driver had worked for LCO for many years and was happy to chat about the surrounding area and its history. I learned that mining has been a huge part of Chile's economic growth, but that modern Chileans are very concerned about the environmental impact as well. Much of Chilean politics concerns granting and refusing international permits to mine pristine areas of Chile, some of which we happened to pass on the way. We followed the coastline closely for the first hour, and then we made a northeast diversion into the mountains, passing many entrances to mining tracts and one large solar farm. The mountains in the Atacama Desert are unlike the east coast mountains in the US; there are no trees and it is very dry and rocky. There are wild horses, donkeys, foxes, and guanacos (a cousin of the llama, as our driver described) living there.

When we reached the mountain, we unloaded our luggage into our rooms, which all have sophisticated blackout curtains for daytime sleeping, and then we quickly set off to check out the Magellan telescopes before dinner. LCO is famous amongst the big telescope observatories for their delicious food service, and particularly for "empanada Tuesday."

It was quite a steep ascent to the Magellan telescopes, and the view of the surrounding mountains is breathtaking. In the control room, we got to meet up with a post-doctoral researcher,



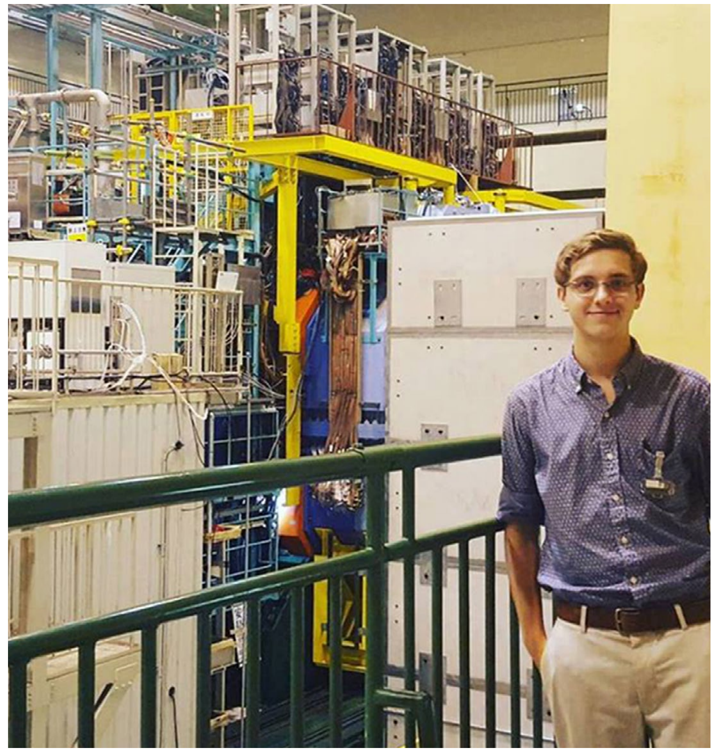
Suraj Poudel (left) and Francie Cashman (right) standing under the Magellan telescope.

Max Moe, from the University of Arizona with whom we would be sharing telescope time. We also got to meet the instrument specialist and arrange a meeting with him for the next day to get a proper tour of the telescope, the spectrograph, and the software we would be using. At dinner, the astronomers ambled in after sleeping most of the day and would soon be spread all over the mountain ridge at different telescopes. They were mostly post-doctoral researchers and what struck me most was that they all seemed to know one another despite being at different institutions and in different fields. For example, each time a new astronomer arrived on the mountain, everyone in the dining hall let out a unified "Hey!" followed by individuals saying, "How are you? I haven't seen you since that conference in …". It impressed on me that observational astrophysics could be a very small world. Everyone was fairly energetic at dinner and much of the discussion on our first day was about wildlife that had been spotted on the ridge, including a family of guanacos.

I was very excited for sunset and for my first time in a really dark sky location in the southern hemisphere. I was not disappointed. As I was watching the sun begin to set behind the mountains, the domes across the ridge were opening and telescopes were beginning to capture their calibration frames. The waxing crescent moon would set soon after the sun. A truly dark sky is phenomenal. There are so many stars. The complete darkness allows the individual colors to pop and the varying brightness levels to truly shine. It took a while for my eyes to fully adjust, and I realized that the Large and Small Magellanic clouds were right before me, low in the southwest sky. The swath of the Milky Way was like a big and bright dusty scar across the sky overhead. It appeared much dustier to me than it does in the northern hemisphere. The contrast between the bright and dark, dusty regions was gorgeous. The next night would be our turn on the 6.5 meter Magellan Clay telescope. We did some of the calibration flats in the afternoon and then returned after dinner to take sky and bias frames. We shadowed Max until midnight, learning from a seasoned observer how best to manage transitions and communicate effectively with the telescope operator to minimize time between exposures. I was very nervous when we took over, but we quickly fell into a groove, and we completed our first night with no problems! Since we were capturing spectra of very distant quasars, we had long exposures, approximately 40 minutes each, which generously allowed for short breaks if observers needed to grab a cup of coffee or tea from the break room downstairs, or enjoy your "night lunch". The telescope operators were impressed with our distant targets, and they welcomed the challenge of pushing the limits of Magellan to capture them. As sunrise inevitably arrived, we finished our end-of-run calibration flats, backed up all our data, packed up, and took the winding path back down the long, steep hill to the dining hall to have a quick breakfast. After a long night fueled by "first night" adrenaline, I was glad to lower the blackout curtains and get some sleep.

The next two nights would be very similar – magnificent weather, gorgeous sunsets, and clear night skies. There were also exciting animal sightings. A large burro was outside the entrance to the dining hall one day, the guanacos were always making an appearance on the walk up to the telescope, and I even got to see a few viscachas, adorable rabbit-like members of the chinchilla family. Astronomers kept arriving and departing, with resulting choruses of greetings in the dining hall, and conversations revolved around comparisons of how the previous night's run had gone, as well as the upcoming night's predicted weather. As busy as we were, our three observing nights seemed to pass quickly, and our time was soon up. We packed up after observing all night, had breakfast, and met our shuttle driver to make the long trip back to the offices in La Serena. Max and another post-doctoral researcher rode with us in the van. They were very kind and didn't seem to tire of inquiries for advice on being a successful graduate student. The scenery changed from high altitude desert mountains to desert plains to mountainous coastline. We slowly passed a group of wild horses near the road that paid no attention to us, and a fox that chased our van for a little while. We stopped at the offices in La Serena for a few hours before our flight and had time for one last visit to the city market for souvenirs. By the time we'd reached the airport, fatigue from staying up all night had noticeably set in, but it was easy to rest on the flight and before we knew it, we were home!

The entire journey was challenging and rewarding. It was the kind of experience where every moment is so new that you cannot help but stay intensely present. These are the life experiences that I crave, and I know that my chosen career path will manifest more chances to travel, thanks largely to the indispensible education and opportunities that I am receiving here at USC.



Undergraduate student Eric Rohm stands in front of the giant Belle II detector, which is now fully connected to the collider beamline at the KEK High Energy Accelerator Research Organization in Tsukuba, Japan.

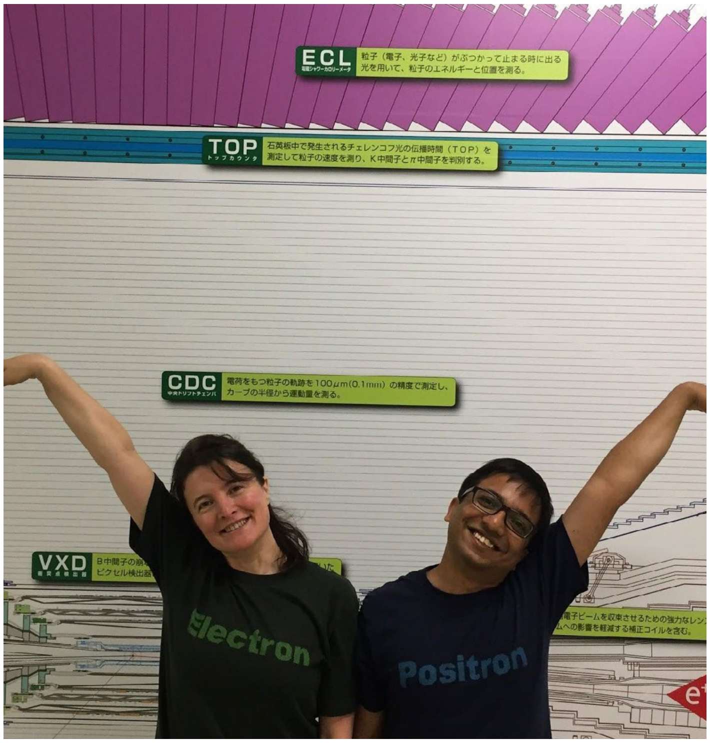
Undergraduate Research at a High Energy Particle Collider

By Eric Rohm

I became interested in physics by accident. I was never seen as a particularly gifted or talented child; my test scores, especially in math, were always statistically average at best. When we learned about Newton's laws, forces, and motion in 5th grade, I remember not caring even the slightest bit. "I'm not cut out for math or physics," I told myself, "I'll leave that sort of thing to the geniuses." I went along believing this sort of reasoning, never striving to excel in any STEM courses I had to take. When I was a teenager, I was browsing the shelves at the school library, looking for a good fiction novel to pass the time. By mistake, somebody had left a general knowledge science book lying crooked at the end of the shelf. I was picking it up to put it into its proper place when the title and cover caught my eye. It was bright and textured, with loads of strange symbols and shapes. It was titled *Physics of the Impossible* by Michio Kaku, and claimed to explain the science behind the incredible yet fictitious occurrences in science fiction and fantasy movies. I didn't care for physics at the time, but I decided to check the book out and read a paragraph or two, just to see if it lived up to its claim. By the next morning, I had finished the book cover to cover and was headed back to the library to find more like it. From that day on, I had found my passion in life; I knew that I wanted to be a physicist. Since it is such a broad subject, I had no idea which particular area of physics I would work towards. When I was in high school, however, the news became flooded with the announcement of the Higgs discovery. After reading about it, I became fascinated with particle physics, colliders, and detectors. This fascination led me to meet Dr. Milind Purohit, a professor of physics and Chair of the Department of Physics and Astronomy at the University of South Carolina. His group works on the Belle II project, a large detector located at the KEK High Energy Accelerator Research Organization in Tsukuba, Japan. The goal of the experiment is to better understand what is known as CP Violation (Charge-Parity Violation), which is the phenomenon responsible for the dominance of matter over antimatter in the early universe. Without this asymmetry, we wouldn't exist today!

Instead of turning away an inexperienced college freshman, Dr. Purohit was happy to mentor and help me become a better student of physics. When opportunities arose, he always ran them by me, and when I slacked or struggled in courses, he always helped me get back on my feet. He showed me the dire importance of hard work and concentration, and my work ethic today is almost entirely derived from such lessons. I began doing research with the group by helping to run tests on carrier boards for the Time of Propagation (TOP) detector, a subdetector of Belle II. After the tests were complete, Dr. Purohit and his graduate student, Alyssa Loos, helped me with a series of projects that taught me the basics of algorithmic programming, sequences of particle decays, and general analysis of data. Throughout all of these assignments, they helped me understand some of the important concepts of theory, experiment, and analysis in particle physics. After a few semesters of learning from him, I was given the extraordinary opportunity to fly out to KEK and work with the TOP group of the Belle II collaboration! For six weeks in the summer of 2017, I helped analyze data from tests on the subdetector under the guidance of our postdoctoral researcher, Hulya Atmacan, who is currently living and working full-time at KEK. Hulya was extremely patient and encouraging, and helped show the process of running tests, collecting data, and navigating through work life as a physicist. During my stay, I was fortunate enough to attend the Belle II General Meeting, a grand conference on the current status of the project, which was attended by scientists from nearly every corner of the Earth. I was able to meet professors and researchers from many different countries and was even able to see Dr. Purohit and Alyssa as they came for the meeting. During and slightly after this conference, there were several in-depth workshops and tutorials on the physics analysis of Belle II data, firmware, software, and many others. I was fortunate to able to attend a number of these meetings. Though most of the material was far over my head, it was still great exposure.

