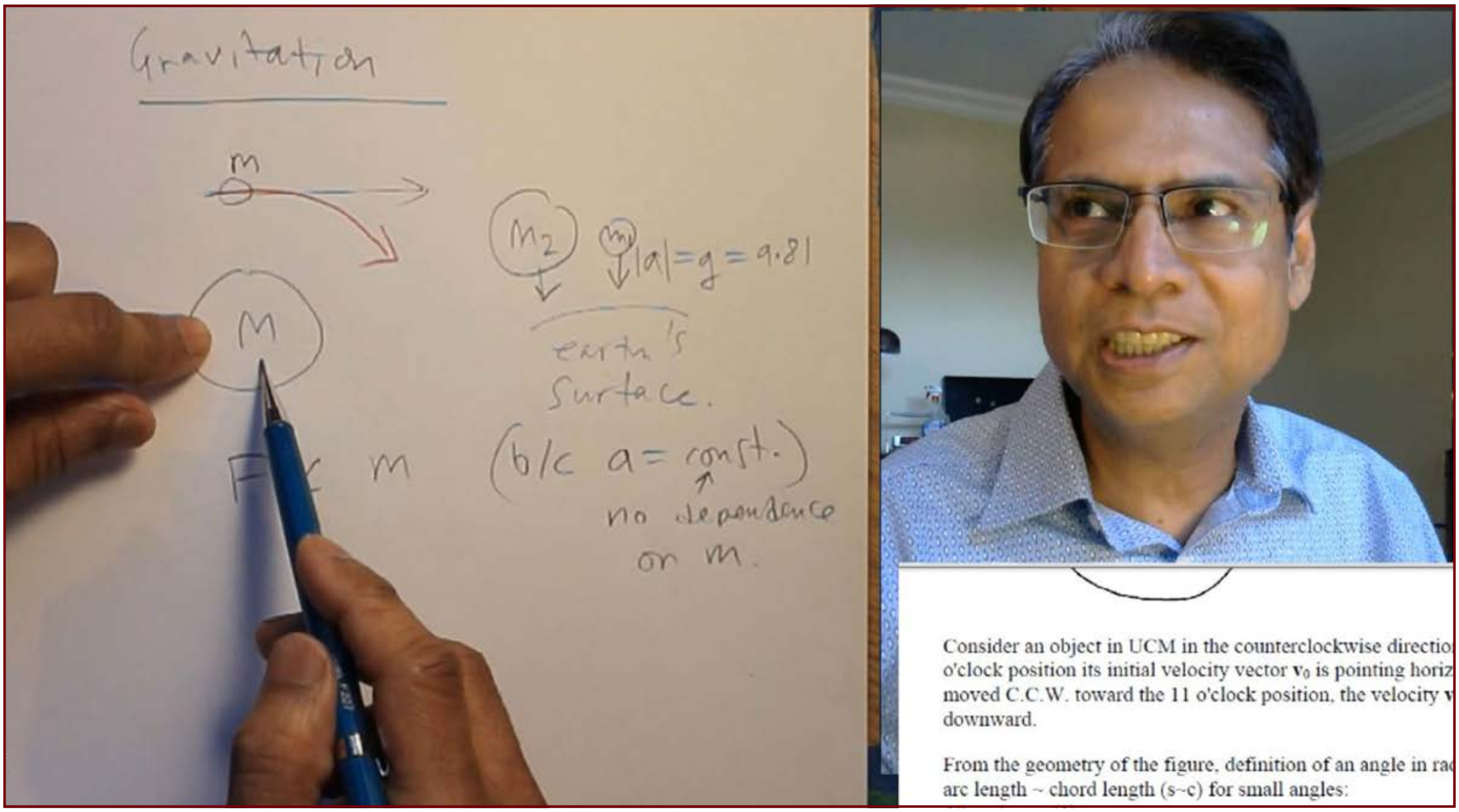
Quantum Leap

University of South Carolina
Department of Physics and Astronomy

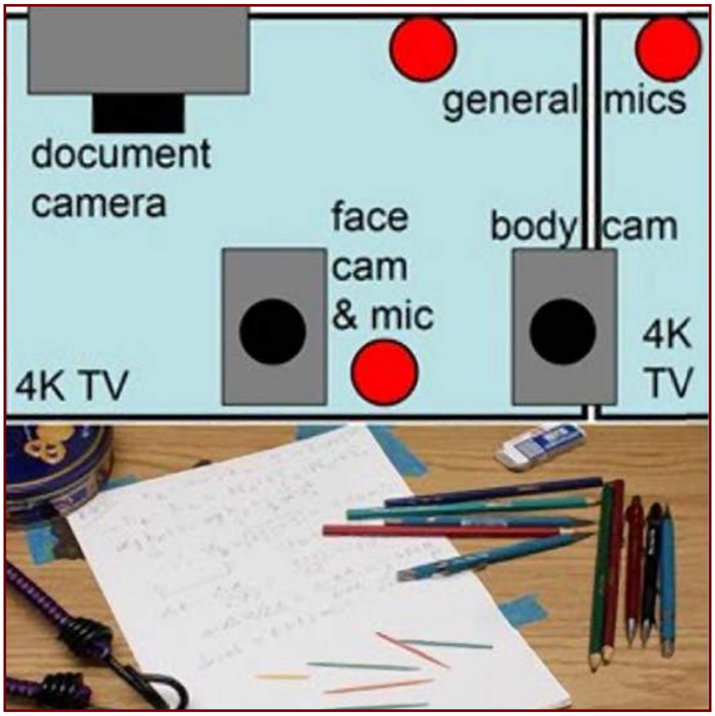
2020



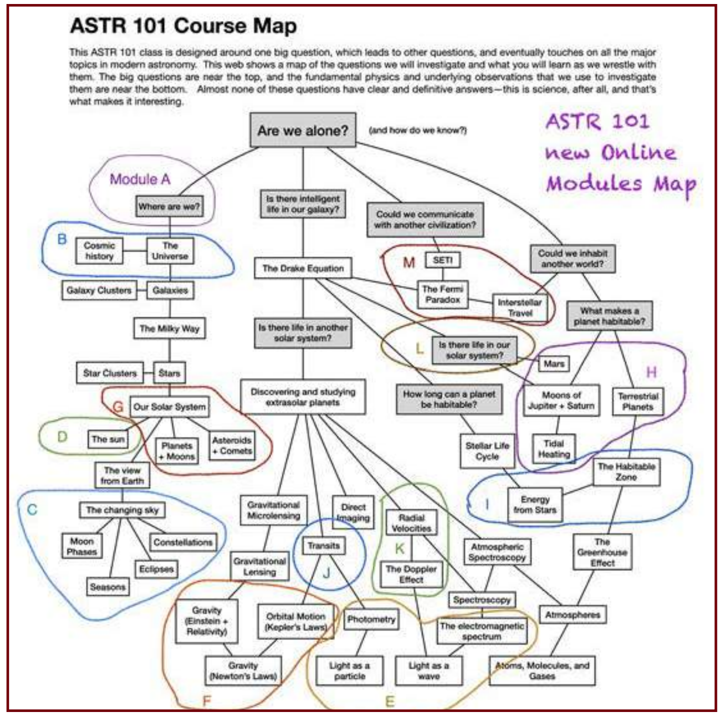
In Prof. Kunchur's virtual classroom, old-school hand-written derivations driven by student input have survived in the COVID era with some new advantages: Multiple cameras allow seeing the professor's face continuously even as they watch him writing, the written sheets don't get erased between classes like a traditional board, students can adjust the sound level to their taste, and, of course, everyone has a front row seat!

Physics and Astronomy Responds to Teaching Challenges

In the spring of 2020, the university administration was adapting fall semester courses to the exigencies of the pandemic. There emerged from this process a variety of models with acronyms like TRAD, BWEB, and DWEBS. These models distinguished themselves predominantly by the proportion of time allotted to in-person versus online instruction. As an additional challenge, both instructors and students needed to have the option for remote learning/teaching to accommodate the need for quarantine and isolation precautions due to COVID-19. The Physics and Astronomy faculty have responded with creativity and ingenuity – crafting custom solutions to fit the different class types. The department's efforts, in conjunction with university support for student connectivity, has allowed our courses to proceed as smoothly as one could hope in these strange times. Many of us have even found that some of our new approaches will be useful post-pandemic. Inside are a few examples.



A paper about this system was presented at the Joint NCS/SACS-AAPT Fall 2020 Meeting. A composite HD video stream combining all cameras, microphones, and documents is conveyed by Microsoft Teams utilizing every pixel on students' screens. Two huge 4K-UHD TVs provide enough screen real estate to see all students' faces. Kunchur still calls them by name if they are staring at the ceiling!*



Dr. Rodney modified his traditional course map for ASTR 101 in Fall 2020 to make it more compatible with a fully online learning structure for students.

From Milind Kunchur (PHYS 201 Honors, 18 Students):

Remote teaching in the COVID-19 era proved to be an interesting challenge. Dr. Kunchur successfully addressed it by using an innovative setup using multiple cameras and microphones, a live paper-and-pencil display, and constant two-way video visibility (with the instructor and most students unmasked). Many students commented on the effectiveness of the system. The paper-and-pencil provides a permanency and continuity beyond a classroom blackboard. The exams, which they also answer with paper and pencil, are proctored more strictly than in-class exams and they have immediate live-voice access if questions arise. Finally, the grading is done by hand in the traditional style with no multiple-choice question. While everyone is eager to see the COVID-19 days behind us and there are obvious advantages to a full-body view without masks, this lemon did produce some lemonade.

From Steve Rodney (ASTR 101, 295 Students):

The popular ASTR 101 course went to fully online instruction in Fall 2020 and hit one of the largest enrollments we have seen in recent years with 300 students. Thanks to a grant from the College of Arts & Sciences, instructor Steve Rodney had a team of graduate students helping to develop new "online learning modules" during the back half of the summer. Each module is fully self-contained, and in Dr. Rodney's version of the course, they build together to the larger goal of understanding "Are we alone in the universe?" Like LEGO bricks, future instructors can dismantle and rearrange the sequence to suit their preference for the course. We have now submitted the online version of ASTR 101 for approval as a new course offering, so we hope to be able to continue teaching some of our introductory astronomy students in this remote learning format even after the campus returns to normal operations.

