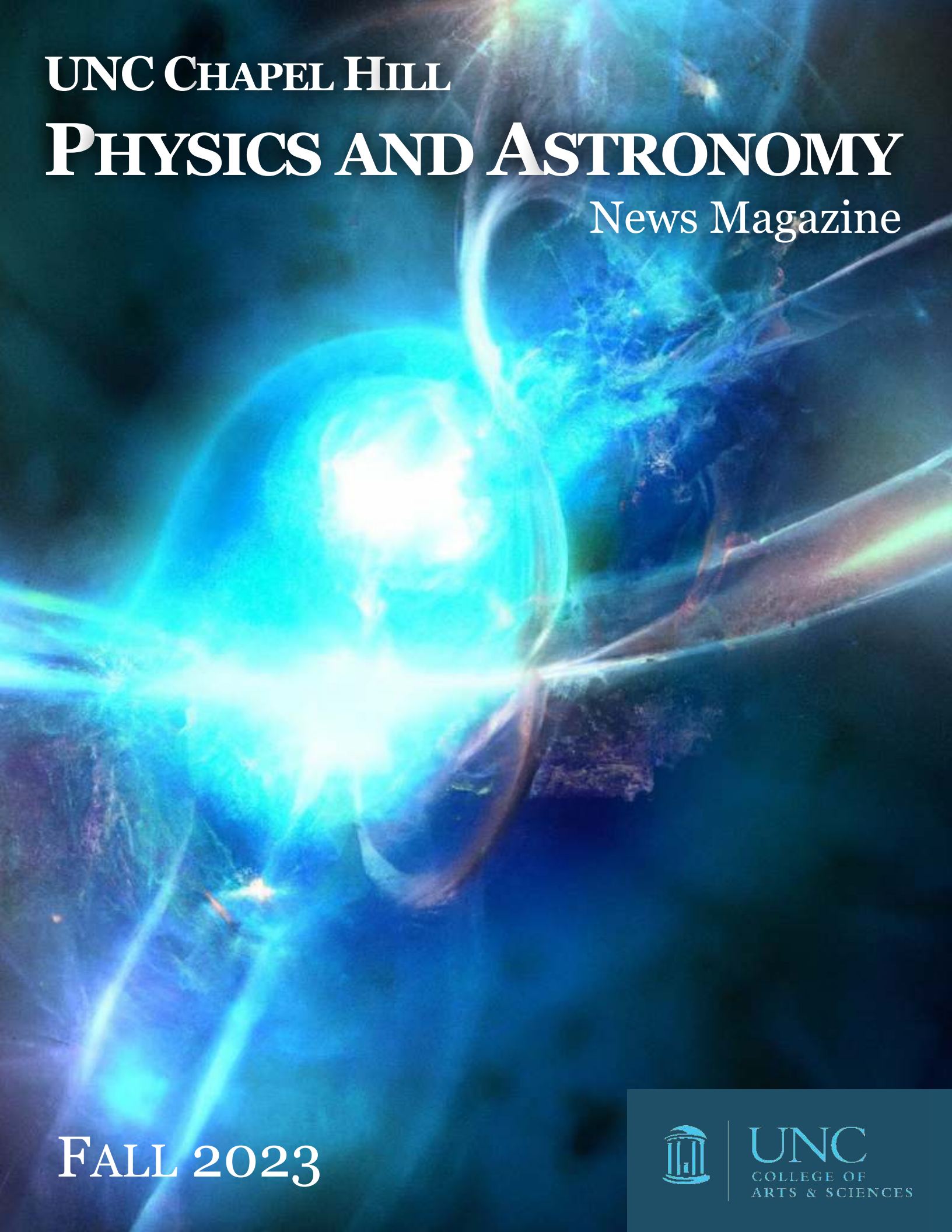


UNC Chapel Hill
Physics and Astronomy
News Magazine

Fall 2023

UNC
College of
Arts & Sciences

Fall 2023

online
physics.unc.edu

Our Department in numbers:

- **32** Tenure-line faculty
- **5** Teaching faculty
- **2** Research faculty
- **11** Academic support staff
- **4** Instrument shop personnel