Now that I am back from KEK, I am eager to continue researching and learning about high energy physics. Our group is hoping to produce a publication from Belle data sometime next year, and I will do all that I can to contribute. In terms of this field of physics as a whole, I have hardly even scratched the surface of knowledge with my experiences so far. There is an infinite amount to be learned, and I plan to keep making progress little by little every single day, from now on to (hopefully) graduate school and beyond. I am extremely lucky to have such amazing mentors and to be surrounded by an environment that promotes research, knowledge, and growth so heavily. The Department of Physics and Astronomy at UofSC and its wonderful faculty and staff have consistently motivated me to continue building on my passion for physics.



Dr. Hulya Atmacan (USC) and Dr. Saurabh Sandilya (University of Cincinnati) represent the asymmetric electron and positron collision resulting in the Upsilon particle. Upsilon decays will be measured with high precision using the Belle II detector. This image was taken at Tsukuba Hall (KEK) where the Belle II detector is located.

Belle2 Program

By Milind Purohit

The Belle2 program at USC, 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. Graduate student Alyssa Loos recently won a U.S. Department of Energy Graduate Research Fellowship Award to work at Pacific Northwest National Laboratory for one year. This past summer, undergraduate Eric Rohm spent 6 weeks at Japan's KEK lab to work with our 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 "Phase II" data!

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

Experimental Nuclear Physics Group

By Ralf Gothe, Yordanka Ilieva, and Steffen Strauch

Figure 1 shows members of the experimental nuclear physics group, which is comprised of faculty members Ralf Gothe, Yordanka Ilieva, and Steffen Strauch and graduate students Gary Hollis, Lin Li, Chris McLauchlin, Nicholas Recalde, Nick Tyler, and Iulia Skorodumina, and joined by many undergraduate students working with us at 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) that recently has been upgraded to higher energies and at the Paul Scherrer Institute (PSI) in Switzerland. We have also been 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, and our research helps to address basic questions such as: what is the origin of confinement and most of the visible mass in the universe, what is the nature of neutron stars, and what are the properties of dense nuclear matter? Answering these and related questions is a complex task requiring dedicated experimental observations and careful testing of theoretical predictions against measured observations.

In many ways, the past year was extra packed with new beginnings and interesting events for all of us nuclear physicists at USC. First, we are very happy to recognize a notable group of freshly graduated Ph.D.s: Dr. Colin Gleason on *Determination of Polarization Transfer Coefficients and Hyperon Induced Polarization for Quasi-free Hyperon Photoproduction off the Bound Neutron* with Yordanka, Dr. Hao Jiang on *Polarization the Observables T and F in the p(,°)p Reaction* with Steffen, Dr. Aneta Net on *Polarization Observables in Double-Pion Photoproduction with Circularly Polarized Photons off Transversely Polarized Protons* with Steffen, Dr. Evan Phelps on *Electroproduction of Mesons off Protons in the Third Resonance Region and Beyond* with Ralf, Dr. Ye Tian on *Exclusive π Electroproduction off the Neutron in Deuterium in the Resonance Region* with Ralf, and Dr. Arjun Trivedi on *Measurement of New Observables from the Electroproduction off the Proton* with Ralf. All of them are now either continuing research at universities, work for companies, or have started their own business. We wish them all a great future and successful careers. With respect to our current graduate students, we are especially proud of Iuliia Skorodumina, see Fig. 2, who has received one of the competitive JSA Graduate Fellowships at Jefferson Lab and of Hao Jiang, see also Fig. 2, who won the Department's 2017 Graduate Student Research Award.

In the past year, we also participated in organizing the INT-16-62-W workshop on the *Spectrum and Structure of Excited Nucleons from Exclusive Electroproduction* at the Institute for Nuclear Theory in Seattle, and with the total solar eclipse in town, our group poured all their heart and soul into organizing and running the international NSTAR 2017 workshop here at USC with 100+ experts from all over the world (see separate article in this *Quantum Leap* edition).

We have also further advanced our hardware projects. Our group plays a major role in the 12-GeV JLab upgrade with the development, construction, and implementation of a new addition to the Time-of-Flight (TOF12) spectrometer for the

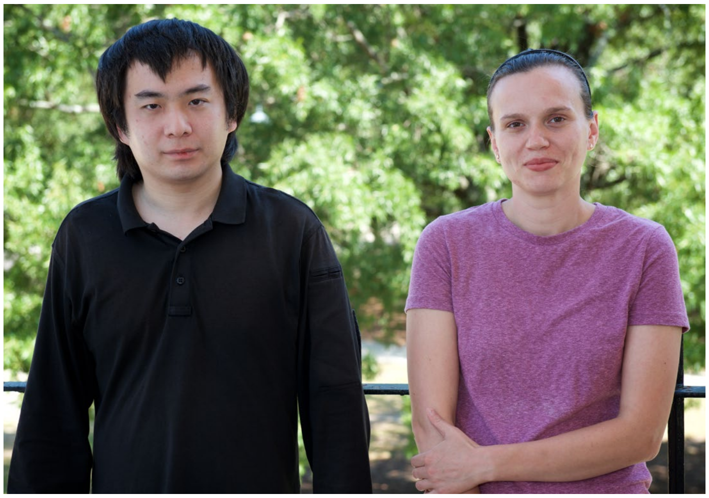


Figure 2: Iuliia Skorodumina (right), winner of the JSA Graduate Fellowships for her outstanding research work and service contributions to Jefferson Lab community and Hao Jiang (left), winner of the 2017 Graduate Student Research Award of the Department of Physics and Astronomy.

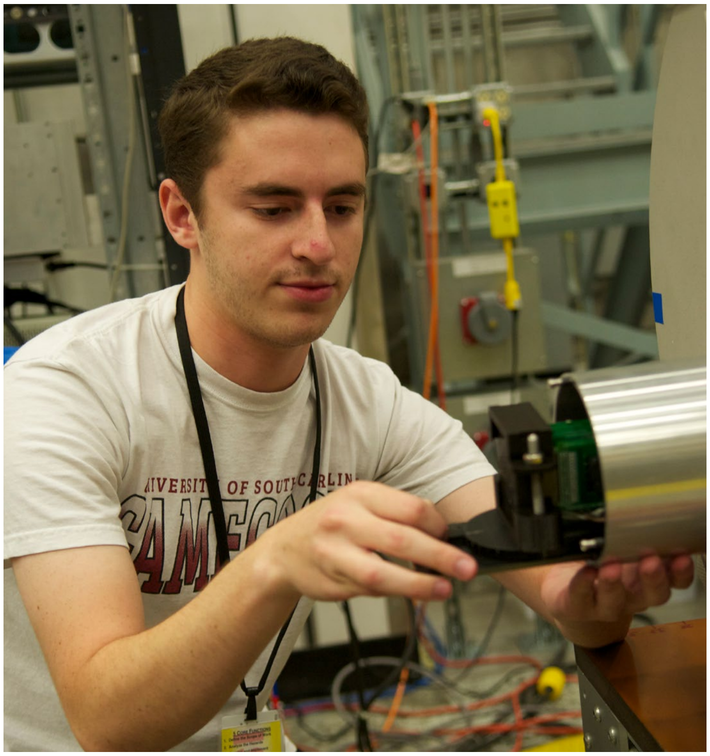


Figure 3: Undergraduate student Joshua Rapoport in the high B-field test facility at Jefferson Lab during measurements of the gain of a small photon sensor in high magnetic fields.

CLAS12 detector in Hall B that is essential for the particle identification during our experiments. Ralf Gothe is leading these efforts and is coordinating all approved experiments on the electroexcitation of nucleons in Hall B at Jefferson Lab. During his sabbatical he was mostly stationed at JLab contributing to a successful first test run to establish the Key Parameter Performance of the CLAS12 detector, the calibration of all time-of-flight systems, and the final preparation for the first experiment with CLAS12. Under Steffen Strauch's lead, we are now finalizing the first big shipment time-of-flight detectors for our Muon Scattering Experiment (MUSE) at PSI. MUSE is a scattering experiment of muons and electrons off protons target that aims to compare the extracted proton charge radii for these two leptonic probes to study the Proton Radius Puzzle. During Steffen's upcoming sabbatical, he will be staying at PSI to supervise the installation and commissioning of all the detector elements built at USC and of the MUSE experiment itself. All these are milestone achievements of our group, and not only of the senior personnel but also of a large number of graduate and undergraduate students, that involved efforts over many years.

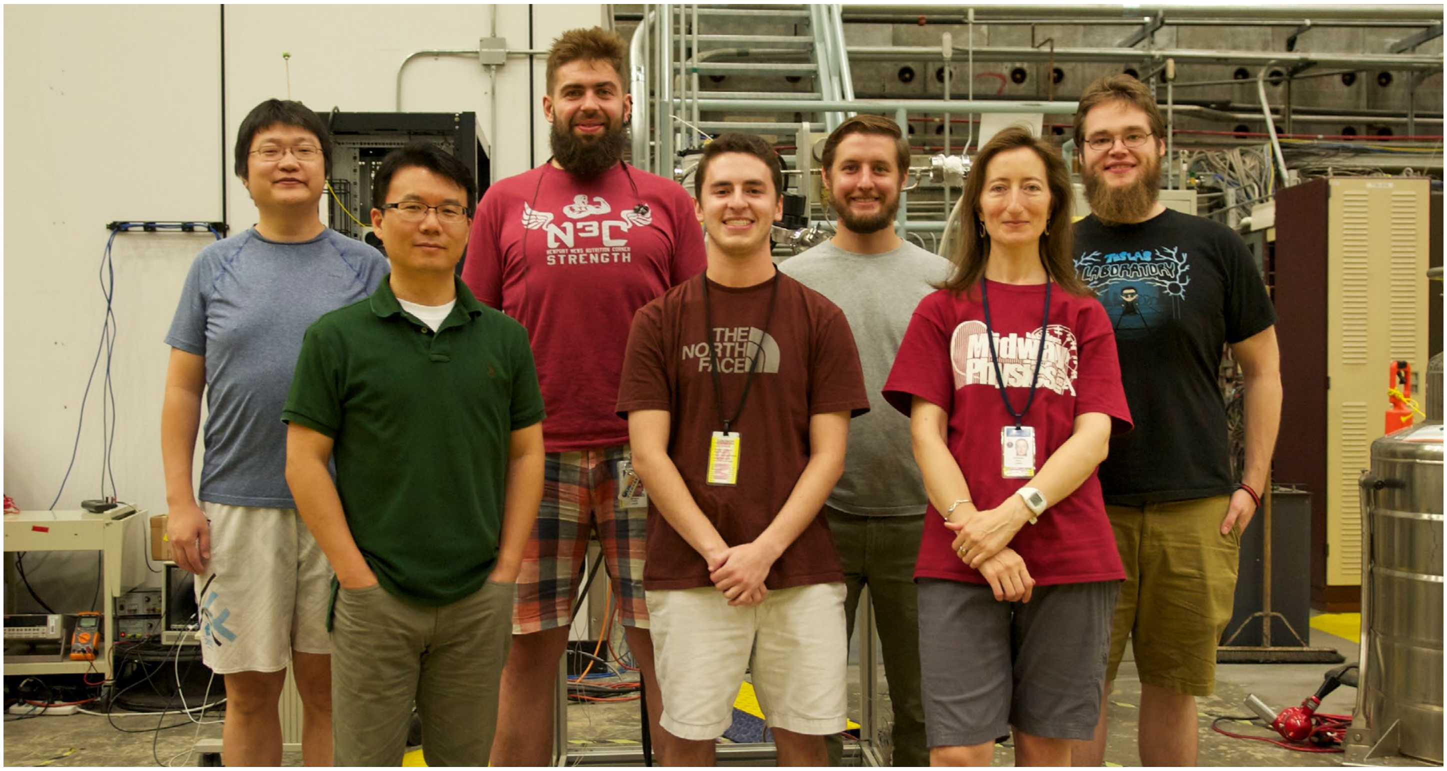
As part of the JLab R&D efforts related to building an Electron Ion Collider (EIC) in the U.S., we are responsible for the maintenance and operation of a dedicated test facility at Jefferson Lab, where the performance of small size photon sensors in high magnetic fields can be evaluated. After setting 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 Tesla. We have secured funding to continue this activity in 2017-2018 through a collaborative *EIC PID Consortium* proposal and plan more measurements in summer 2018. We have also begun implementing the sensor structure in Geant4 simulations to support the design optimization of the manufacturers. Graduate student Colin Gleason and undergraduate Joshua Rapoport, see Fig. 3, contributed to this project led by Yordanka Ilieva.