From David Tedeschi (PHYS 153, 8 Students):

The UofSC Honors College course, "Physics in the Visual Arts," is offered to non-science majors that includes a laboratory and usually lots of hands-on demonstrations. D. Tedeschi has transformed the class into the *Hyflex* format – teaching in person half the time and remotely half of the time. The lectures are broadcast and recorded via the University's Learning Management System (LMS), and all assignments are completed online. While staying mainly "synchronous", the structure allows for loose deadlines thus providing some asynchronous flexibility. The course enrollment was reduced to ensure social distancing; however, students can also choose to be entirely remote. Many of the classroom demonstrations were replaced by interactive computer simulations. It was quite a lot of effort to transform the course material for online delivery, but there are benefits from the course improvements that will outlast the pandemic. For example, to ensure social distancing, each student now performs the lab exercises individually. Remote students would perform the laboratory and could speak with Dr. Dave via the LMS for real-time help. (He has even been seen on campus delivering laboratory equipment to students isolated due to the pandemic.) Thus, the pandemic has done away with lab partners, but this has provided a better gauge of each student's understanding of the material and has allowed D. Tedeschi to focus on each student's individual needs. This improved aspect of student assessment will remain as part of the course in future semesters.

Prof. Rosenfeld's alter ego. Battery powered clones of this device will allow remote students to converse with their lab partner and to have a close-up real-time view of the apparatus and instruments.

From Carl Rosenfeld (PHYS 199, 19 Students):

As it had been for the preceding seven semesters, Prof. Carl Rosenfeld's teaching assignment for fall 2020 was a lab course for physics majors (PHYS 199). For many instructors, a lab course could comfortably fall somewhere on the spectrum from fully in-person to half and half. Rosenfeld, however, who is at high risk by virtue of age, was a poor fit to all of the university's models. Driven by the pressure of circumstances, he elected to structure his course as in-person for the students, meaning they would be physically present in the teaching lab, but Rosenfeld with the aid of technology would instruct from a remote location. With some credit to Prof. Jeff Wilson, it quickly emerged that if presence from a remote location was feasible for the instructor, why not also for half of the students working one-to-one with a buddy in the teaching lab? If the students swap the remote participation role with their buddy each week, they would all get hands-on experience, and social distancing could be maintained notwithstanding the constraints of floor space and lab equipment.

The principal technology needed for this instructional model is a video camera on wheels with pan, tilt, and zoom (PTZ) that is viewable and controllable from off campus. In mid-July, Rosenfeld identified a suitable (and inexpensive) video camera and the department promptly acquired one. The camera connects to a Wi-Fi network and the principal challenge is to engineer a communications chain that makes viewing and control truly useful even from off campus.

Rosenfeld had hoped to commission this system by the start of classes in late August, but as so often happens, other academic responsibilities interfered. As of mid-October, Rosenfeld has used the camera from off campus to instruct and assist students in the Jones PSC lab. The communications chain, however, needs improvement critical to a scaled up system suitable for use by the students. Success could be just around the corner, but, at this moment, the project is a work in progress facing considerable challenges. The present arrangement depends on teamwork between Rosenfeld and a graduate instructional assistant who is continuously present in the lab and that requirement will persist even after all technical problems are resolved. Rosenfeld would be delighted if someday a commercial product could supplant the system that he is pursuing. For the here and now, he has his work cut out for him.

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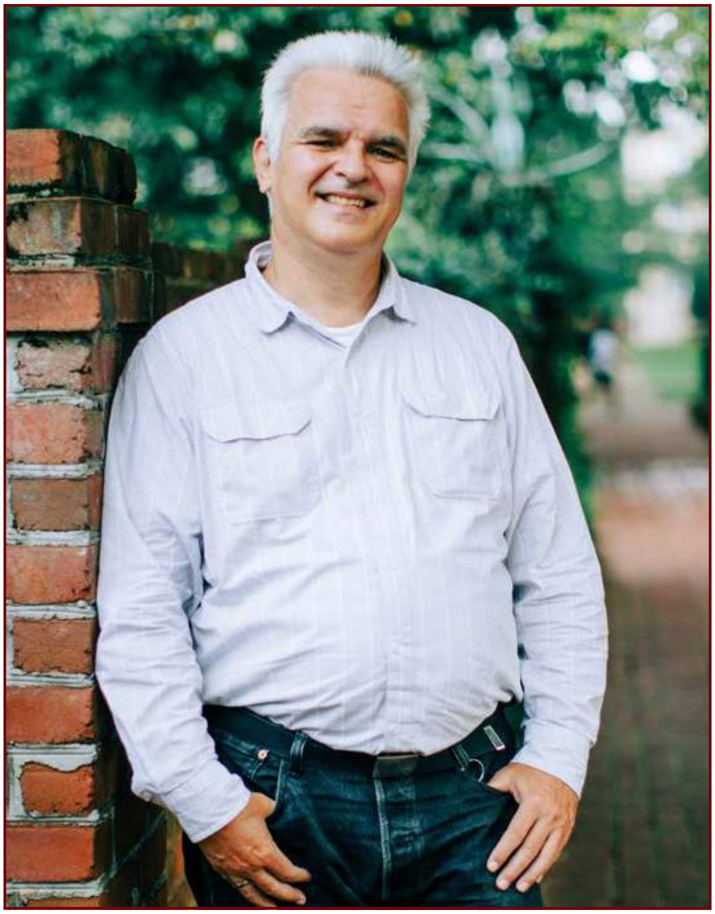


Message from the Chair — 2020: Life's $2\hbar$ Year

By Ralf Gothe

In 2020, we have all been exposed to more uncertainty than physically allowed and also experienced all around us that more localization comes with more agitation. This was clearly no different at our university nor in our department. It started in early spring, when we all had to adapt to teaching and working remotely, and has not gotten better ever since. Rules and regulations are continuously changing faster than anyone can adjust to, and everyone had to work twice as hard when trying to achieve what we achieved before. Meanwhile, a lot of the initial anxiety is covered up by fatigue and exhaustion and a feeling that, if we only get through 2020, life will be less uncertain and better again. However, although I am generally an inveterate optimist, I do not believe that we will get off so easily.

What always lifts me up when I need it most are people coming together to help each other despite being stressed themselves more than ever before. The staff was giving up leave days to meet on a daily or at least bidaily basis to discuss, initiate, and optimize new procedures that then needed to be implemented and to resolve never-ending problems that always needed attention right away. For the first time, we had regular faculty meetings during the summer to help each other and keep each other informed. Being open-minded, creative, and willing to go the extra mile was what allowed us to keep the university and the Gamecock Family alive. This spirit makes me prouder than ever and happy to work here and to serve the department to the best of my abilities, and although not all days well lived are happy days, each day well lived builds the foundation for a blissful life.

We all - students, staff, faculty, and higher administration - can also be very proud of weathering 2020 much better than any other education institution I know of. Our summer enrollment increased and our fall enrollment was against all predictions almost at the same level as in the record year 2019. UofSC developed high-volume fast-return saliva-based COVID-19 testing that was approved early on by state and federal authorities and will now even be made available to the public. With dominantly responsible behavior, daily disinfecting, frequent testing, good tracking, and rigorous quarantining, UofSC successfully opened for this fall again, and we are still teaching the majority of our courses fully, or at least partially, face-to-face.

As 2020 is winding down, we have restarted our SmartState Center chair search that was abruptly halted in its final phase as UofSC closed down, but we are still lucky to be allowed to go forward in the time of hiring freezes. Unfortunately, we are unbelievably unlucky in getting Alexander Monin here. Whenever he is one step away to finally succeeding to come with his family, some other insurmountable immigration issue emerges that holds him back yet again. Dear Alex, although there is nothing we can do about it, we at least want to let you know that we love you and cannot wait to welcome you here at UofSC.

This year, it seems to be even more important than in previous years to remind us that we best master uncertainties and new challenges by holding together as we coherently share our experiences, resources, time, talents, as well as joy with each other whenever we can. While browsing the 2020 newsletter, I hope you find the right mixture of new developments, changes, and updates to stay informed and familiar stories reminiscent of good times at UofSC. I wholeheartedly wish all of us Happy Holidays and the very best for a hopefully less stressful 2021.

News from the Director of Graduate Studies

By Matthias Schindler

We welcomed five new graduate students to our graduate program this year: Kim Stubbs joined us in Spring 2020, while Franklin Adams, Joshua O'Connor, Thisura Rathnayaka Mudiyanselage, and Nur Rifat started in Fall 2020. But this unusual year has also left its mark on our graduate program. We were looking forward to welcoming an additional seven new graduate students to the department this fall, but because of COVID-related restrictions, they were unable to obtain visas and come to Columbia. We are strongly hoping to welcome them in Spring 2021 instead.

The sudden switch to remote instruction in March also meant that our introductory classes had to be transitioned to online delivery. We are grateful to all our graduate assistants for how quickly they adapted to the new situation and for their creativity and dedication to making sure that students from across the university could continue with their physics education.

There was plenty of good news throughout the year as well. We were excited to learn that Frances Cashman was selected as a UofSC 2020 Breakthrough Graduate Scholar. The award recognizes doctoral students at UofSC who show great promise for distinguished careers in research and scholarship, and Francie is already on her way to fulfilling that promise. Within the department, Justin Pierel received the Graduate Research Award, Govinda Kharal the Graduate Service Award, and Kevin Wilson was the recipient of the Graduate Teaching Award.

We congratulate our recent graduates and wish them all the best for their future, wherever it may take them. Frances Cashman, Richard DeCosta, Cory Dolbashian, Bing Guo, Gary Hollis, and Suraj Poudel obtained their doctoral degrees, while Kyle O'Connor and Justin Pierel finished their M.S. degrees.