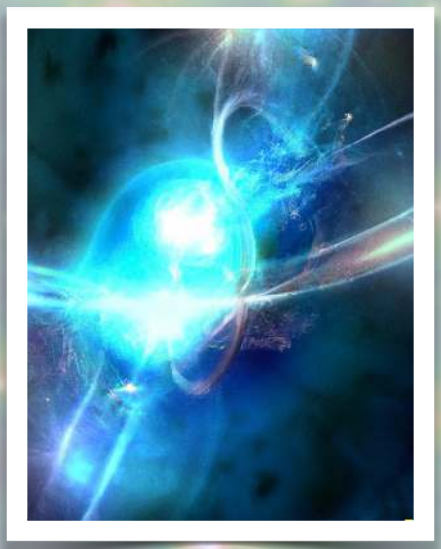
- **13** Elected Fellows of the APS, AAAS, SPIE, or AIMBE
- **$12M** Annual Research Funding received (avg 2020-2023)

- **89** Graduate students
- **9** Postdoctoral scholars

- **15,643** Credit hours taught in 2022-2023
- **246** Majors
- **49** Bachelor's degrees awarded in Spring 2023

UNC COLLEGE OF ARTS & SCIENCES

Physics and Astronomy News Magazine



***On the cover**: An AI-generated image made by DALL-E, using a prompt based on the article by D. Khveshchenko (page 6).*

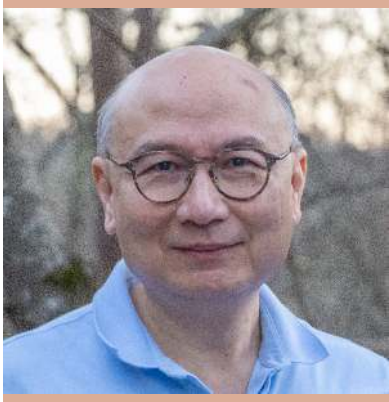
Contents

Plus

Questions? Comments? Contact us: drut@email.unc.edu

Background image: check out the Fall 2021 issue available on our website at physics.unc.edu/home/department-newsletters

From the **Chair**



Transform and Enlighten

By Frank Tsui

Greetings from Carolina Physics and Astronomy! I hope this letter finds you in good health and spirits.

As the holiday season approaches, I am delighted to share with you some of the exciting news and achievements from our department. In this issue of our news magazine, you will find stories about our faculty, students, and their research projects that showcase the excellence and diversity of our department.

We have welcomed one new faculty colleague to our ranks, Professor Muxin Zhang, an expert in the mechanisms of physics learning. Her hiring will enhance our continued efforts to transform and modernize physics education. Our research excellence has been recognized by the 2023 Vera Rubin Early Career Award of the American Astronomical Society awarded to Professor Carl Rodriguez, two more colleagues elected Fellows of the American Physical Society, and two new NSF Graduate Fellowships.

We continue to develop our undergraduate curriculum to meet the needs of our majors and attract more students to physics and astronomy. We have seen significant increase in the number of physics majors, in particular our BA tracks in quantitative finance and computational physics, in collaboration with Kenan Flagler Business School and Computer Science Department. Next year, we plan to offer a new BA concentration in Engineering Physics. Students in this BA track will take more lab-based and engineering-focused courses in addition to the foundational physics courses, to develop much needed hands-on technical skills to solve engineering problems. We have made significant progress modernizing our graduate program. More than one third of our doctoral students are women. During the previous academic year, about 40% of our graduating PhDs are women, twice the national average.

In this issue, faculty research spotlights feature groundbreaking work in modern theoretical physics, experimental neutrino physics, and physics education. In particular, the article on the nature of the neutrino describes the extremely sensitive experiments to determine whether neutrinos are their own antiparticle and search for exotic particles and dark matter, which will help to answer some of the most fundamental questions of the universe.

Another story that you will enjoy reading is the resumption of our annual "Science is Awesome Day!" last May from its three-year COVID-related suspension. Phillips Hall was filled with elementary school kids, their teachers and parent chaperons, and volunteers. Everyone had a fun and meaningful day, getting exposed to physics and astronomy through in-person interactions and hands-on activities.

The department and the CoSMS Institute have renovated the second-floor west wing of Phillips Hall, transforming old, dilapidated lab and storage spaces to modern conference/seminar rooms, and office suites for visitors and collaborators. The Institute has resumed its distinguished speaker series, welcoming renowned physicists to visit the campus and give lectures on the latest advances in cosmology and dark matter research.

We are very grateful for your continued interest and involvement in our department. Your support and feedback are vital for our success and growth. We hope you enjoy reading this issue of our news magazine and feel inspired by the achievements of our department.

Thank you for being a part of our department and our community. We look forward to seeing you at our upcoming events and reunions.