We are always proud of the significant amount of effort we invest into teaching, mentoring, and training of our students and are happy that some of these efforts have been recognized by the Michael J. Mungo Undergraduate Teaching Award for Ralf Gothe.

News from Fred Myhrer

By Fred Myhrer

This year, Dr. Myhrer has been working on a radiative correction to low-energy lepton proton scattering project, a study needed for the MUSE experiment where our USC Experimental Nuclear Physics group is actively involved. This study is a project for Mr. Pulak Talukdar, who is a graduate student of Dr. Udit Raha. Dr. Raha, who was a postdoctoral fellow at USC, is now a professor at the Indian Institute of Technology, Guwahati. Dr. Myhrer is also actively involved in other research projects with Prof. E. Epelbaum and his group at the Ruhr University (Bochum) in Germany. Dr. Myhrer has visited Bochum a few weeks each summer for the last several years. The research projects are all based on low-energy effective field theory. The research results have been presented in seminars and at conferences.



Recent doctoral graduate Colin Gleason (2nd row, 2nd from right) and his group participating in research and development activities at the Electron-Ion Collider (Brookhaven National Laboratory – Upton, NY). This picture was taken after completing two weeks of experiments in the Test Lab at Jefferson Laboratory (Newport News, VA).

Research by Colin Gleason

By Colin Gleason

On July 6, 2017, I successfully defended my dissertation after six years of being a graduate student at the University of South Carolina. My work was part of an international effort to try to understand how quarks and gluons interact inside of particles like the proton and neutron. Understanding how these particles interact would mean understanding how protons and neutrons gain their mass. This has been a problem puzzling the scientific community for many years, and one that will continue to do so.

In addition to this work, I spent a lot of time working on two fun and interesting side projects. I call them side projects only because they were not a part of my dissertation. The first side project was working on research and development for the next major particle accelerator to be built in the United States, known as the Electron Ion Collider (EIC). The EIC will be able to probe the gluons that bind quarks together. The second side project was helping develop and build a detector to be used in measuring the radius of the proton for the MUon Scattering Experiment (MUSE).

For the EIC R&D, I spent about 7 weeks over the course of 2 years at Thomas Jefferson National Accelerator Facility (JLab) working with a wide range of people, from undergrads to staff scientists, on testing the performance of light sensors (MCP-PMTs) in high magnetic fields. Experiencing the atmosphere of JLab, and being around hundreds of physicists, such as grad students struggling on their work to the staff that built this massive electron accelerator and seem to know nearly everything, is quite inspiring.

For the MUSE project, I was actually able to help build a piece of a detector that would be used in one of the most exciting (at least in my opinion) upcoming nuclear physics experiments. Prior to joining this project, I had always thought of nuclear/particle physics detectors as these massive pieces of equipment. On this project, I actually learned how these detectors get built. I got to be the person testing this sensor, wrapping that piece of equipment, and solving the problems that inevitably arise when one tries to do something new.

When I look back on my last six years as a grad student, memories from my time doing research are the ones that have stuck with me. I will always remember that I got to work on exciting projects with fun, knowledgeable, and interesting people. As I was approaching my defense and (hopeful) graduation, I began applying to postdoctoral positions located at JLab. Not only did I want to continue pursuing similar research that I was doing for my dissertation, I wanted to be part of the JLab community and work on projects at the forefront of nuclear physics research. Being part of this community means working with, learning from, and getting to know some of the best researchers in the field. I had a great experience working with the Experimental Nuclear Physics Group at South Carolina, and even though I am leaving the university, I will still be connected to the group through JLab.

Figure 2. Graduate student Chatura Kuruppu participates in an early morning NOvA project shift in the ROC-West (Remote Operation Center) at Fermi National Accelerator Laboratory (Batavia, IL).

High Energy Neutrino Physics Group

By Sanjib Mishra and Roberto Petti

The focus of the Carolina Neutrino Group is the NOvA and DUNE experiments. The group currently comprises two faculties, Prof. Sanjib. R. Mishra and Assoc. Prof. Roberto Petti; one post-doctoral fellow, Dr. Hongyue Duyang; two graduate students, Bing Guo and Chatura Kuruppu; and three undergraduate research assistants, Edward Dunton, Travis Dore, and Avery Freeman.

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 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 2017, published updated measurements of neutrino oscillations using both the electron appearance and the muon disappearance channels (Fig. 1). Future data-taking in antineutrino mode will help resolve the remaining degeneracies in the mixing parameters, as well as search for possible hints of CP violations. 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, Guo, and Kuruppu work on NOvA.

The Carolina group has a duplicate of the NOvA control room fully operational 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 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 detector of 40 metric-kilotons located 1,300 km away at the

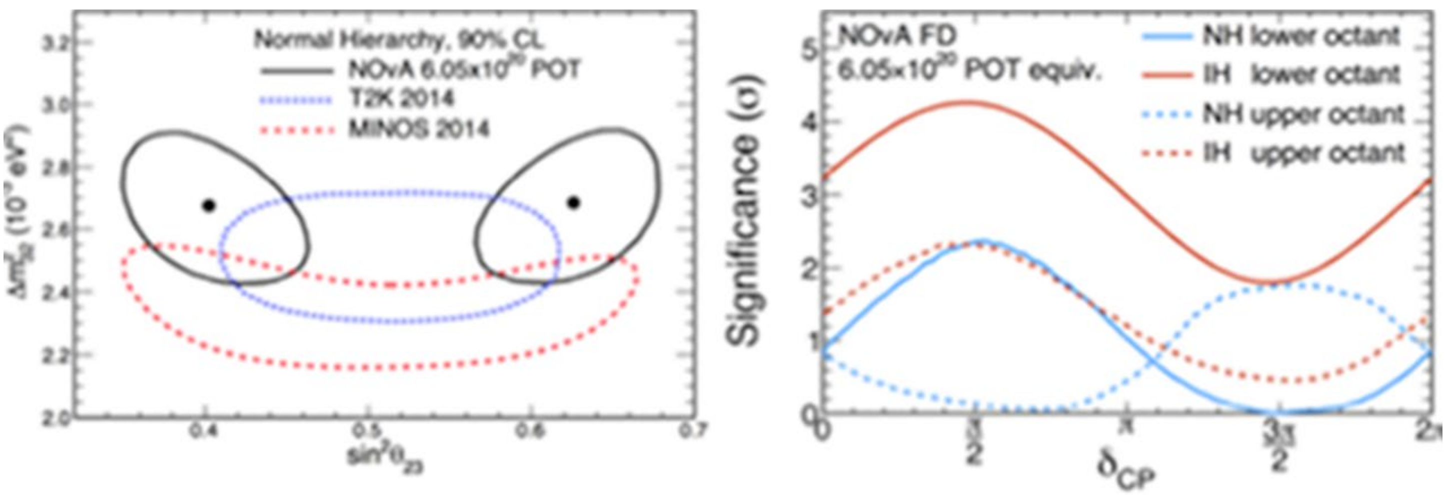


Figure 1. Results from the NOvA experiment at Fermilab published in 2017. Left panel: allowed regions at 90% CL for the oscillation parameters consistent with the new NOvA measurement of muon-neutrino disappearance (solid line) compared with previous measurements from other experiments (dashed lines). Right panel: significance at which each value of the CP-violating phase $_{CP}$ is disfavored by the combination of the NOvA νe appearance and NOvA's latest νμ disappearance measurements.

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. The FGT detector would combine for the first time 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. In 2017, the DUNE collaboration decided to augment the ND capabilities by adding a 30 ton modular liquid argon detector in front of the FGT. The Carolina group is expected to play a leading role in the R&D phase in preparation for the CD2 approval in 2019.

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

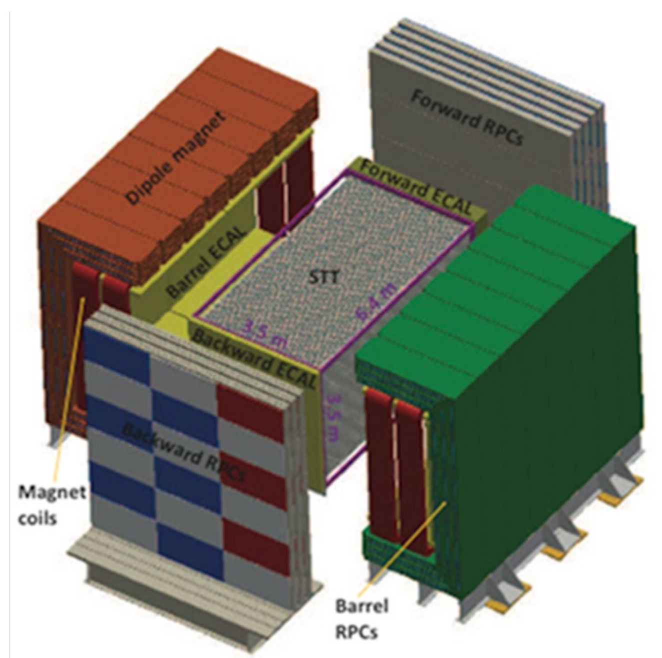


Figure 3. Schematic of the reference Near Detector of the DUNE experiment. The central Straw Tube Tracker (STT) is surrounded by a 4pi electromagnetic calorimeter (ECAL) placed inside a large aperture dipole magnet. Muon identification is provided by RPC located inside the iron yoke of the magnet and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

The large and bright corona of the Sun seen from the Melton Memorial Observatory during the total solar eclipse on August 21, 2017. Image taken by researcher Erdogan Ozel.

News from Timir Datta's Group

By Timir Datta

This year was marked by graduate student Lei Wang's completion of his doctoral dissertation - "Geometric Influence on Electronic Properties: Graphene with Antidots, Two-Dimensional Electron Gas and Three-Dimensional Carbon Nanostructures."

Also memorable was the trip (March 13-17, 2017) to New Orleans, LA for the annual APS March Meeting. Our collaboration included Ming Yin's DOE supported program at Benedict College. They gave four talks and chaired a superconductivity session at the meeting. As in the past, former group member, Erdogan Ozel (with funding from Balikesir University, Turkey), joined us as a summer research intern.

In August, Javier Estrada (Ph.D., 1989) and family from Michigan passed through his old lab on the way to summer vacation at Pawley's Island, SC. Incidentally, Estrada took possession of his old champagne bottle at USC and brought it back home with him.

The biggest news of the year was the total solar eclipse. The group planned to re-do Arthur Eddington's famous experiment of 1919, which, for the first time, verified Einstein's theory of general relativity and the predicted the bending of light paths (geodesics) due to the curvature of space-time geometry.