News from the Director of Undergraduate Studies — All COVID-19, All the Time

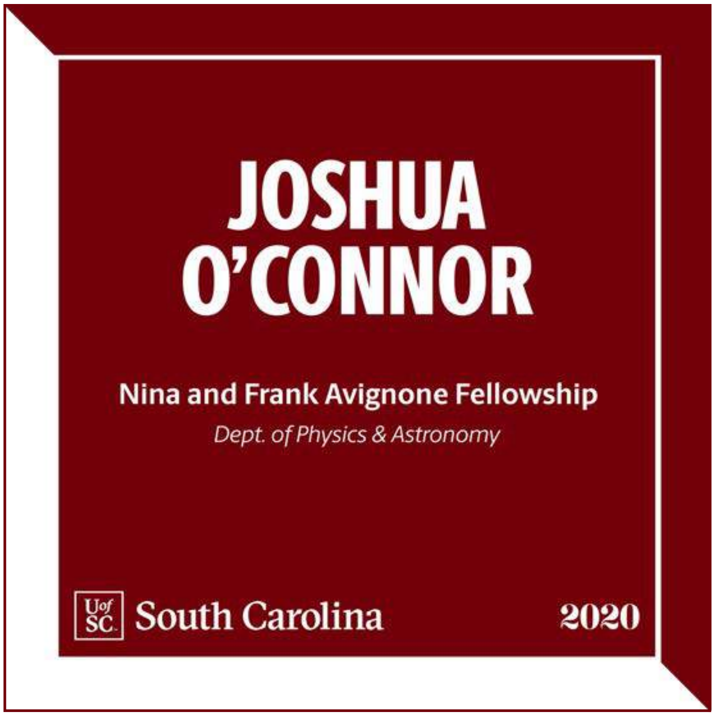
By Jeff Wilson

In the university setting, it is fortunate that we are able to carry on with our primary missions (research and education) even under the reality of the COVID-19 pandemic. In undergraduate teaching, this has required changes to how we connect with students.

Because our course offerings are so varied, a one-size-fits-all approach is never going to work. For example, our large courses are restricted to online delivery only — a general university-wide decree that was made during the summer. Many of our instructors in those courses were able to take part in a College-wide online course development program intended to introduce us to "best practices" in online instruction. I used that opportunity to develop a host of mini video lectures and "flip" my course. Rather than use in-person lectures to deliver content, I delivered the content via premade video, and then class time (which was online) could be used for guided problem solving via a bunch of step-by-step iClicker questions. The transformation was an enormous amount of work and I was only able to attempt it because I am not a funded researcher and I have "free" time in summer that active researchers don't. Even so, I was only able to complete about half the transformation before the Fall semester started. Other instructors with larger summer time commitments had to be satisfied with more modest changes to their existing course materials - usually just using their standard lecture format, but delivering the lecture via our Blackboard streaming service.

Our smaller courses had more options. Some instructors chose to go entirely face-to-face (FTF), some chose fully online, and others invented hybrid formats where some of their material was delivered either in streaming format or as premade video.

Our most problematic conversion had to do with the laboratory sections that went with our large introductory physics courses. These had smaller sections, so there were possibilities for FTF delivery, but we still had to accommodate instructors and students who were uncomfortable being in an FTF classroom. Most of our sections were switched to a hybrid format where half the labs were done in the classroom and half were done via video "examples." This allowed us to cut the class size in half and fit the students in the lab room while maintaining a safe amount of distancing. Then we could give the lab instructors the option of managing the FTF half, or the online half, of the course.



Joshua O'Connor received the Nina and Frank Avignone Fellowship Award at a virtual "Awards Day" in April 2020. Due to the COVID-19 pandemic, the university was unable to host the traditional spring awards ceremony on the Horseshoe. Joshua earned his BS in Physics over the summer and continued on to our PhD program in the fall.

Photo credit: *UofSC Department of Student Life.*

Since we are still in the middle of the ongoing pandemic, we are planning to continue in the current mode for at least the upcoming Spring 2021 semester. My impression at the end of our first online semester is that no one (instructors or students) is completely happy with the style of instruction we have been forced to deal with and we are all eager to return to our normal FTF instruction.

RESEARCH GROUPS

Astronomy

By Varsha Kulkarni

There have been a number of remarkable new developments in astronomy research at UofSC during summer 2020. Both of our astronomers (Prof. Steven Rodney and Prof. Varsha Kulkarni) were successful in securing observing time on the Hubble Space Telescope. Competition for Hubble time is always extremely intense, so the selection of multiple UofSC-led research programs for Hubble observations is very exciting! Prof. Rodney plans to use Hubble to observe multiple images of a gravitationally lensed supernova to determine the time delay between the lensed images, which can provide constraints on the expansion rate of the universe and test dark energy models. Prof. Kulkarni is using Hubble to observe gaseous regions around exquisitely imaged galaxies to study gas flows around these galaxies and the interactions between the galaxies and their surroundings. Prof. Kulkarni was also awarded a new NASA grant to study the evolution of interstellar dust grains in galaxies over the past 12 billion years. In addition, she was awarded two new NSF grants for atomic physics improvements needed for studies of chemical evolution of galaxies, and for a collaborative project aimed at developing an interpretation guide for observations of the circumgalactic medium. Of course, the past six months have also brought numerous difficulties to the astronomical community due to COVID-19. Given these challenges, Kulkarni and Rodney are most grateful for the latest developments in their research efforts, made in collaboration with their wonderful external collaborators around the world, as well as their amazing UofSC research students at both the graduate and undergraduate levels!

In student news, Frances Cashman and Suraj Poudel completed their PhDs in summer 2020 and left UofSC to start postdoctoral positions with exciting research projects. Justin Pierel received the Department of Physics and Astronomy's annual Graduate Student Research award. Frances Cashman received the Breakthrough Graduate Scholar award from the UofSC Office of the Vice President for Research. Kyle Lackey received a NASA/South Carolina Space Grant Graduate Student Fellowship. We are also happy to report that a number of new undergraduate students are joining our research efforts and enrolling in the Astronomy minor. Despite the myriad challenges caused by COVID-19, the students are also continuing to do well and thrive!

Figure 1: *Members of the Experimental Nuclear Physics Group captured in a Zoom meeting.* ***From left to right and top to bottom:*** *Yordanka Ilieva, Steffen Strauch, Brandon Tumeo, Nicolas Recalde, Anne Flannery, Nick Tyler, Benjamin Moses, Ralf Gothe, and Krishna Neupane.*

News From Milind Kunchur's Group

By Milind Kunchur

Professor Milind Kunchur's group investigates phenomena in superconducting nanowires and other condensed-matter systems, at ultra-short time scales and under extreme conditions of current density, electric field and dissipation levels. This has led to the discovery or quantitative confirmation for the first time of the following phenomena/regimes:

1. Free flux flow
2. Hot-electron vortex instability
3. Flux fragmentation
4. Vortex explosion
5. Flux-creep based memory effect
6. Current-induced pair breaking in a high-temperature superconductor
7. Superfluid ballistic acceleration.

Dr. Kunchur's group also developed new instrumentation and methodology for testing the temporal-resolution capabilities of human hearing as well as the neurological understanding of this fundamental perception.

Recently, Prof. Kunchur began a collaboration with Prof. Yuriy Pershin to develop tunable Josephson-junction devices for quantum computing applications. In other research this year, Kunchur proved that two-channel stereo sound reproduction can naturally portray all three dimensions: the controversial height dimension as well as depth and lateral differentiation.

Experimental Nuclear Physics Group

By Ralf Gothe, Yordanka Ilieva, and Steffen Strauch

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

Currently, our group is comprised of faculty members Ralf Gothe, Yordanka Ilieva, and Steffen Strauch, graduate students Anne Flannery, Gary Hollis, Lin Li, Chris McLauchlin, Krishna Neupane, Nicolas Recalde, Brandon Tumeo, Nick Tyler, and Iulia Skorodumina, and undergraduate student Benjamin Moses.

Most of last year was marked by the effects of the SARS-Cov-2 global pandemic. Foremost, we are glad to share that all of our group members have stayed healthy and safe. Research wise, we adapted to the changing conditions. The restrictions placed on travel and the limited access to the labs forced us to postpone our planned hardware work at PSI and JLab. Furthermore, many large research conferences, particularly in spring and summer, were canceled, and our conference presentations decreased in volume, compared to what we have been used to in the past. However, as the world settles into the new circumstances, the number of major research meetings that take place online is ramping up, and, in fall, we have experienced an increase in the opportunities to present. This has been especially valuable for our students, who can again present their research to the broader nuclear-physics community. Interestingly, the number of online small workshops and collaboration meetings increased significantly, so our work-from-home schedules have turned out to be even busier than the pre-pandemic ones.