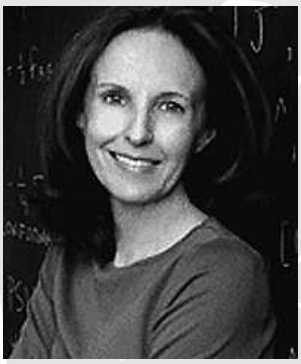
Best wishes,

Frank Tsui

Chair, UNC-CH Physics & Astronomy

Elementary Particle Theory at UNC

By Louise Dolan



I do research in theoretical particle physics. I will describe some of my work in string theory and gauge field theory. I identified a hidden symmetry of the two-dimensional principal chiral models as the infinite-parameter Kac-Moody algebra, bringing these mathematical structures to high energy physics for the first time. This symmetry algebra has an infinite number of transformations compared with just the three generators of the rotation group, for example. The work further implied through the Polyakov correspondence, that a Kac-Moody Lie algebra must be the hidden symmetry of Yang-Mills gauge fields, the fields of the strong interactions in particle physics. This phenomenon leads to the powerful result of integrability and accesses nonperturbative information. Later, together with Chiara Nappi and Edward Witten, I gave an explicit construction of this symmetry in gauge theory in four dimensions of space-time. It makes contact between a symmetry of a certain worldsheet theory for the type IIB superstring, and a non-abelian infinite-dimensional symmetry algebra for the weakly coupled superconformal gauge theory. The symmetry algebra $\hat{G}$, the Kac-Moody extension of the conformal group G, is in the same equivalence class with Drinfeld's Yangian algebra. This supersymmetric Yang-Mills theory has come to be known as the harmonic oscillator of the 21st century, because it is the first example of a four-dimensional quantum field theory that is integrable, i.e. solvable for all values of the coupling. It plays a cornerpost role in relativistic quantum field theory just as the harmonic oscillator does for non-relativistic physics.

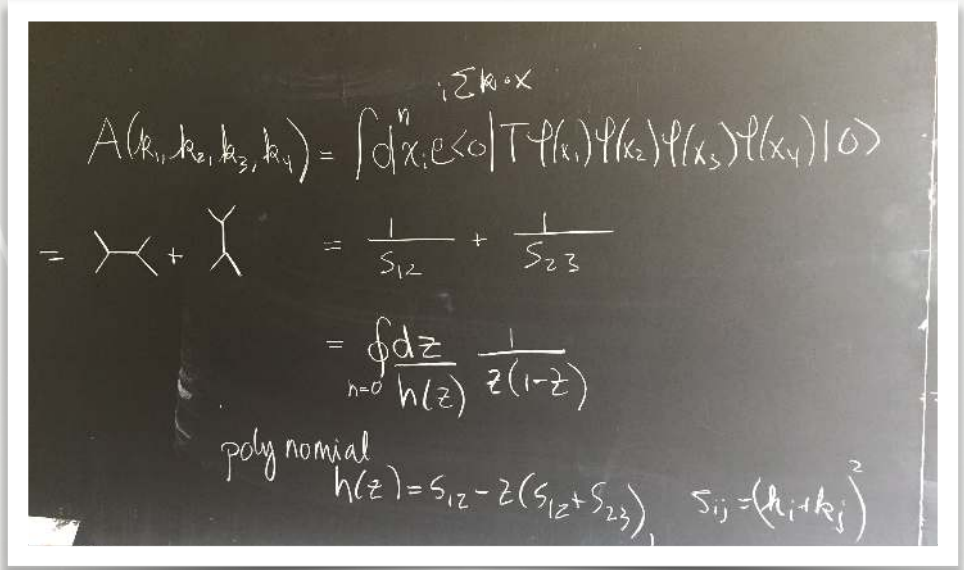
Seeking a better understanding of twisted conformal fields in relation to gauge symmetry in string theory, I computed a system of vertex operators for the two-dimensional twisted conformal field theory associated with a d-dimensional momentum lattice and a binary code, when d is a multiple of 8 and the lattice is even and self-dual, with Peter Goddard and Paul Montague. We derived a triality structure for all d mod 8, including the d=24 Leech lattice and the Golay code, where the induced triality is the extra symmetry needed to generate the Monster group from Conway's group of isomorphisms of the lattice. The Monster group is the largest sporadic finite simple group. The vertex operators create states in the representation theory of the Monster. Our work shows how the Frenkel-Lepowsky-Meurman construction of the Monster is a special case of a more general structure.

"What is at stake here is a new way of thinking about quantum gauge theory... the dual formulation given by the scattering equation approach computes scattering directly without alluding to space-time.."

I have given a proof, together with Peter Goddard, for the scattering equation approach to Yang- Mills theory, which writes the gluon tree scattering amplitudes in terms of contour integrals. This non-Lagrangian approach was proposed by Freddy Cachazo, Song He and Ellis Yuan (CHY), who supplied numerical evidence for it. Goddard and I have also given a polynomial form for the scattering equations, which makes them easier to analyze, and accesses sophisticated techniques of algebraic geometry to analyze sets of polynomials.