On Monday, August 21, 2017, the day of the eclipse, totality looked spectacular from the deck atop the Melton Memorial Observatory. The beautiful corona was bright and extended all around the sun, which made it difficult for us to image the 9-11th magnitude stars that were within the field of view. Former Melton staff member Dan Overcash has some images that we plan to analyze soon, which will hopefully show enough detail to resolve the expected shift associated with GR.

Recent graduate Lei Wang places the signed, dated (July 26, 2017), and emptied celebratory Ph.D. champagne bottle on top of "the cabinet of doctoral fame."

SmartState Center for Experimental Nanoscale Physics

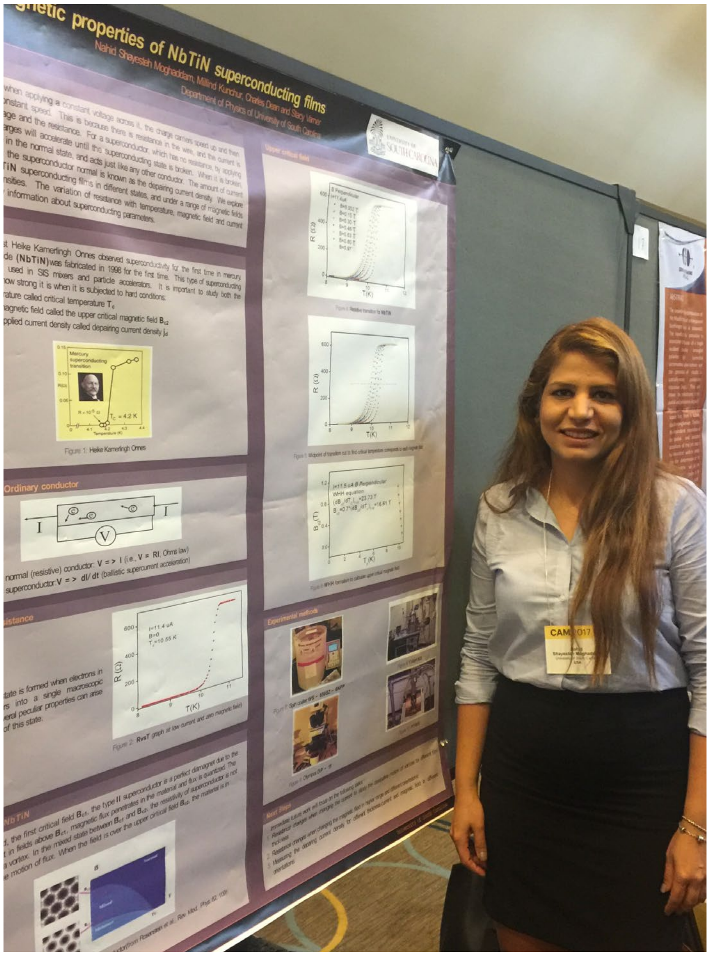
By Thomas Crawford

2016-2017 has been a strong year for the SmartState Center for Experimental Nanoscale Physics. The Center's junior faculty member, Yanwen Wu, was awarded a prestigious CAREER grant from the National Science Foundation. Her proposal, *"CAREER: An all-optical plasmonic device to control and couple quantum dots for optical and quantum information processing"* was funded at 500k for 5 years, from 2017-2022. From Wu's NSF abstract, "The objectives of the proposed research project are two-fold. The first explores a new approach for manipulating and tuning the internal energy states of a single quantum dot through the optical modification of its local dielectric environment using a plasmonic gate. This indirect method exploits the strong near-field effect of the plasmonic structure as a means of control while avoiding significant changes to the intrinsic properties of the quantum dot due to ohmic loss. The second investigates the coherent and incoherent couplings between two spatially separated quantum dots via a plasmonic waveguide and establishes entanglement between the linked dots through a dissipative coupling channel. This coupled design protects stored information in the presence of ohmic loss while maintaining the ultrafast optical readout and broadband guided transfer enabled by a plasmonic waveguide. All of these capabilities are highly desirable in a wide range of applications from ultrafast optical switches to quantum information processing."

Asst. Professor Yanwen Wu won a 5 year NSF CAREER award in spring 2017

Associate Professor Yuriy Pershin was awarded the APS-Brazil-U.S. Physics Professorship award, which supported Prof. Pershin to travel to Brazil during summer 2017 to teach a short course entitled "Nanoscale memory devices: Fundamentals and applications". This lecture again demonstrates Prof. Pershin's leadership in the area of novel memory concepts, at both the circuit level, i.e. the Memristor and Memcapacitor, as well as at the material level, where he has published some exciting simulations of graphene nanodevices. Associate Professor Scott Crittenden, working with Assoc. Prof. Brett Altschul and Prof. Thomas Crawford, has prepared a paper on chemical modification of thin metallic films, "Ligand induced magnetic changes in metal thin films". In addition, Crittenden's 2nd Ph.D. student, USC Physics undergraduate alumnus, Jason Giamberardino, is preparing to graduate with the Ph.D. in December 2017. Associate Professor Yaroslaw Bazaliy continues to collaborate with Prof. Revaz Ramazashvili, of the Laboratory of Theoretical Physics at the University Paul Sabatier, Toulouse, France. In a recently published paper appearing in the journal *Applied Physics Letters,* they studied local injection of pure spin current into an electrically disconnected ferromagnetic-normal sandwich. The authors state, "Curiously enough, it turns out that *local* spin injection inevitably induces electric current vortices, that are centered at the normal-ferromagnetic interface. This finding invites us to revisit various aspects of spin injection in spintronic devices." Professor Thomas Crawford continues to collaborate with Jennifer Andrew, Materials Science, University of Florida, studying magnetic field-directed assembly of multiferroic Janus nanofibers. Ph.D. candidates Bryan Chavez and Cory Dolbashian are both studying these novel nanomaterial systems, with Chavez focused on imaging these fibers in a curing polymer as they chain end-to-end in a magnetic field. Interestingly, Chavez has found that the chaining dynamics are strongly dependent on nanofiber concentration, with standard power law length growth occurring at low concentrations, and much more rapid assembly occurring at high concentrations. Chavez presented these findings in June at the "Frontiers in Biomagnetic Particles" conference in Asheville, NC. Dolbashian, meanwhile, has been able to measure the hysteresis loops of these chained fibers using the Mageneto-Optical Kerr Effect. Crawford continues to study self-assembly of magnetic nanoparticles onto patterned magnetic recording media, in collaboration with Thompson Mefford (Materials Science, Clemson), and recently with Prof. Karen Livesey, a theorist in the Physics Department at the University of Colorado-Colorado Springs. Ph.D. candidates Sara FitzGerald and Rahman Mohtasebzadeh are studying how the recording media properties and the write head behavior, respectively, impact the shapes and precision of self-assembled structures that form on the disk surface. These projects have both been funded by NSF through a standard grant (Multiferroic fibers) and as a subaward to MagAssemble LLC's NSF Phase 2 SBIR award. A separate article in this edition of *Quantum Leap* focuses on Center startup MagAssemble, LLC.

Associate Prof. Yuriy Pershin won the APS Brazil-U.S Professorship program award, "Nanoscale memory devices: Fundamentals and applications"



Graduate student Nahid Shayesteh proudly displays her research poster at the Canadian-American-Mexican Graduate Student Physics Conference (Washington, D.C.) in May 2017.

Research by Nahid Shayesteh

By Nahid Shayesteh

In our research group, we systematically investigate the superconducting properties of different superconducting thin films with different geometries using two different systems: PPMS (Physical Property Measurement System) and Cryomech. I was selected among applicants to present our work at both Discover USC 2017, sponsored by the Office of the Vice President for Research, and also the Canadian-American-Mexican Graduate Student Physics Conference 2017 in Washington, D.C. Discover USC was an exciting and inspiring experience, in which I was able to get strong feedback from other students and judges on my work and also learn more about other research areas led by fellow graduate students. The CAM (Canadian-American-Mexican) Conference was another great opportunity to build my international networking skills and develop my key professional abilities. During my travels, I was exposed to a wide variety of perspectives, which I believe can ultimately help me be more successful and productive.

News from 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. During this past year, Kunchur has presented his research results at invited talks at international conferences including the "DAE Solid State Physics Symposium in Bhubaneswar, India" and at the "Second International Workshop on Towards Room Temperature Superconductivity: Superhydrides And More" in Orange, California. During this year, Kunchur wrote two invited review articles—one in "Physics News" and one in "Quantum Studies: Mathematics and Foundations" —which are currently in press. Professor Kunchur currently has three graduate students—Charles Dean, Nahid Moghaddam, and Stacy Varner. Two undergraduate students—Christine Reid and Habiba Fayyaz—worked in Kunchur's group during 2017.

Professor Kunchur won the Michael A. Hill Outstanding Faculty Member award in May of 2017. The Michael A. Hill award winner is chosen by the graduating seniors from the Honors College, as the faculty member who had the most profound influence and impact on their lives and careers during their four years at USC.

Physics and Astronomy Alums find employment on campus in SmartState Center-incubated startup MagAssemble LLC

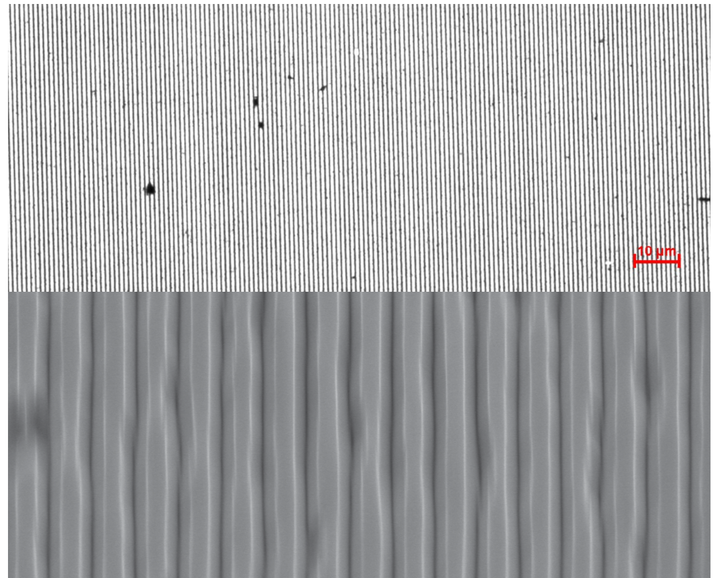
By Thomas Crawford

While graduation often means a bittersweet goodbye to a place one has called home for a number of years, several recent graduates from the Physics and Astronomy department have found a way to extend their stay on the USC campus, working for a USC-launched startup venture, MagAssemble LLC. MagAssemble is currently renting lab and office space in the SmartState Center for Experimental Nanoscale Physics, which is housed on the first floor of Sumwalt.

James (Adam) Fisher graduated in Spring 2015 with his Bachelor's degree in Physics. He performed undergraduate research in Prof. Crittenden's lab, was accepted to graduate school to study Materials Science, and was planning to matriculate at the Arizona State University. Because of unforeseen difficulties, he ended up deciding to hold off on graduate school. The timing couldn't have been better, as MagAssemble LLC received a Phase 2 SBIR award from NSF that began in March 2016, and Fisher joined MagAssemble's team to execute the Phase 2 project. Now in charge of Production for MagAssemble, Fisher has been involved in everything from building MagAssemble's diffractive optical elements (DOEs), to writing custom software, to doing telephone outreach to potential MagAssemble customers. "A Physics degree provided me with the tools to apply analytical and data-driven solutions to real-world products," says Fisher. "I think being involved with a start-up company is a good experience because you get a crash course in the nuances of technical R&D, as well as an understanding of the motivations on the business side."