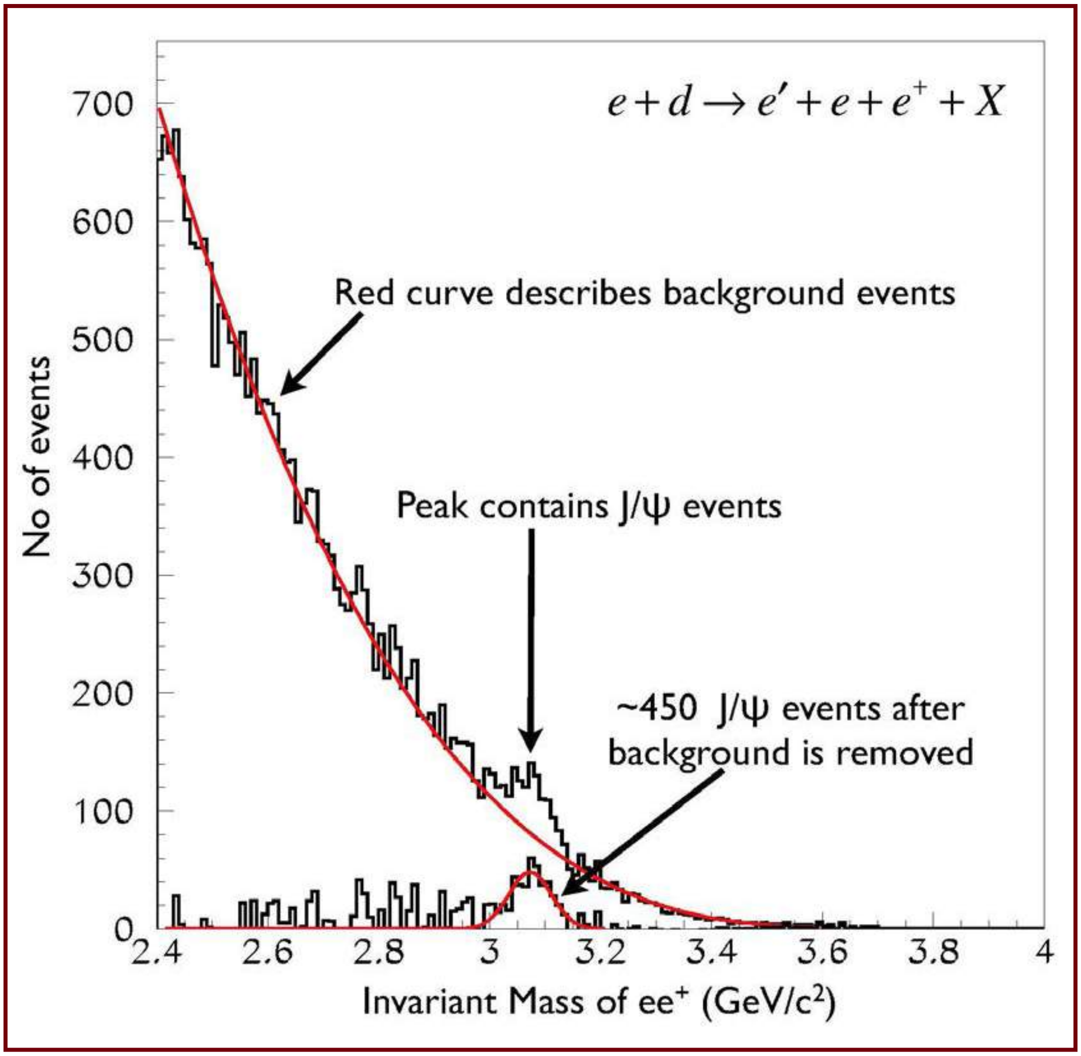


Figure 2: Preliminary results of our analysis of J/ψ photoproduction off deuteron. The data came from our JLab experiment E12-11-003B, which ran in 2019 and spring 2020. We observe about 450 events of interest in the e+e- decay channel of J/ψ. We expect as many from the muon decay channel.

Our research, of course, did not halt — we moved our weekly group meetings online and focused on our analyses projects full steam! Figure 1 shows the ENP group in a Zoom meeting this October. Even though UofSC opened for face-to-face classes in fall, most of our day-to-day research activities are still conducted remotely and we expect this to continue until travel restrictions ease up. We are quite excited to share some new, hot results from our recent experiments at JLab. In one of these, we discovered a new resonance that could only be identified through our electron scattering data. In another experiment, an even higher-energy electron beam smashed into a proton target, which caused a spray of nuclear reactions that were then measured by the new CEBAF Large Acceptance Spectrometer (CLAS12). We will use these novel data to search for new excited states of the nucleon and to probe deeper into the origin of the visible mass in our universe. Krishna Neupane, with the help of Nick Tyler, has already extracted first acceptance-corrected yields for one of the more complicated multi-particle final states to achieve these goals. Nick and Krishna will both present their recent results for the CLAS Collaboration at this year's fall DNP online meeting.

In another JLab experiment, deuteron nuclei were used as the target, and in a tiny fraction of the spray of nuclear reactions, a charm quark-antiquark pair, called J/ψ meson, was produced. The production of this particle is quite interesting since it serves as a clean tool to study the properties of gluons inside the nucleus. A preliminary analysis of a subset of the collected data yielded about 450 J/ψ events (see Figure 2). These are the very first J/ψ's produced on deuteron at JLab and we are super excited to have seen the signal already with a preliminary selection, given the rarity of the events. We continue to work to quantify the exact probability for J/ψ production in specific final states, which will help us learn about the strength of the interaction between a charm and up/down quarks and gluon dynamics in the deuteron. We will continue studying the gluon content of light nuclei in the era of the U.S. electron-ion collider (EIC), which is currently being designed. Since summer, Benjamin has been working to determine the EIC detector acceptance needed to make this study possible. His research shows that we need to be able to detect recoil nuclei down to about 15 mrad. These results will help the design of the hadron detector in the very forward detection system at EIC.

Using data from another, lower-energy deuteron experiment from the 6-GeV JLab era, Brandon observed for the very first time Λ-deuteron elastic scattering events. This is another exciting finding from last year as such scattering has never been observed before and our data sample is the only one of its kind worldwide. We anticipate that these data will shed light on the elusive hyperon-nucleon three-body force that could be key to resolving the hyperon puzzle in neutron stars. Brandon will be defending his MS thesis on this analysis in December.

Our NSF funded Muon Scattering Experiment (MUSE) at PSI will extract the proton charge radius from elastic electron- and muon-scattering off protons. While recent results from the PRad experiment at JLab shed new light on the proton-radius puzzle, open questions remain, and data from MUSE are highly anticipated. Also unique to MUSE is its capability to measure two-photon exchange processes directly in the scattering reaction. The pandemic is a tremendous challenge in our preparations for the experiment. We needed to give up our initial plans for detector maintenance at PSI during spring break. The lab shut down. Six weeks of approved beamtime in the summer were canceled. While the lab resumed operation, travel restrictions, quarantine requirements, and health concerns make it unlikely that we can make full use of the remaining eight weeks of beamtime at the end of the year. We instead have increased our effort to prepare for the experiment remotely, focusing mostly on software development and remote acquisition of calibration data spearheaded by Anne. The collaboration organized several full-day workfests where groups of students, post-docs, and faculty worked in Zoom breakout sessions on various aspects of the data analysis. The UofSC group will continue to play a leading role in MUSE with our development of the detector simulation and the management of the operation. Lin and Anne will represent our group for the MUSE Collaboration at the DNP 2020 online meeting. Lin will report on her studies of radiative effects in the experiment. Her work was critical to establish a new detector component in the experimental setup that helps reduce systematic uncertainties from radiative effects. Anne will give an update on the energy calibrations of the MUSE plastic scintillators.

Particle Astrophysics Group

Faculty: *Frank Avignone, Richard Creswick, Vincente Guiseppe, Carl Rosenfeld, David Tedeschi and Jeffrey Wilson*
Graduate Students: *Douglas Adams, Christopher Alduino, David Edwins, Thomas Lannen, and Kevin Wilson.*

The UofSC group continues its search for neutrinoless double beta decay. The MAJORANA project has reached its goals and will run for another year before decommissioning. D. Tedeschi and V. Guiseppe have been awarded a new three-year grant by the DOE Office of Nuclear Science for work on MAJORANA and the new LEGEND effort — an extension from 50 kg to 200 kg (and ultimately 1000 kg) of detector material. Graduate student David Edwins is currently away on military leave. He is expected to rejoin the group in the spring of 2021.

The CUORE experiment continues to run smoothly. At this point, the volume of data that has passed the quality cut has reached one ton-year of TeO2 exposure, which is equivalent to 200-kg years of 130Te exposure. The collaboration will be submitting the new results this December. The future for this collaboration will be similar to CUORE with bolometers of lithium molybdate (Li2MoO4) with optical particle identification. This will reduce alpha particle background, the most serious background in CUORE.

An inside look at the Germanium detectors used in the MAJORANA Demonstrator. The larger detectors in the foreground are newly installed and are being performance tested for future use in the LEGEND experiment.