We also established a polynomial form for the off-shell CHY scattering equations proposed recently by Lam and Yao. Re-expressing this in terms of independent Mandelstam invariants, Goddard and I have found a new expression for the

polynomial scattering equations, immediately valid off shell, which makes it evident that they yield the off-shell amplitudes given by massless scalar ϕ^3 Feynman tree graphs. We were then able to construct a CHY expression for individual Feynman graphs, valid even off shell, through a recurrence relation. The off-shell expressions shed light on how to construct loop graphs, higher order quantum corrections, in this non-Lagrangian formalism.



4-point scalar tree level scattering amplitude in momentum space.

What is at stake here is a new way of thinking about quantum gauge theory. Instead of a field theory description, which assigns a value for the particle fields at each point in space-time, the dual formulation given by the scattering equation approach computes scattering directly without alluding to space-time or Lagrangian physics and Feynman diagrams, and should facilitate analytic calculation of Yang-Mills loop amplitudes. One expects this may lead to a new underlying geometry, that will explain space-time or go beyond it.

Follow this QR code for more information on the joint string theory seminar with the Duke Center for Geometry and Physics.

Louise Dolan received her PhD from the Massachusetts Institute of Technology (MIT) under the supervision of Francis Low in 1976. Thereafter she was a Junior Fellow at Harvard University before joining the faculty of Rockefeller University in New York City, where she became Lab Head in 1990. She has been Full Professor at UNC Physics since 1990, and University Distinguished Professor since 2013. In 1971-72 she was a Woodrow Wilson Fellow at MIT and Fulbright Scholar at the University of Heidelberg, Germany. She is a fellow of the American Physical Society and received their Maria Goeppert-Mayer Award in 1987. She was a John Simon Guggenheim Fellow in 1988, won the Wellesley College Alumnae Award in 2004. She was Director's Visitor at the Institute for Advanced Study, Princeton (IAS) in 2011-2012, and has been a frequent visitor there since 2006. She is known for her work on quantum field theory at finite temperature, infinite-dimensional symmetry algebras in particle physics, and the proof of a non-Lagrangian representation of Feynman graphs. She has written papers with Peter Goddard, the director of the IAS (2004-2012), and with Edward Witten. Her former PhD students and postdocs have received permanent positions and include Stefan Horvath at UCLA, Katrin Wendland at Trinity College Dublin and Ralph Blumenhagen at the Max Plank Institute in Munich. An archive of their string theory seminar, held jointly with the Duke Center for Geometry and Physics, can be found at the QR code above.

Applied holography with no strings attached

By Dmitri Khveshchenko

Have you ever looked in a mirror, wishing that it would not only reflect your visual appearance but also reveal all the unique complexity and sophistication of your inner self? Well, in the realm of ordinary optics, that kind of a 'tell-all' mirror has not yet been achieved, even with the use of the most advanced holographic techniques - all they can do is show what's 'around the corner,' rendering 3D shapes from 2D projections of the real objects. The available CT/PET/MRI/ microwave scanners produce 3D images, too, but holographic interference is difficult to attain due to the small (or long) wavelengths involved.

However, in modern theoretical physics, the idea of penetrative holography has gone far beyond the methods of image restoration. Akin to a number of other novel concepts, it was first put forward in the context of the long-standing paradox of potential information loss due to the black holes. Gerard t'Hooft, Leonard Susskind, Charles Thorn, and others conjectured that information about all the intricate interconnections (nowadays called 'entanglement') between particles of 3D matter falling into a black hole does not disappear without a trace, leading to the said paradox - instead, this information somehow gets imprinted on the 2D event horizon, thus remaining accurately preserved.

This elegant idea caught on a few years later when Juan Maldacena applied it to relate the properties of one fundamental theory "compactified string theory (a.k.a. 5D supergravity)" to yet another theory "4D supersymmetric Yang-Mills gauge theory" that lives in one lesser dimension but can record all the details of the 5D 'bulk' physics as its 4D 'hologram.'

While neither supersymmetric gauge theories, nor black holes would be readily available in an average physics lab, a number of mathematically related spin-offs of the holographic conjecture suggest that these ideas could also be relevant to such experimentally accessible physical systems as heavy-ion collisions, ultracold atomic gases, and even the various novel electronic materials. Extensive theoretical work on these topics has been vigorously pursued by a broad community of reseachers from several seemingly disjoint fields, including high energy/string theory, quantum information, classical gravity, quantum many-body and condensed matter physics. In most of this work, the pertinent 2D and 3D systems would be viewed as 'holograms' of some relatively simple Einstein-like 'bulk' models of classical gravity in one higher dimension. Unlike the esoteric strings and back holes, though, many of the pertinent electronic materials could - and some have already been - studied in condensed matter labs.