Ph.D. program alumnus Dr. Longfei Ye has been working for MagAssemble since spring 2014, when he took over as the Principal Investigator on MagAssemble's NSF Phase 1 SBIR award. After a 6 month Phase 1 period, which was followed by a 6 month Phase 1B, Ye served as PI on MagAssemble's Phase 2 submission in July 2015. With matching funds from SC Launch and the SC Launch University Startup Assistance Program (USAP), Ye was able to keep MagAssemble going until the Phase 2 award funds arrived in late spring of 2016. Now head of Research and Development for MagAssemble, Ye is reflective about the uncertainty and hard work he's had to endure to get MagAssemble "off the ground." "Though we have made tremendous progress in optimizing our technology towards manufacturing prototypes that meet customer specifications, we're still not done yet", Ye says. "We have to find the product

Fisher (left) and Ye (right) discuss the operation of MagAssemble's software for recording patterns onto disk drive media in Prof. Crawford's lab at USC.



Images of MagAssemble transmission and reflection diffraction gratings. Top: Optical image of SiO2 lines with a square-wave profile and 1.5 μm trench depth. Bottom: SEM image of Si grooves with a triangular profile.

and market fit that launches MagAssemble. I believe we will, as we continuously understand customers' 'pain' and our 'point of impact' better. Wherever MagAssemble ends up eventually, our hard work will pay off."

During the Phase 1 and Phase 1B phases, Ye worked closely with another P&A undergraduate alumnus, Cameron Nickle, who graduated from USC in Spring 2014 with his B.S. in Physics, and went straight to work for MagAssemble. After a year with the startup, Nickle entered the Ph.D. program in Physics at the University of Central Florida in Fall 2015, and has joined UCF College of Optics and Photonics' Center for Research on Electro-Optics and Lasers (CREOL).

Currently, MagAssemble, which is commercializing aspects of research done by P&A Professor Thomas M. Crawford, is offering reflective (amplitude) and transmission (phase) diffraction gratings (DOE) for sale that were made using Crawford's Pattern Transfer Nanomanufacturing, PTNM™ technology (see Figure below for images of MagAssemble DOE's). "Getting beyond Phase 2 is a very hard challenge," says Crawford, MagAssemble's Founder and current CTO. "You have to achieve sufficient scale to deliver a product to an actual customer and meet their specifications if you want to convince potential investors that you are a real company. But it requires capital, time, and the right team to deliver this scale, so it's kind of a chicken-and-egg problem, or threading a tiny needle, if you will." Together with Ripple Management's (Atlanta, GA) Tyler Tatum, who was MagAssemble's CEO from 2014-July 2017 and is now CCO (Chief Customer Officer), Charleston native, Moore School (USC) graduate, and local entrepreneur John Busch, who took over the reins as CEO in July 2017, Ye, Nickle, Fisher, and Crawford, have all spent many minutes on phone calls with potential customers. "We spoke with more than 250 other companies at the Optical Fiber Conference this past year," says Tatum, who is also a Mentor for NSF's Innovation Corps (I-Corps) program, which assists NSF-funded faculty and students in determining whether to pursue commercialization of their research. "While many of these contacts do not end up as customers, the experience of trying to understand their "pain," as customer need is referred to in modern business jargon, is one that really helps focus startup R&D on the primary goal," says Tatum. While starting a company may not be the easiest task, it offers different kinds of experiences, both challenging and rewarding, as compared with basic or applied academic research. "You are building every day, moving something forward," says Crawford. As for being at USC, "Being a part of the start-up culture can be fast paced and exciting. Being on a campus, I am familiar with leveraging all of the tools at my disposal," says Fisher. As Busch states at the end of every Operations meeting that are held Tuesday afternoons in Crawford's office in Sumwalt, "Let's go build a company."

Prof. Frank Avignone talking to Dr. France Cordova, the new Director of the National Science Foundation (NSF), that the CUORE detector array is the coldest cubic meter in the universe. Dr. Cordova visited the Gran Sasso Laboratory (LNGS) in Assergi, Italy on September 25, 2017 as the NSF supports a half dozen major experiments in Particle Astrophysics at LNGS.

CUORE researchers working on the bottom of the CUORE Dilution Refrigerator at LNGS.

Particle Astrophysics Group

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

Particle Astrophysics focuses on the study of phenomena in astrophysics and cosmology associated with the properties of elementary particles including neutrinos, axions, and candidates for Cold Dark Matter (CDM). In 1933, Fritz Zwicky discovered that far more mass is needed to explain the dynamics of the Coma Cluster of galaxies than can be accounted for by stars, gas, and dust alone. The gravitational influence of CDM on the velocity distribution of stars in spiral galaxies 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. Three Ph.D. graduates from our group have joined the PNNL staff. Two are now PNNL Laboratory Fellows.

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, the Jesse Beams Medal of the American Physical Society was awarded for USC's 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 fully constructed Majorana Demonstrator experiment operating within a low background shield on the 4850-ft level of the Sanford Underground Research Facility (SURF) in Lead, SD.

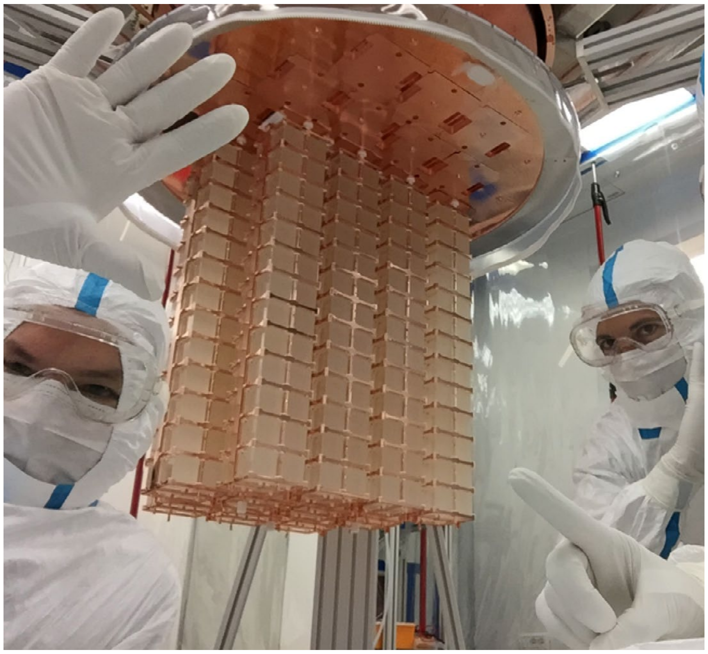
oscillation experiments clearly demonstrate that neutrinos have mass, but they can only measure mass differences of the mass eigenstates. The measurement of the rate of 0vBB–decay would determine the absolute masses of all three neutrino-mass eigenstates.

The USC group was deeply involved in the construction of the CUORE double-beta decay experiment in the Gran Sasso Laboratory from the very beginning. CUORE-0, the latest prototype, 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 0vBB–decay of ^{130}Te. CUORE, a 760-kg detector using the same low-temperature technique, began operation recently, and is performing well and taking physics data. The group's main construction responsibility was the fabrication of the front-end electronic system led by Carl Rosenfeld. The USC group has been maintaining a presence of students and staff at the Gran Sasso Laboratory year around since 2001.

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. This technique was used by other groups 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) now operating 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 currently concentrates on two searches for the exotic zero-neutrino nuclear double-beta decay (0vBB–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

When Jeff Wilson joined the USC Particle Astrophysics Group, he brought computational expertise in Monte Carlo simulations using GEANT and the most up-to-date data analysis techniques. He previously worked on data analysis for the BaBar experiment at the Stanford Linear Accelerator Collider (SLAC) facility. Jeff has guided several graduate students in their orientation to the CUORE computational tools. For example, the group is introducing a new concept of using the CUORE array to study the 0vBB–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. Jeff Wilson is guiding Christopher Alduino 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 previously worked with Rosenfeld and Avignone while playing a major role in the fabrication of the CUORE electronics. He is now a graduate student in the group.



Hanging the CUORE towers of bolometers at LNGS.

Our group has played a leading role in development of the Majorana Demonstrator, a 21-million-dollar research and development project designed to establish the feasibility of building and operating a next-generation ^{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. In the last year, the collaboration started operation of both detector modules with a total detector mass of 45 kg (30 kg enriched in ^{76}Ge) within a low background shield. Physics Ph.D. student Clint Wiseman had spent significant time onsite preparing the detectors and assisted in the careful loading and installation of the strings of Ge detectors that form the detector array. Most recently, Clint spent most of last year at Los Alamos National Laboratory for his DOE Office of Science Graduate Student Research Program award. There, he worked with Majorana Collaborators on R&D of a novel gas scintillation cryostat and new digital signal processing techniques for analysis of low energy physics data. Prof. David Tedeschi continues to lead the data production for the Majorana Demonstrator experiment and tracks the run status in real time through his custom run database. Asst. Professor Vincente Guiseppe was recently elected the as a new Co-Spokesperson of the Majorana Collaboration and continues to manage the operation of the experiment's mechanical systems and contributes to data analysis topics. The Majorana Demonstrator has achieved the best energy resolution and its initial backgrounds are amongst the lowest in the region of interest. Collaborators in the USC Majorana group are founding members of the newly formed LEGEND Collaboration (Large Enriched Germanium Experiment for Neutrinoless BB Decay), which is planning a next generation experiment based on the successes of Majorana and the European GERDA experiments.

Searching for Solar Axions in Los Alamos

By Clint Wiseman

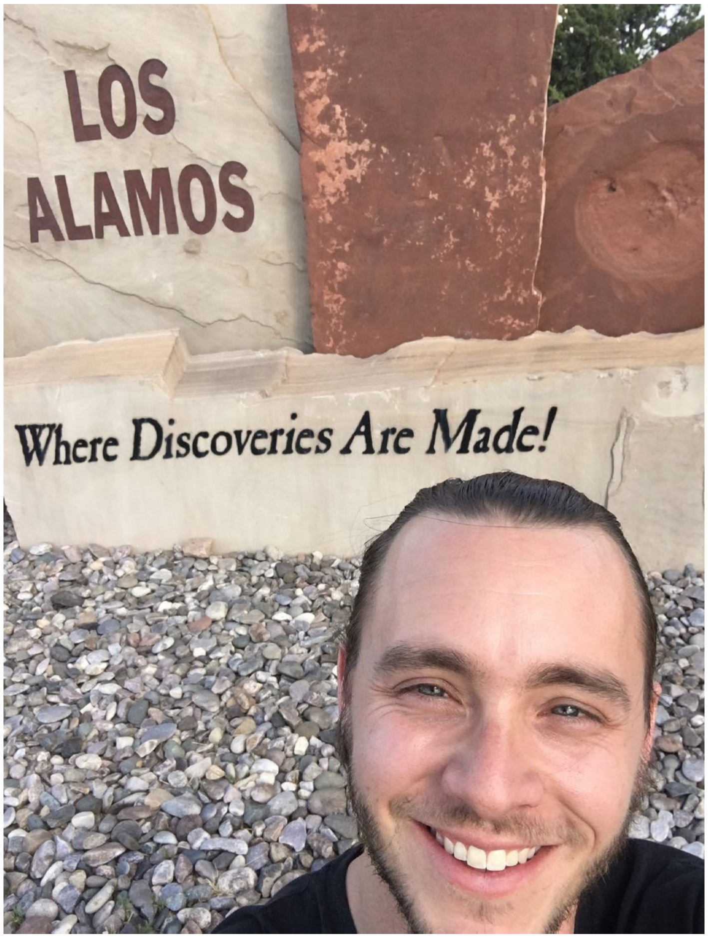
Almost overnight, a secret city appeared in 1942, high on a desert mesa in northern New Mexico overlooking the Rio Grande. Working under the highest security, a group of engineers, soldiers, and the brightest minds in physics came together to build a "device" that, for better or for worse, defined our modern era. Nearly 75 years have passed since then, and the city has grown up. The once-secret facility has grown into the Los Alamos National Laboratory (LANL). At the local brewery, right across the street from houses that belonged to Oppenheimer and Bethe, you can overhear scientists of all stripes discussing some of the strangest technical topics under the sun. You might even hear them discussing the sun itself, and the mysteries it might help us solve.