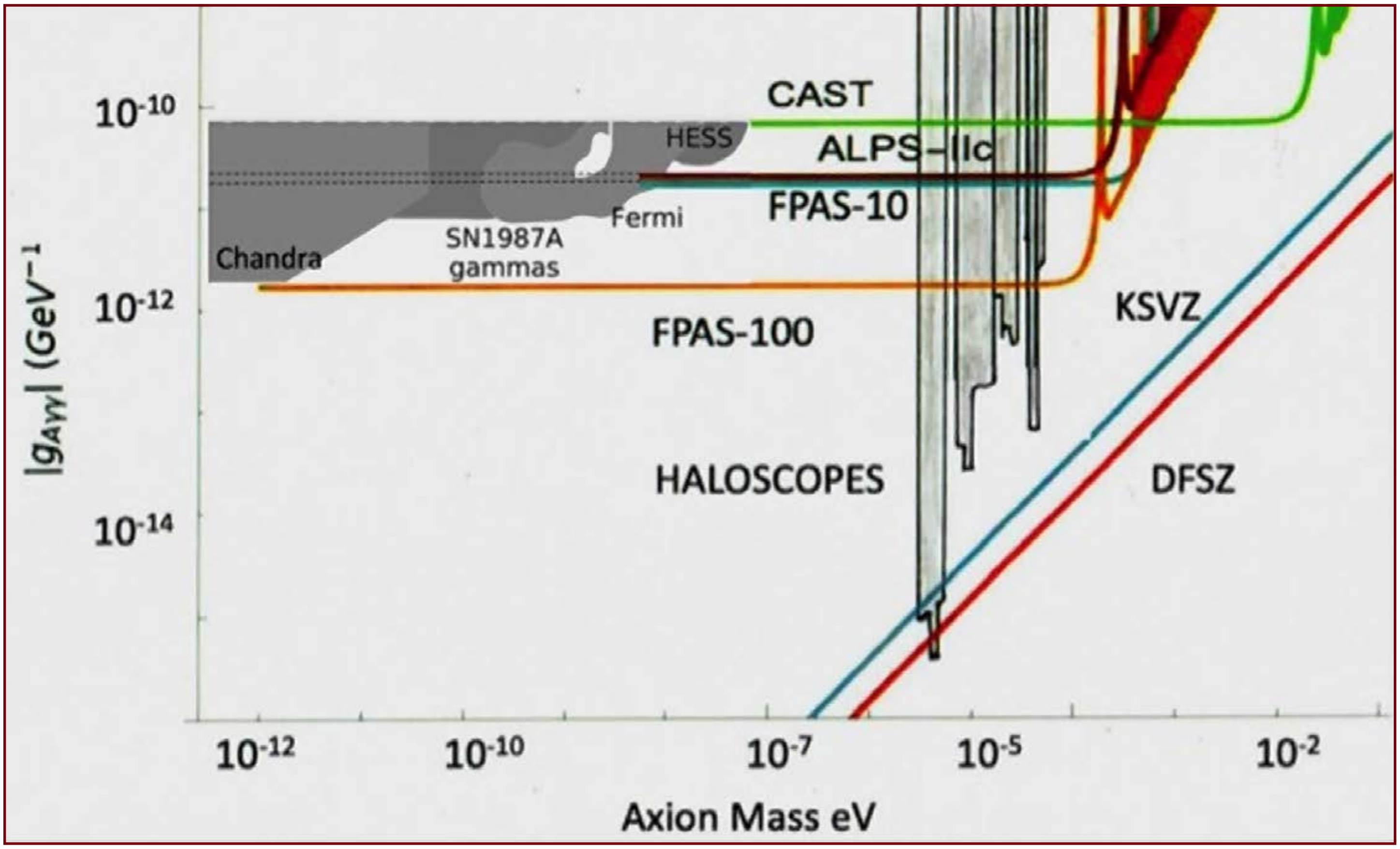


Figure 1: *ALP parameter space. Peccei-Quinn axions lie in the band between the lines labeled KSVZ and DFSZ. ALPs with parameters in the region above the green curve labeled CAST have been excluded by the CAST experiment. ALPs IIc and FPAS 10 indicate the sensitivity of the proposed experiments ALPs IIc and FPAS 10 (FPAS with a 10m cavity). FPAS 100 indicates the sensitivity possible with a 100m cavity.*

New Collaboration to Look for Direct Evidence of Axion-Like Particles

By Rick Creswick

Yanwen Wu, Mas Crawford, Frank Avignone, and Rick Creswick teamed up to construct an experiment dubbed the Fabry-Perot Alp Search (FPAS) to directly detect axion-like particles, or ALPs. While the fundamental physics question we want to address falls firmly in the area of particle astrophysics, Professors Wu and Crawford have generously contributed their expertise in quantum optics and laser physics to make FPAS possible.

Axions and the Strong-CP Problem

Axions arose within the standard model of strong interactions to solve a long-standing question, "Why is the neutron dipole moment so small?" Current experimental bounds on the neutron dipole moment are 10 orders of magnitude smaller than what might be expected, requiring fine tuning of the parameters of the standard model. The 'unnaturally' small value of the parameter required for the theory to be consistent with experiment is called the Strong CP Problem.

In 1977, Peccei and Quinn introduced a new symmetry into the standard model that solves the Strong CP problem. Shortly after that, Weinberg and Wilczek showed that spontaneous breaking of this symmetry leads to a new pseudo-scalar particle, the axion. In the intervening years, other extensions of the standard model have led to pseudoscalar bosons generically called axion-like particles, or ALPs. ALPs couple to photons, electrons, and quarks and they appear in many different contexts in cosmology and astrophysics as well as particle physics. However, at the moment, they are purely hypothetical. For the past 40 years, there has been an intense effort to either discover ALPs or rule them out, some of which is summarized in Figure 1.

In addition to solving the Strong CP problem, ALPs created in the Big Bang are a leading candidate for dark matter. Current estimates are that 84% of all the mass in the universe is dark matter, and yet we do not know what form this matter takes. We know dark matter only through its gravitational effects on the large-scale structure of the universe, galactic clusters, and individual galaxies.

Since ALPs are very weakly interacting with ordinary matter, they can play a significant role in stellar evolution. ALPs have also been invoked in explaining the Pair-Production Anomaly in which very high energy gamma rays emitted by active galactic nuclei are observed on Earth. These gamma rays should collide with the extra-galactic background light producing electron-positron pairs and never reach detectors on the Earth. And yet they do! A possible explanation of how this could happen is that the photons convert to ALPs in the

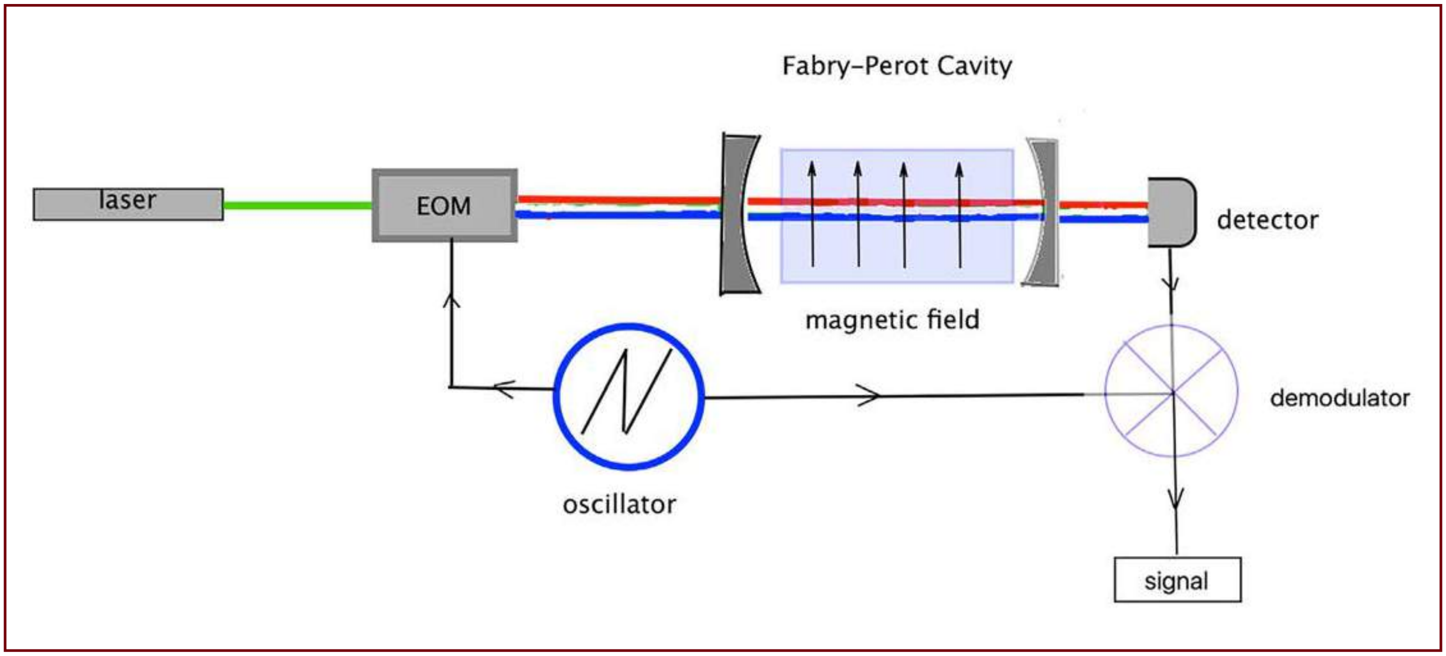


Figure 2: *A highly over-simplified view of FPAS. Light from the laser passes through an electro-optical modulator (EOM) that and then enters the Fabre-Perot cavity where photons are converted to ALPs in the magnetic field (indicated by the black arrows). The intensity of the light that emerges from the cavity has an intensity modulated at the driving frequency of the EOM.*

magnetic field of the AGN, propagate unmolested through intergalactic space, and then reconvert to photons in the magnetic field of the Milky Way.

FPAS is designed to look for the unmistakable signature of the coupling of ALPS to the electromagnetic field through the scalar product of the electric field of a photon and a fixed magnetic field. As shown in Figure 2, FPAS takes linearly polarized light from a laser and passes it through an electro-optical modulator (EOM) causing the polarization to precess at a known frequency. The light then enters a Fabry-Perot cavity embedded in a strong uniform magnetic field. The cavity is essentially a pair of parallel super-mirrors that reflect the light back and forth within the cavity, extending the optical path length from 1m to 446 km. As photons traverse the magnetic field, some of them convert to ALPSs leading to a periodically modulated dichroism. The signal in FPAS is proportional to g_aγ^2, making it very competitive with second-generation experiments like IAXO and ALPs IIc whose signals are proportional to g_aγ^4. Our estimates for the sensitivity of FPAS are indicated by the curves labeled FPAS 10 (for a 10m cavity) and FPAS 100 (for a 100m cavity).

Over the summer, we fleshed out the design of the experiment are preparing an NSF EAGER proposal for a 'proof-of-principle' version of FPAS with a 1m cavity and no magnetic field.

Theoretical Physics Group

Members: *Brett Altschul, Jacob Dunbar, Vladimir Gudkov, Sapan Karki, Pawel Mazur, Harry Oslislo, Thomas Richardson, Abhishek Rout, Matthias Schindler, Luis Suarez*

The department's Theory Group, led by Drs. Altschul, Gudkov, Mazur, and Schindler, has been extremely active in 2020, in spite of the pandemic. There are currently five graduate students and one South Carolina undergraduate doing research in collaboration with the group's faculty mentors.