Physicists searching the universe for signs of the mysterious "dark matter" have proposed many different potential candidates, but experiments searching for these exotic particles have yet to make a discovery. One such candidate, the "axion," may be being produced in the interior of the sun in vast quantities. A single axion emitted from the sun would be able to pass through enormous distances of solid matter without causing a single disturbance. Fortunately, if the models are correct, roughly 10^{11} solar axions would hit a single square centimeter of the Earth every second, bringing the chance of observing a handful of interactions into the realm of possibility.

Looking for these axions has taken me from classrooms in South Carolina to a deep underground lab in South Dakota, and, this year, a risky new detector design and a DOE fellowship took me to Los Alamos. During my time in New Mexico, new results from the experiment in South Dakota opened up an exciting new research avenue for me, and with my teammates at LANL, I found myself pivoting to take advantage of it.

For the last four years, I have been heavily involved in the construction and testing of the Majorana Demonstrator experiment in South Dakota. This is an array of some of the world's most sensitive radiation detectors (high purity germanium or "HPGe"), nestled inside a multi-layer cosmic ray shield -- which includes a Boeing 737's weight in lead bricks -- buried under nearly a mile of rock in a former gold mine. The idea is simple: if you take the most sensitive particle detector you can make, and try to block out as many types of "known" signals as possible, then anything that still makes the detector go "click" could be the sign of something new - like the signal of an axion.

Shielding a detector from the natural radioactivity of its own components is a difficult challenge. One solution is to submerge



Graduate student Clint Wiseman at Los Alamos National Laboratory in New Mexico. Clint spent six months at LANL on a DOE fellowship searching for solar axion dark matter with the MAJORANA collaboration.

it in a vat of liquid argon, and look for events where scintillation light in the argon and a signal in the germanium occur simultaneously. This is a sign that an "unwanted" event has happened (we require our signals come from a single germanium detector only) and we can then "veto" these events from our analysis. However, the liquid argon has a very undesirable side effect: it produces large numbers of low-energy signals that completely obscure any solar axion or other dark matter signals we might see.

One evening on-site in South Dakota after our underground shift was over, I was talking with a scientist from Los Alamos who mentioned that he was trying to operate germanium detectors in a gas environment. We soon realized that it would also be possible to try and detect the scintillation light from argon gas (though it would be a much weaker signal than in liquid) and try to use that as a "veto" system, with any luck preserving the detector's ability to search for axion signals. He said offhand, "oh, you should come to Los Alamos and try to build this." That night I did some googling and found a Department of Energy fellowship program for graduate students - the Office of Science Graduate Research Program (SCGSR). The program offered a stipend to come and work with a mentor at a national lab. After talking with my USC advisor, Dr. Vincente Guiseppe, and getting in contact with people at LANL, I submitted my application, and a few months later, got the award and drove across the country to New Mexico.

I spent six months living in Los Alamos, at the town's 7000-ft elevation, with breathtaking views of the Sangre de Cristos and Jemez mountain ranges, and equally breathtaking traditional New Mexican food; the green and red chile grown in the area happily finds its way into nearly every dish. A savvy person ordering a breakfast burrito in nearby Santa Fe can ask for "christmas" and receive a burrito smothered in equal parts red and green, and be spared the agony of trying to decide between the two.

In the laboratory, I designed and built a cryostat which could be filled with gas and instrumented with sensitive silicon photomultiplier light detectors and a few other tricks to amplify the weak scintillation light signal I would get from a noble gas. I developed custom electronics and a data acquisition system, and tested different noble gases under a variety of conditions. Although it was unable to detect the scintillation light — the "high-yield, high-risk" nature of the work — the functioning prototype I built established the baseline design requirements for this system, and is still a valuable contribution to the ongoing effort to design the next large-scale germanium experiment to succeed the Demonstrator. I am proud to say that the team at LANL will continue to develop this design with my input.

Early in my time in Los Alamos, the Majorana collaboration published a paper in Physical Review Letters discussing the analysis of the initial set of Demonstrator data, searching for dark matter and solar axions. A search like this one is made more competitive the lower the detection threshold can be pushed, and the longer the experiment can be run. In practice, such a measurement is complicated by the presence of vast amounts of electronics noise at these low thresholds. My team and I saw an opportunity to improve on the initial result using a larger dataset, and we began to pursue development of new digital signal processing techniques. We believe we are well-positioned to publish a timely and competitive paper searching for solar axions with this larger dataset.

It's interesting to look back on the strange roads this search for axions has taken me down, from a deep underground lab to a high desert mesa. My experience at the lab, working so closely with so many smart people, not only sharpened the focus of my research but broadened the network of people I've been able to talk to and work with. Living in Los Alamos was an incredible experience. My wife and I hiked through the ancient Ancestral Pueblo ruins in Bandelier, explored the desert and the Rio Grande, and I nearly froze while camping in Taos. It was fascinating to soak up the complicated history of the Manhattan Project, and to walk around the same little pond where so many famous physicists have walked over the last 75 years.

Theoretical Physics Group

Members: Brett Altschul, Alessandro Baroni, Vladimir Gudkov, Pawel Mazur, Matthias Schindler

It is a pleasure to welcome postdoctoral researcher Dr. Alessandro Baroni to the Theoretical Physics Group. Dr. Baroni is joining us from Old Dominion University, where he recently received his Ph.D. Dr. Baroni is an expert on chiral effective field theory and its application to light nuclei. We are looking forward to exciting research collaborations.

Two Theory Group graduate students, Rasha Kamand and Camilo Posada-Aguirre, received their Ph.D. in the past year. Both did exciting work and we wish them the best for the future.

Dr. Kamand, working with her advisor, Dr. Schindler, and in collaboration with Dr. Altschul, has made important strides in understanding tests of fundamental symmetries with strongly interacting particles. While quantum chromodynamics (QCD) is known to be the theory describing the strong interactions, direct calculations of nucleon and nucleus structure at low energies using QCD are currently not feasible. One of Dr. Schindler's interests is chiral perturbation theory, which is a low-energy theory of pion and nuclear interactions based on the symmetries of QCD. It also provides an excellent framework for studying how those symmetries may be broken.

This approach interfaces very smoothly with Dr. Altschul's work on violations of three-dimensional rotation symmetry and the Lorentz boost symmetries of special relativity. These symmetries are, so far as is currently known, exact. If any violations of Lorentz symmetry were actually uncovered experimentally, that would be a discovery of paramount importance, opening a window onto a wholly new regime of fundamental physics. In the past, Dr. Altschul has analyzed the results of astrophysical observations, as well as atomic and accelerator laboratory experiments, to set constraints on Lorentz symmetry violations. However, prior to Dr. Kamand's work, very little was understood about the relationships between experimental results obtained with protons and neutrons and how Lorentz violation would affect the underlying quarks and gluons that make up such hadrons.

Collaborating with the two faculty members, Dr. Kamand extended the Lagrangian for chiral perturbation theory to account for possible violations of Lorentz symmetry. There are only a relatively small number of parameters describing how the symmetry may be broken at the quark level. While previous experiments, using protons, neutrons, pions, kaons, and other hadrons, have used separate phenomenalistic descriptions of Lorentz violation for each hadronic particle species, Dr. Kamand's work showed the relationships that must exist among the parameters relevant for different particles types. As a result, experiments performed exclusively with nucleons can now be used to set constraints on symmetry violations for pions (or vice versa). This new technique, which formed the backbone of Dr. Kamand's Ph.D. dissertation, improved the bounds on some parameters by more than ten orders of magnitude.

Dr. Posada, under the supervision of his advisor, Dr. Mazur, did remarkable work on the properties of slowly rotating homogeneous Schwarzschild stars, in particular in the rotating gravastar limit. Gravastars are black holes with a nonsingular interior, which result from the gravitational collapse of a star. The gravastar model was proposed by Dr. Mazur and his collaborator Dr. Mottola, who first studied static solutions. One of the important results of Dr. Mazur's work is that during the collapse of a homogenous non-rotating Schwarzschild star to its black hole limit the matter in the interior undergoes a zero temperature phase transition to a phase with negative pressure.

Dr. Posada extended this research to rotating stars by performing both analytic and numerical studies of properties such as the moment of inertia and the quadrupole moment. The results of his numerical investigation of the approach to the limiting gravastar configuration were published in the prestigious Monthly Notices of the Royal Astronomical Society. Dr. Posada has shown that the moment of inertia and the quadrupole moment of the slowly rotating homogeneous Schwarzschild star when its radius is very, very close to its Schwarzschild radius differ from the values of these moments for the Kerr black hole gravitational field by one part in 10^{15}. In essence, this shows that the regular source of the slowly rotating Kerr black hole is indeed the slowly rotating gravastar. Since its discovery in 1963, many unsuccessful attempts have been made to discover the regular source of the exterior gravitational field of rotating black holes described by the Kerr metric. Finding the interior metric and the source of rapidly rotating Kerr black holes is still an outstanding problem, and its experimental importance cannot be overestimated in view of the discovery of gravitational waves by LIGO.

Drs. Gudkov and Schindler continue their work on tests of fundamental symmetries in nuclear systems. In particular, Dr. Gudkov plays a leading role in providing crucial theory support to two experimental programs in the US and Japan that study time reversal invariance violation in nuclei. Drs. Gudkov and Schindler also continue their close collaboration with researchers from Oak Ridge National Laboratory to aid in the interpretation of new experimental results on parity violation in light nuclei.

Band of the Milky Way in the Sky. Image Credit: John P Gleason.

Astronomy Club

By Alex Kirby

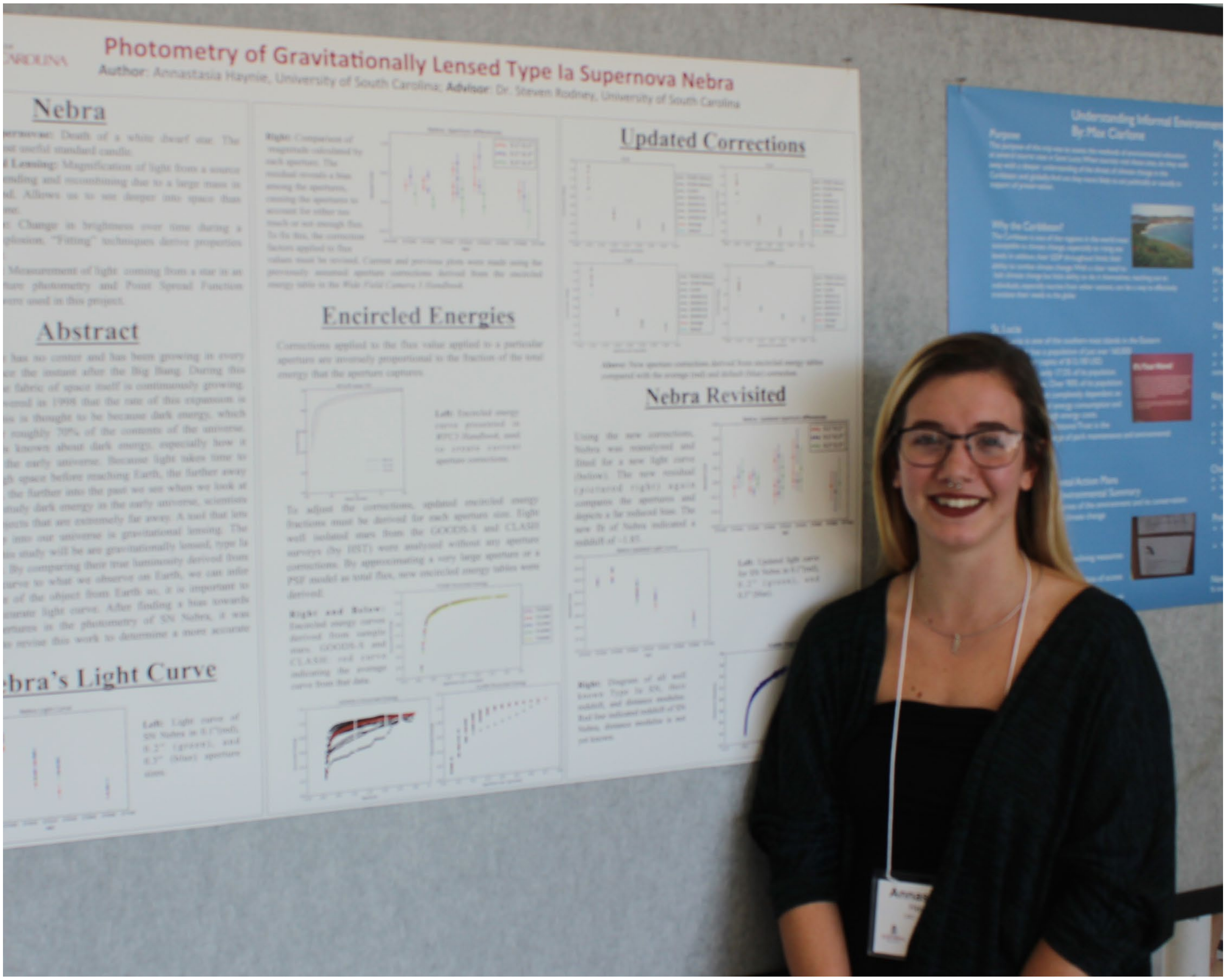
This past year has certainly been an interesting one for the Astronomy Club. Still as a relatively new organization, we spent much of our time laying down roots to be able to more adequately spread astronomy education and enthusiasm to the campus at large. In the future, we will be further pursuing community projects to reach the public with education on the basic concepts of astronomy. For this purpose, we hope to initiate a sidewalk astronomy initiative during which we will be stargazing through our telescopes in a public space (not necessarily a sidewalk), and encouraging others to join in while teaching them about what we are looking at. So, if you ever see us on campus, come by and look through our telescopes!

As always, we offer exclusive trips to a quiet dark site in Bethune, SC to get optimal viewing in conjunction with the Midlands Astronomy Club. Unique opportunities like this are open to all members of the organization. Our mission is and remains to spread knowledge and enthusiasm about astronomy throughout the student body and we shall strive to fulfill this purpose in the years to come. For those who find themselves looking up to the sky, whether you know what you are looking at or not, we hope to excite that curiosity even more! If you have any questions about the club or are interested in becoming a member, please contact us at soastron@mailbox.sc.edu.

Society of Physics Students (SPS)

By Yanwen Wu and Eric Rohm

This year was a very productive year for our chapter of the Society of Physics Students (SPS). In addition to our in-club activities, we have been striving to increase our community presence in many ways. One way was through our eclipse outreach. August 21, 2017 marked the date for the All-American Total Solar Eclipse. The path of totality for this eclipse passed through the upper-west coast and then made its way through to the lower-east coast. Luckily, we were in the center of the path of totality when the eclipse came around. As such, we pursued some community activities in preparation for it. One activity was the construction of camera obscura. For this, we used cardboard tubes and toilet paper to make the cameras, which were then given to the guests who came to create them with us. This mainly involved a few children from the community and was a relatively small event. Another way in which we helped the community is through our volunteering efforts on the day of the eclipse. During the eclipse, we aided the department through volunteering at the eclipse information stations set up across campus in addition to handing out eclipse glasses for both the students on campus as well as those passing by. We also received donations from the general public at several of the information stations on the day of the eclipse that will go toward future club outreach. The club's contributions to these events unquestionably increased our presence in the general community. Another notable event that we hosted this year was our first fundraiser. We agreed with a local pizza restaurant, Uncle Maddio's Pizza Joint, to host a percent night in which the club received a certain percentage of sales for a few hours. This was, in the end, quite successful and we look forward to additional fundraisers in the future. Another helpful hand that we have given back to the community is our judging of a couple of local science fairs. One was simply a high school science fair at a nearby school, which a few of our members and our advisor aided by judging the projects. Another was a regional science fair, which was also judged by a couple of students, as well as our advisor. On top of this, we also participated in the annual Midway Physics Day at the South Carolina State Fair. This is an event in which physics students and professors teach high school students about interesting physics concepts through real-world demonstrations. The typical demonstrations include cooling food with liquid nitrogen, launching metal rings by induction currents, and demonstrating wave motion using springs. This, as always, was a wonderful event that was enjoyed by all, and we look forward to participating in it next year as well. Through these major events and a few smaller ones, we have sought to increase our community presence and we were relatively successful in doing that. We will continue in our attempts to both help the community and increase our presence in it, and one can only hope that we will be even more successful in the years to come.



Undergraduate student Annastasia Haynie presents her work on the photometry of gravitationally lensed supernovae at the 2017 Summer Research Symposium at the Thomas Cooper Library (July 2017).

Photometry of Gravitationally Lensed Type Ia Supernova Nebra

By Annastasia Haynie

In July 2017, I was able to present my research on the photometry of Type Ia supernovae at University of South Carolina's Summer Research Symposium. The poster I presented was an accumulation of roughly nine months of research with Dr. Steven Rodney. I began working with him in the fall of my junior year and this past spring was awarded a Magellan Scholarship to continue this research through the end of my senior year.

My main focus at the beginning of this research project was to perform photometry on known Type Ia supernovae and build their light curves. The light curves, a plot of the star's change in brightness over time, can be "fitted" using well known light curves to derive the true luminosity and redshift of the star. The broad scope of this work is to build up a bank of high redshift supernovae to study the dark energy composition of the early universe. Additionally, the supernova I have been focusing on, Nebra, is gravitationally lensed, meaning it sits behind a very massive galaxy cluster, causing more light to bend into our field of view than normally would. This magnification allows telescopes to look deeper into the universe than they would be able to on their own. With a redshift of roughly 1.8, Nebra is among a dozen of the highest redshift Type Ia supernovae today. This makes it a valuable source of information because so much about it can be derived from its light curve.

At the end of last spring, I discovered a bias in our photometric data. I regularly used three aperture sizes to preform the photometric measurements (0.1", 0.2", and 0.3"). The apertures look at the circular area around the star, and therefore the flux gathered by each aperture should only differ due to extra noise taken in by the larger one. However, the smallest aperture was accounting for much higher flux than the other two (See Figure 1). The most likely culprit was the correction factors applied to flux measurements from each aperture. Ideally, to collect all

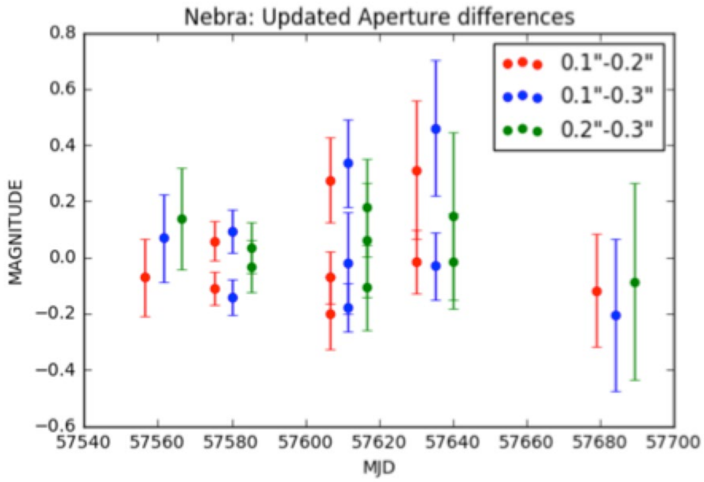


Figure 1: A residual plot of the star's magnitude calculated in three different apertures. The only difference between each aperture is the amount of noise taken in, therefore the differences should be bouncing around 0 Mag. This shows a clear bias in our calculations.

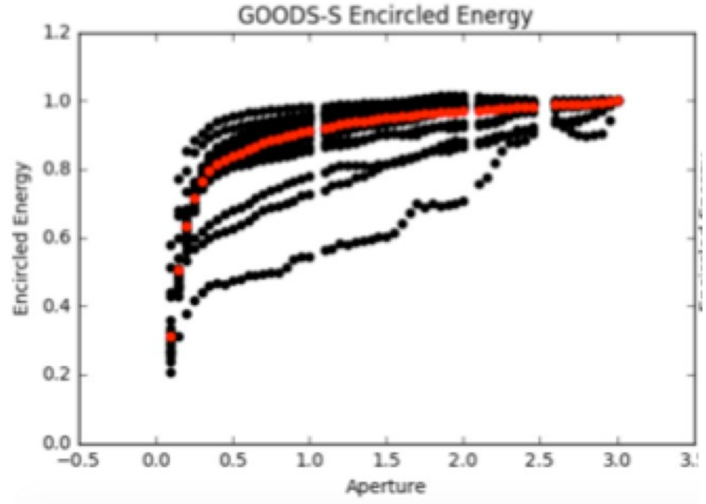


Figure 2: The encircled energy table of the five GOODS-S stars. Their average encircled energy curve is shown in red. The plot shows the fraction of the total flux gathered by each aperture size.