One more graduate student, Richard DeCosta, received his PhD this past summer, having completed a dissertation under the supervision of Dr. Altschul. His research touched on a number of different areas in theoretical physics, but the last major project he worked on was related to problem of separation of variables in a cylindrically symmetric inverse square potential. (This potential is of interest because it describes the behavior of a polarizable atom in the electric field of a long charged wire.) Dr. DeCosta's dissertation work showed that there was an alternative way of separating the Schrödinger equation for this system, using the same parabolic coordinates that are useful for studying the behavior of neutral atoms in external electric fields. In parabolic coordinates, solving the Schrödinger equation for the cylindrical problem is equivalent to solving two Schrödinger equations in a Coulomb potential — one attractive and one equally repulsive.

This past spring, graduate student Thomas Richardson published his first paper, in which he and Dr. Schindler studied the coupling of two nucleons to magnetic and axial vector fields using the large-N expansion of quantum chromodynamics. Their work sheds light on the puzzle of why two different modes of coupling to magnetic fields have very different strengths.

Another graduate student, Sapan Karki, also published his first paper in spring, in collaboration with Dr. Altschul. Karki showed that certain supergravity cosmologies, describing parity-violating effects in the early universe, are beset by instabilities. This raises difficult questions about whether these models can provide consistent models of cosmological physics.

At the same time, Drs. Gudkov and Schindler continue to be involved in a variety of projects to study fundamental symmetries in particle physics and nuclear systems. Their theoretical work supports several experimental programs in the United States, Europe, and Japan. For example, Dr. Gudkov was a co-author of a recently submitted proposal by the international NOPTREX collaboration for a search for time-reversal invariance violation in neutron scattering at the J-PARC facility in Japan. Drs. Gudkov and Schindler also presented their research at a number of remote workshops and conferences. Dr. Altschul has also continued his work on tests of fundamental symmetries, including publishing new bounds on relativity violations for top quarks.

News from Sasha Monin

By Sasha Monin

First of all, I am looking forward to join the Department and hope it will eventually happen. My research is two-pronged. Namely, it is aimed at better understanding the main tool we have in high energy physics, quantum field theory (QFT), and applying it to provide support for current and future experiments, in particular those pushing forward the Intensity frontier.

The standard generic way to deal with QFT is perturbation theory. However, it is not always helpful. First, there are systems (like QCD) where coupling is large, thus leading to inapplicability of naive perturbative computations. On the other hand, even for systems with small coupling certain processes with many quanta cannot be reliably described by (the standard) perturbative analysis. Finding new methods and techniques to address those, so called non-perturbative, effects presents one of the biggest challenges for theoretical physics in 21st century.

Why is it relevant for phenomenology you may ask? On the one hand at energies accessible by the next generation of colliders, multiplicity of final states renders perturbative computations useless. On the other hand, many high intensity experiments probe intermediate energies, for which no perturbative description of QCD is known.

Currently, I am working on developing a method allowing to probe non-perturbative regimes. At present, it has been tested successfully on theories with enhanced bosonic symmetries (conformal field theories) at small coupling. In the future, the goal is to extend the technique first to a more generic weakly coupled theories, without relying on the conformal invariance, and then to theories with arbitrary coupling.

EVENTS, EDUCATION, AND OUTREACH

Virtual Viewing at the Melton Memorial Observatory

By Martin Bowers

Every clear Monday evening, the Melton Memorial Observatory hosts a night of public viewing. In normal times, guests ascend the observatory's winding staircase for glimpses of celestial wonders. But, of course, these are not normal times. When the need to maintain social distancing emerged this past April, the observatory staff moved to another approach: live-streaming. Now, instead of greeting guests inside Melton's dome, we greet them on *Facebook Live*.

None of this would work without the considerable support of faculty, staff, and student volunteers. Much effort goes into setting up equipment, operating telescopes and cameras, resolving technical glitches, and monitoring the Facebook page for submitted questions.

Providing live images through a telescope presents unique technical challenges. Telescopic objects are often quite dim, so capturing a sufficient number of photons, processing them, and presenting them in a usable form is much more complex than launching a *Zoom* meeting. After a great deal of experimentation, our live streaming sessions now consist of split-screen displays from two telescopes using two different types of cameras. We even include live audio commentary.

A recent example is shown on the next page in Figure 1. This screenshot shows two different views of the planet Jupiter, taken through a pair of identical telescopes (Celestron C8's) but with two different cameras. The large image on the left is from a video camera and the much wider view on the right is from a DSLR. Using the freeware program *OBS Studio*, we were able to stream live views from both cameras and to even add labels of the four visible Galilean satellites.

One issue when viewing from a city is the rather considerable light pollution. Our location in downtown Columbia works fine for bright objects like planets, but the light from dim objects is overwhelmed by city lights. However, using timed exposures with our DSLR through a Light Pollution Rejection filter, we actually show a bit more detail than would be visible at the eyepiece. During our live-streaming sessions, we have provided views of galaxies, nebulae, and clusters that would be almost invisible at the eyepiece. An example is shown on the next page in Figure 2, a screenshot taken from a live-stream of M42, the Great Nebula in Orion. This image is a screenshot of a 30-second exposure streamed live on April 27, 2020.

When we host guests in the dome, they sometimes use smartphones to capture images off the eyepiece. With cameras already mounted in the telescope for our live-streams, though, we can directly capture our video images for later post-processing.

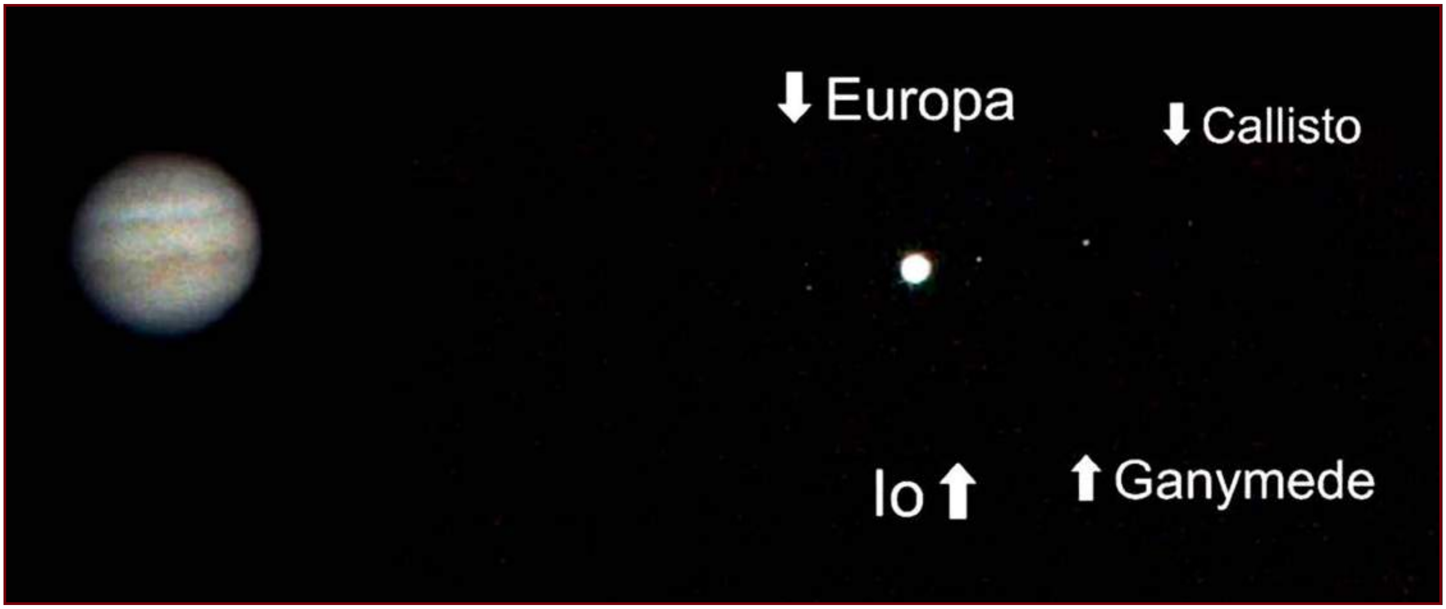


Figure 1: *Jupiter*

A recent example is in Figure 3 below. Taken on October 12, 2020, this image of Mars was made using the same telescope and video camera from our live-stream.