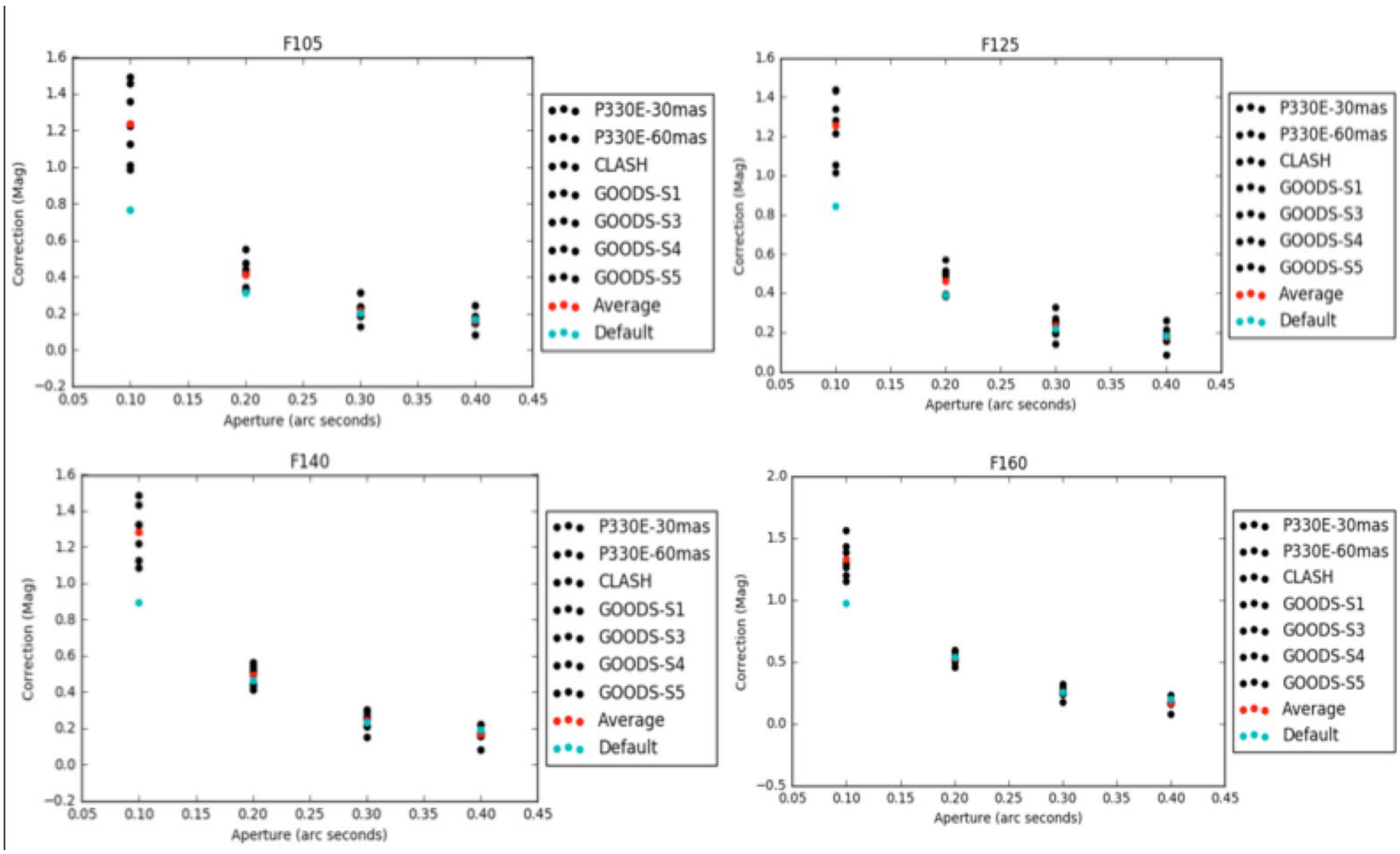


Figure 3: A plot of all the created correction factors using each star, the average (red) and the default correction we were using before (blue), across four different filters. The correction factors necessary for the calculation differ slightly depending on the filter the image was taken in.

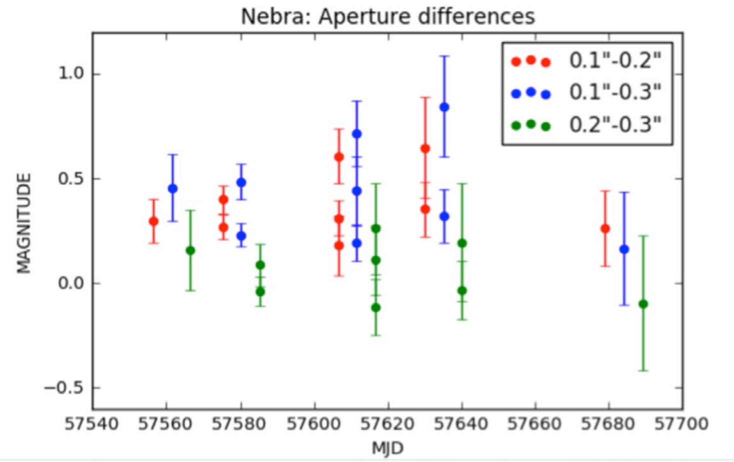


Figure 4: A new residual plot of the star's magnitude in the three original aperture sizes. This plot shows that by using the new corrections, the three apertures now agree much more than before, now centered around ~0.2 Mag.

of the flux coming from a star in an image, an aperture would have to be infinitely large. In reality, we can use fairly large, ~3.0', apertures for the same effect, however this runs the risk of taking in light from nearby sources. Therefore, small apertures have a correction factor applied to them to produce the flux value as if the aperture was infinitely large. I spent the summer recreating the aperture corrections to see if they differed from the ones we were using from the *STSCI Wide Field Camera 3 Instrument Handbook*.

To create new aperture corrections, I used eight bright, well isolated stars and took flux measurements from 0.1"-3.0' apertures (in increments of 0.05") taking the value measured at 3.0' to be the "total flux". I then compared the flux of each aperture to this total to find out what fraction of the total each aperture size was able to gather. These are called the encircled energy fractions (See Figure 2). By taking the average encircled energy fraction for each aperture size across my group of eight stars, I was able to come up with a new list of aperture corrections. Figure 3 shows a comparison of the previously used corrections and the new corrections derived from the encircled energies. After applying the new corrections to my photometry of Nebra, I again compared the flux measurements between my three aperture sizes and found that they agreed much more, but are still not in perfect agreement (See Figure 4). Right now, I am focusing on finding more stars that can be used to further adjusting the aperture corrections. Once I am satisfied with the new corrections, I can begin applying them to the photometry of Nebra and other high-redshift supernovae.

Horsehead Nebula. Image Credit: Ken Crawford.

Constraining Dust Models in Extragalactic Sources

By Alex Kirby

When we look up into the sky, we aren't seeing quite the light that those stars are producing correctly. As it traverses the universe, the light passes through dust, which dims and reddens the light, sometimes dramatically. The Horsehead Nebula (imaged below) is a prime example of this. This dust is extremely prevalent through our Milky Way galaxy, and can, in fact, be seen in a very dark area at night as obscuring the band of the galaxy. On top of reddening light, this dust also dims whatever light passes through it. Known as extinction, this process is of the utmost importance to astronomy, and a greater understanding of it could drastically alter some observations.
The dust in the Milky Way is well known at this point, however this is not true for the dust of other galaxies. This causes quite a bit of uncertainty in the observations of objects, which lie behind these galaxies, as they have to pass through all of this dust on their way here. That is where my research comes in. We are currently going through the data of many different objects, which we will use to construct models for dust, which lies in other galaxies. With this information in hand, observations will become even more accurate, and we will be able to learn much more about the universe around us.

Alex Kirby is an undergraduate physics major currently working with Dr. Varsha Kulkarni.

Prof. Cook's PHYS 212 students responding to a "Think-Pair-Share" question in the Fall 2017 semester.

An Instructor's Perspective

By John Cook

In June 2017, I traveled to College Park, Maryland to attend the American Association of Physics Teachers New Faculty Workshop (NFW). The NFW is designed to provide faculty and instructors in their first two years of employment with more effective ways of presenting material and engaging students in the classroom. Using active learning techniques in the classroom was a major focus throughout the conference.

I attended workshops on topics including Just-In-Time-Teaching, Think-Pair-Share Questions, Rethinking Labs, Integrating PhET Simulations into Lecture, and Interactive Lecture Demonstrations.

The active learning technique I found interesting and am using in my courses this semester is Think-Pair-Share Questions using paper voting cards. Instead of working all of my example problems myself or letting one vocal student shout out the answers in class, I display the question along with a selection of answers. I then use the voting cards to poll the entire class and get instant feedback via the colored squares. If the majority of students do not choose the correct answer, I have them pair up with a neighbor and discuss the question and why they chose the answer they chose. Once a majority has the correct answer, I explain the proper reasoning and method of solving the problem and we move on.

I decided to use Think-Pair-Share Questions in addition to iClickers in my courses to add an informal (but also instant) method of engaging and polling the entire class. Already this semester I have noticed far fewer students dozing off in class!

John Cook is currently in his third year as a departmental instructor.

Alumnus Jim Talbert takes a break from writing his thesis at the University of Oxford (England) and makes a quick trip to Morocco in May 2016.

Alumni News: Postdoc Predilections

By Jim Talbert, Class of 2012

What a pleasure it was to be back in the 'fortress of science' (my undergraduate pet name for Jones) in mid July! I was nervous, obviously covered in a shield of Columbia's summer sweat, and indeed a little bit nostalgic as I prepared to give a professional seminar to the same faces that knew me when harmonic oscillators were as foreign as gravity waves. Just a few weeks prior, I met with my old mentor, Prof. Fred Myhrer, in my new home of Hamburg, Germany. We discussed many of the comings and goings of the 5 years that have passed since May 2012, when I graduated from USC and continued my journey as an aspiring theoretician, first to my Ph.D. at the University of Oxford and then, in September 2016, to join the theory group of Deutsches Elektronen Synchrotron (DESY) as a post-doc. I told him, for example, that after sitting through my first QFT course in the UK, I was absolutely mortified by my European peers — most of them had Master's degrees from here or there, and many had already published novel work in leading journals. I also lamented the fact that they all seemed to know who they wanted to work with, what conferences they wanted to attend, and which papers they planned on arXiving in the coming months. I was still sorting a bank account and rusty bicycle, not to mention Feynman Diagrams and Renormalization…

Those six peers are now some of my closest friends, and I think I've got an amateur's grip on QFT, although that's always up for debate! As the lectures lurched onwards and I became more comfortable with my surroundings, I learned to rely on the same habits and traits that led me to a successful degree at USC — long hours, frequent injections of caffeine, more frequent injections of b(i)er, and skin thick enough to accept it when I was being…well…thick. When I was completely lost with my coursework, I normally just found someone to help (a foreign concept, it seems, to many of my own students…) Often, this was my friend, Reggie Bain, who I luckily get to see at conferences all around the world due to shared research interests. But, the faculty members were also freely available and immensely supportive. From my first lab with Prof. Ilieva to my last exam with Prof. Pershin, there was always a helping hand to be found. In fact, I doubt I would be a physicist were it not for Fred Myhrer's willingness to take me under his wing in my second year. Yes, the USC Physics Department taught me how to deal with physics when it gets tough. But more importantly, it also taught me how to enjoy it when things fall in to place, when a derivation is complete and all those factors of two dissolve into a proper normalization. These are the exciting moments, and they slowly bubbled up during the course of my Ph.D. I warmly remember the when-and-where of my first 'idea', the preparation of my first paper, and the first e-mail I received asking me to be a part of a collaboration. I learned how to love physics while I was at USC, and that's what has kept me in the game until now, regardless of the headaches. I make no predictions about my future career, but certainly know that my time in Columbia was well spent, the relationships forged there invaluable, and the education I received a great preparation for the many challenges to come.

I'm writing this alumni letter on a train from Cornwall to London, where I'll fly back home and begin the Autumn academic season with the fearful anticipation of any young post-doc. At this very moment, I see more unanswered e-mails in my inbox than I care to address, a Dropbox filling up with my collaborators' sweat (tears?), and four or five paper drafts that need my attention. Who knows, maybe I'll (finally) finish the work I presented in July. Time, though hopefully not too much, will tell.

Dr. Carl Oliver Clark

In Memoriam: Dr. Carl Oliver Clark

By Frank Avignone

Those of us who knew Dr. Carl Clark were very sad to receive the news that he passed away in August 2017. Carl received his Ph.D. degree from our department in 1976 under the direction of Horacio Farach and Charles Poole. He was the first African-American to earn a Ph.D. in Physics at USC. He did so while on the faculty of South Carolina State University, where he distinguished himself as an outstanding teacher, having received the "Distinguished Teaching Award" of the American Association of Physics Teachers. At the time of his retirement from SC State in 1995, he was the Dean of Natural Sciences. Shortly afterward, he went on to become the Chair of the Physics Department at his undergraduate alma mater, Morgan State University (Baltimore, MD), for six more years before his final departure from education in 2001. The first African-American to graduate from the Baltimore Polytechnic Institute in 1955, he was inducted into the Polytechnic Hall of Fame in 2004 and named "Polytechnic Distinguished Award Winner" in 2005. His wife, Barbara Randall Clark, even wrote a book commemorating her husband's achievements, which she entitled, *Trailblazer: The Journey of Black Physicist Carl Oliver Clark*. Carl had a delightful personality, an attribute that made him a natural in the classroom, as well as an outstanding student advisor and mentor.

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

We look forward to hearing from you!

Quantum Leap

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Space Elements imaged by Alex Mowery from the Melton Observatory