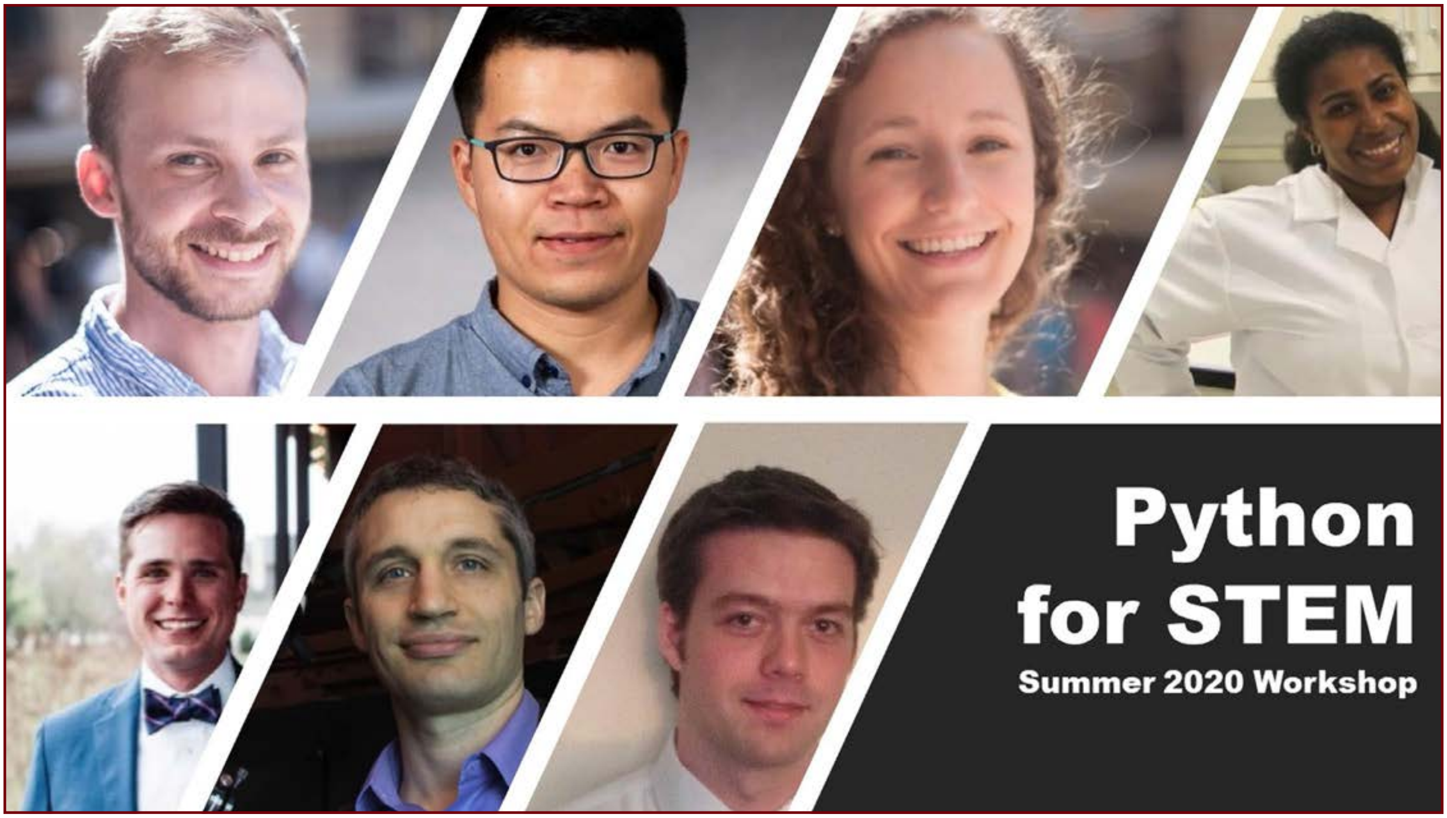
Live-streaming also has the advantage of reaching a greater audience. When we physically hosted guests, we typically had 100-200 visitors per session; with live-streaming we are now averaging ~1,200 viewings per week.

Although live-streaming has its advantages, it is still not the same experience as physically looking through the eyepiece. Just like in-person classes differ from online instruction, there's something special about being physically present at the eyepiece that's hard to describe. Although we can answer posted questions in pseudo-real time, it is not an effective way of carrying on a conversation. But streaming has its place, and, in 2020, it is a good place to be.

Figure 2: *M42*

Once we are again able to host guests in the dome, we are hoping to provide the best of both worlds by continuing live streams through one telescope while live guests look through the others. Until that time comes, we hope you can stop by the Melton Facebook page to check us out!

Figure 3: *Mars*



A collage containing the "Python for STEM" summer workshop instructors.

From left to right and top to bottom: *Justin Pierel (UofSC Physics & Astronomy), Yuhan Rao (NC Institute for Climate Studies), Eleanor Davis Pierel (UofSC Geography), Benedicth Ukhueduan (UofSC Biology), Nicholas Tyler (UofSC Physics & Astronomy), Dr. Steve Rodney (UofSC Physics & Astronomy), Douglas Adams (UofSC Physics & Astronomy).*

"Python for STEM" Workshop: A Virtual Success

By Justin Pierel and Steve Rodney

The "Python for STEM" workshop offered a free, STEM-focused, interactive programming experience. Graduate students from multiple departments collaborated to create materials and teach the workshop, led by efforts from the Department of Physics and Astronomy. The workshop was broken into two weeks: a beginner level and an advanced level. Both weeks ran from 8:00 am to 12:00 pm on Monday through Friday with afternoon "office hour" sessions.

The initial registration for the Python for STEM workshop was 316 people, but there were approximately 64 "beginner week" and 43 "advanced week" active participants. There were also 86 participants who chose to receive the workshop's recorded sessions and Project Jupyter notebooks after the course was completed. To date, there have been more than 250 views of the workshop's session recordings. Participants came from more than 10 different departments throughout the Columbia campus.

The workshop began with a conceptual understanding of programming as well as tips for searching for and reading documentation. Module topics for the beginner week included troubleshooting errors, science-focused packages, and modules specific to individual research areas. The advanced week covered more complex topics including machine learning, probability theory, and model fitting.

This workshop was held entirely on the Zoom video conferencing platform. This ultimately provided several unforeseen benefits to the workshop structure. First, it allowed for straightforward recording and video distribution on the workshop's **GitHub repository.** Second, the use of breakout rooms within the Zoom platform enabled hands-on support and group work. This in turn created the opportunity for a more personalized and interactive experience for students than would have been possible in a similarly sized classroom. Third, the ability to host people virtually allowed instructors to provide this workshop to more people than would normally have been able to attend an in-person and on-campus workshop.

Surveyed participants gave the workshop rave reviews. **87.5% said they would recommend the workshop to a friend and 100% rated their experience a 4 or 5 out of 5.** One student commented, "It was great, well executed, challenging, and encouraging. You all rule!" Participants responded well to the interactive small group activities. One participant wrote, "I liked the interactive game portion from the beginning of the week […] Also, keep the small breakout rooms for participants to practice the codes together." This comment illustrates the general themes from the participant responses. Short lectures with hands-on problem solving activities resulted in higher survey scores throughout both weeks.

More STEM-focused Python workshops would be a valuable addition to the University of South Carolina's offerings. 100% of participants said they would like to see more Python workshops and short workshops at the university. Graduate students gained valuable teaching and course development experience as they conceptualized, developed, and taught the workshop under general guidance from Dr. Steve Rodney. The instructor team hopes that this resource can be expanded and continued into future years based on the continual high level of interest.

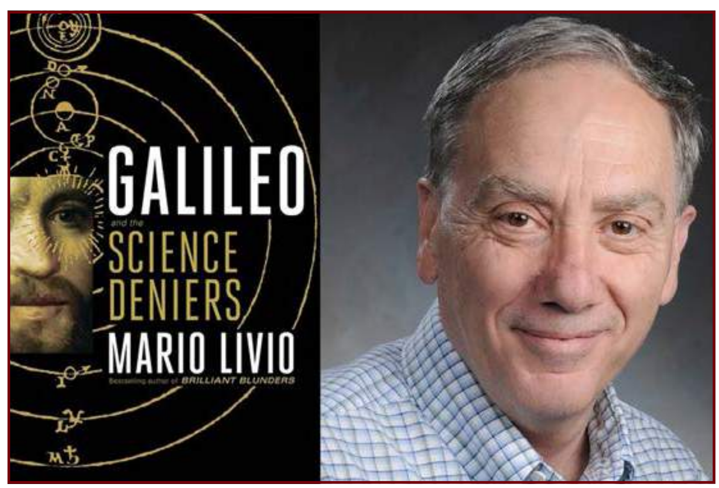
Galileo and the Science Deniers

By Steve Rodney and Sam Beals

In recent years, our Distinguished Lecture Series in Physics and Astronomy (*uof.sc/physicslectures*) has brought many eminent physicists to campus for colloquia and public lectures. We have hosted Nobel laureates, presidents of the APS and AAS, and many other distinguished researchers sharing their work and their passion with us. These free events are open to the whole campus and the surrounding community and we have regularly attracted hundreds of attendees. Unfortunately, it is not possible to safely host an event like that during the COVID-19 pandemic. We are, however, all becoming more adept with online events and we turned our public lecture into a live-streaming event available to friends of UofSC from all around the world.

On October 1, 2020, we hosted Dr. Mario Livio, astrophysicist and best-selling author, for a return to this lecture series (he last visited us in-person in 2016). Mario's recent book, *Galileo and the Science Deniers*, is a fresh biography of Galileo Galilei, which puts his scientific discoveries in context. Disturbed by rampant science denial in America—and around the world—that has only intensified in recent years, Livio began researching the life, ideas, and actions of this brilliant man who encountered similar pressures centuries ago. The result is a biography filled with lessons relevant for today—whether with respect to the COVID-19 pandemic or climate change.

To learn more about this event and access a recording of the lecture, please visit the event page at *event.sc.edu/galileo.*



Astrophysicist and author Dr. Mario Livio visited UofSC virtually in Fall 2020 for a Microsoft Teams remote lecture about the life and science of Galileo Galilei.

An Update on the Society of Physics Students (SPS)

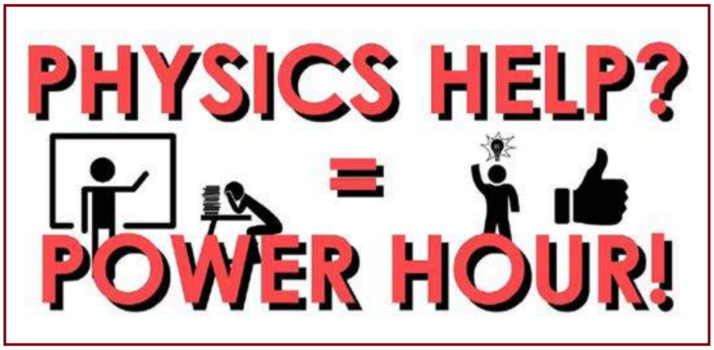
By Benjamin Ranson (Class of 2022)

The SPS is our organization, for and by students in this department. The reasons for its continued existence are that it gathers us in a social network. It aids our collaboration in work, whether it is for classwork or research. It facilitates professional development, an issue which every student must be concerned of in light of their impending transfer into the workforce, graduate school, or academia.

In the last year, the SPS updated its program to better suit these needs. Physics students do not have time to spare. This realization has driven our reformulation. Our old program involved core leadership delivering a weekly in-person update on news and events. This was inefficient in every sense. It asked for three or four members of the leadership to devote their few spare hours to planning these events and asked students to attend in order to have the information deposited into them like coins into a bank. Not surprisingly, the attendance at these meetings was sparse.

Moreover, it was bureaucratic, or rather it had the same nascent form present within all bureaucracies: it was a minority of people imposed on a wider base, aimed to 'lead' and 'serve' it. Therefore, if the SPS had grown, it would have become alienated from us. Following would be a two-sided effect: we, as students, would cease to have an organization of our own. To put it differently, the SPS would have been an organization to serve students, like UofSC's Student Health Services or the Student Success Center, albeit one staffed by unpaid physics students. We would have become customers, subordinate to it, only interested in proportion to its ability to aid us, in proportion to the willingness of its leadership to contribute hours. Therein lies the other side of the coin: the leadership would be reduced simply to interns: drafting emails and budget requests out of some external obligation, rather than real desire to help our peers. Their compensation would have taken the form of a title on their college resume, not satisfaction at the construction of a practical community.

This state of affairs was already forming and it could not have stood for long; it was sure to collapse. The leadership was sure to tire of their self-exploitation and we the students were sure to become dissatisfied with the insufficiency of their service. Possibly, the administration of this department, out of noble intent, could have kept it alive artificially by various donations, rewards, recognitions, and proposals. However, the contradictions would remain. Instead, what was needed was a sublation, a complete doing away with the previous order. And this is what we aimed to deliver.



In the spring of 2020, the SPS established a new "Physics Power Hour" weekly event, which provided undergraduate students with a unique outlet to share ideas, ask questions about homework, and enjoy community with others.

In the last year, our regular programming has been:

1. A weekly 'Power Hour,' in which all students in physics classes gather in-person to collaborate on assignments, projects and other work.
2. A monthly game night, in which students gather to play various board games, socialize, and eat.

The phrase "change in programming" obscures the shift in organizational basis present. In both events, we students serve each other. Whether by the voluntary assistance we provide at Power Hours, motivated only by our desire for mutual aid, or unconscious compulsion to make friends and acquaintances, bonds are formed at these events more reliably than any bylaw or policy passed down by command.

While this system escapes the problems of the old one, it is imperfect. Since it is driven by a general collaboration, it requires a certain minimum number of participants to even function. It has been the task of the leadership in the last year to generate that group. For the majority of us, who have dealt with seemingly uncaring bureaucracies our whole lives, this model is unfamiliar to us. It is much closer to a large group of friends united by common concern than it is to those typical systems and it will therefore require a certain amount of socialization before we are comfortable with it.

We have not escaped (nor tried to escape) the needs that the old system addressed more directly: school selection, GRE help, resume writing, and traveling to conferences. These are needs imposed on us externally and it is a partially open question as to how we can consistently provide this training to each other in a sustainable manner. The common need for this training will be brought forward and addressed in the coming months.

In the task of testing our new model, the COVID-19 pandemic has not helped. It is no longer safe to meet in person for either of these events. For the foreseeable future, we have set up an active online space (through the website Discord) to communicate and help each other. Undergraduate and graduate students should contact us to join. We welcome feedback from anyone on our new system.

STUDENT SPOTLIGHT AND ALUMNI NEWS

STUDENT SPOTLIGHT

Expedition Physics

By Joshua O'Connor

It was June 6, 2020 when I received news of being accepted to University of South Carolina doctoral program. This was **BIG** news after my unorthodox journey and I felt like I had won the lottery! In high school, my life was not academics. I was an athlete who solely focused on winning state championships in wrestling and football. My plan was to get a scholarship to UofSC to play football. Obviously, this plan did not work out as I was injured my senior year while wrestling.

After my injury, I was unfocused during my senior year in high school and did not have a plan for my future. Although I had scholarship offers to small colleges, the dream to play football started to shift. I met and married a wonderful woman, so I needed to begin thinking about which career path was going to provide my family a financial stability. Due to an injury during wrestling, I was not able to join the military. I researched various employment opportunities and decided to train to be a firefighter.

While working at the fire department, I started attending college. At that time, I had not declared a major and was unsure what my interests would be. As I began my journey at UofSC, I interacted with several influential professors who inspired me. I discovered how much I loved learning and growing. I began thinking differently as I was expanding my knowledge in philosophy, mathematics, and physical sciences. As my knowledge grew, my confidence in the area of academics increased as well. My first science professor had a profound impact on what I would study in the future. His passion for drawing organic structures of molecules and how these structures can be represented quantum mechanically sparked my interest in physics and I wanted to know how we could tract these particles.

Now that I am in graduate school at UofSC, I am beginning to find my main interests. I set out to study physics and mathematics to answer some of the deepest mysteries in the physical and unphysical world. Equating the infinitely tiny and the infinitely large is one of the greatest mysteries in physics. Although I haven't yet found a specific research area, I am interested in nuclear astrophysics and cosmology. As scientists, we are trying to find solutions to problems that have never been solved. A great physicist once said, "If we act like we know everything we may miss the chance to learn something." It is the questions we do not have the answers to that motivate us to innovate, put forth new ideas, and advance civilization. After my unorthodox journey to the doctoral program, I plan to offer new approaches and new ideas to contribute to physics of the unknown.

ALUMNI NEWS

My Journey to a PhD

By Suraj Poudel

I am a recent PhD graduate in Physics from UofSC Columbia. I feel very lucky to have the opportunity to work with my advisor, Dr. Varsha Kulkarni. As a PhD student, I studied the cosmic chemical enrichment history during the first billion years after the Big Bang using hydrogen-rich galaxies. I used the distant quasars as background sources of light to probe the foreground galaxies. It was such an enlightening experience to use some of the world's largest telescopes to study the galaxies several billion years back in time. Besides doing research, I also have beautiful memories of hiking and kayaking through the trails, creeks, rivers, and lakes in South Carolina.

This past spring break, I decided to visit my home country in Nepal to marry my girlfriend. While I already defended my PhD thesis before traveling to Nepal, I had yet to submit my dissertation and graduate. My plan was to get back to the US with my wife and work on finishing my dissertation. But, as soon as I got to Nepal, the pandemic began to spread all around the world, and I could not make my way back to the US. I am grateful for my friends at UofSC who helped me clear my apartment in Columbia and take care of my valuables. As an international student in the US, there are several requirements to meet in order to maintain the proper status as a graduate student. In the beginning, I was a little worried on whether I could submit my dissertation and graduate remotely. However, with the mutual help of International Student Services, my advisor, and the Department of Physics and Astronomy, I was able to wrap up my dissertation and graduate last summer.

In the hope of spending quality time with my parents and wife during this global lockdown period, I decided to work from my hometown in Syangja, Nepal, despite several challenges. I was born and raised in this typical rural Nepalese village. We neither had electricity nor any means of transportation. We had to walk about an hour downhill to get to our school and more than an hour uphill to get back home. During the rainy season, the journey to school and back home used to be even more challenging as we had to cross the flooded river and walk through slippery roads. Thanks to my parents who constantly helped and motivated me to complete my PhD in Physics from such a renowned US university when they could hardly make ends meet.

Nowadays, we have electricity and public vehicles to get to the nearest cities in Nepal. However, we did not have any Internet connectivity until last April. We worked hard to get WiFi at our village by connecting optical fiber from another village several kilometers away. Afterwards, I was able to work with my research group at UofSC as well as collaborators around the globe remotely while staying at home. In the meantime, I also applied for several postdoctoral candidate jobs and participated in several interviews. Finally, I accepted a postdoctoral position in Chile to work on the gravitational arc-tomography project. We study the halos of distant galaxies located in between a giant background galaxy and a huge foreground gravitational lens in order to understand the connection between halos and host galaxies. Fortunately, my employer in Chile has allowed me to work remotely during this global pandemic until the situation returns to normal. Chile is one of the best places to study astronomy as it is home to many of the largest telescopes in the world. I hope the pandemic will end soon and I can get to Chile, visit the Chilean astronomy community as well as the Chilean observatories, and fulfill my dream of becoming an independent scientist.

IN MEMORIAM

Edwin Rudolph "Rudy" Jones, Jr.

In Memory of Rudy Jones

By Frank Avignone

The Department of Physics and Astronomy lost a long-time friend and faculty colleague on January 31, 2020 with the passing of Edwin Rudolph "Rudy" Jones, Jr. Rudy came to Carolina as an assistant professor in the fall of 1965 after graduating with his PhD from the University of Wisconsin. He arrived one semester after I did and we team-taught physics courses and laboratories for a year. I quickly recognized his natural ability in connecting with students and his strong interest in pedagogy. He was a native South Carolinian, born and raised in Dillon, graduating at the top in his class from Dillon High School and then attending Clemson University, where again he distinguished himself by winning the Norris Medal, in 1960, which is awarded to the best all-around graduating senior at Clemson.

Rudy taught physics at Carolina for 50 years and was the director of undergraduate studies for 25 years. He held that position for most of the 19 years that I was the department chair. During that critical time of growth in the department, I was never burdened with problems associated with undergraduate curricula and teaching, because Rudy was clearly on top of the day to day details, as well as on the continued development of our undergraduate program. During that time, he also led The National Junior Physics Academy, The Junior Science Fair, and Midway Physics Day at the South Carolina State Fair.

Early in his UofSC career, he collaborated in research at the Savannah River National Laboratory in making magnetic susceptibility measurements of actinide compounds. When that project ended, he turned his full attention to teaching and writing educational materials. Rudy published a text on solid-state electronics and later teamed up with his colleague Richard Childers in writing the text, Contemporary College Physics, which was published by Addison-Wesley in 1992. The book was used widely as an undergraduate text in algebra-based physics for many years. A second edition was published in 2001 and is still widely in use. Rudy was an active member of the American Physical Society, the American Association of Physics Teachers, and the International Society for Optics and Photonics (SPIE). With this interest, he introduced laboratory experiments in modern optics in the advanced laboratory.

Many are amazed to learn that during his long and active career at UofSC, Rudy and his wife of almost 60 years, Elizabeth (Betty), were raising 10 children. Rudy will be missed by his family, friends, and colleagues and will be remembered for the many contributions that he made over his 50-year teaching career in our department.

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Space Elements imaged by Alex Mowery from the Melton Observatory