Although this concerted effort began more than two decades ago, the true status of the most tantalizing holographic predictions still remains impossible to ascertain definitively. The main reason appears to be that almost all of the 'applied holographic' (which is the actual name of this field, as used by its practitioners) research was limited to the so-called 'bottom-up' (heuristic or 'ad hoc') approach which copies 'ad verbatim' all its machinery and practical recipes from the original string-holographic Maldacena's conjecture. This makes the so-called AdS/CMT (where AdS stands for the Anti-de-Sitter space-time and CMT for Condensed Matter Theory) holography an 'experimental' technique which, while being capable of delivering fast non-trivial results, is intrinsically lacking any solid foundation and firm justification.

In fact, after having remained abundantly present in the information space of strongly correlated systems for some 15 years, the AdS/CMT approach has been disappearing under the radar, as of lately. At its inception, this holographic approach offered a seemingly straightforward practical recipe which strove to provide a universal tool for studying a broad variety of strongly-correlated quantum many-body systems. And even though such ambitious goals do not appear to have been met, one might still wonder as to whether or not, at least, some of the intriguing holographic claims could indeed be right (perhaps, even 'for the wrong reason').

Since 2012, my work has been focusing on the possible manifestations of holography and its purported condensed matter evidence. For one, much of the recent holographic discussion has been centered around the topic of (non)linear hydrodynamics, one of the main issues being a possible (non)existence of fundamental bounds for the various kinetic coefficients and (non)universal

relations between them. It was found, however, that such relations can readily arise within the standard theory of quantum transport with no reference to any holographic conjecture whatsoever.

The latter realization appears to be well in line with the general expectation that a truly systematic - as opposed to heuristic - approach to generic many-body quantum systems could be developed in the form of a path integral over some Wigner function-type collective field variable acting in the corresponding phase-space, as proposed in my recent work. A subsequent reduction of this formally exact description to the first few moments of the Wigner's function, alongside their hydrodynamics, can then be thought of as establishing a holography-like relationship between the (2d+1)-dimensional 'bulk' and its boundary defined in some lesser (d+1, as the lowest) number of dimensions.

In practice, such a (pseudo-)holographic picture is likely to have much in common with the so-called 'geometric bosonization' technique that was discussed three decades ago by a number of authors (including myself). This prospective direction is still awaiting for its further development, though.

The other important holographic spin-off topic is signified by the Sachdev-Ye-Kitaev (SYK) and the related (0+1)-dimensional modelswhich are often portrayed as the water-proof examples of holographic duality. Curiously enough, this characterization would typically be made despite readily acknowledging that in 1+1 dimensions the pertinent Jackiw-Teitelboim (JT) bulk gravity appears to be non-dynamicaland can be fully described by the boundary degrees of freedom, thereby revealing its intrinsically topological (hence, effectively (0+1)-dimensional) nature.

Apart from some subtle high-energy features which may require an introduction of extra bulk non-gravitational (matter) fields, the 0+1-dimensional boundary dynamics determines all the long-distance bulk correlations, low-temperature thermodynamics, etc. Moreover, the AdS_2/SYK correspondence turns out to be very non-specific, as the dual AdS_2 geometry emerges universally in the near-extremal regime of any generic (d+1)-dimensional bulk gravity.

Thus, although in the above cases certain many-body properties can indeed look ostensibly holographic, such correspondence appears to represent a mere equivalence between the systems of, effectively, same dimensionality. And while still being potentially useful, such topological - akin to that in, e.g., the Quantum Hall Effect - duality clearly does not rise to the same level as genuine, 'non-topological', one where the two dual systems do, in fact, belong in different dimensions. In that regard, the former may be viewed merely as the result of using a redundant, non-minimal, description, while the latter would indeed be radically new and requiring a major paradigm shift.

In other recent work, I demonstrated that one can extend the list of pseudo-holographic correspondences by mapping a certain class of $d \geq 1$ dimensional Fermi systems with short-range, yet potentially strong, interactions (e.g., neutral Fermi gases) onto a (2+1)-dimensional gravity of the AdS_3 variety. However, the latter theory happens to be topological as well, and, therefore, is neither specific enough to positively identify the boundary system of interest, nor practically useful for determining all the boundary properties by studying the bulk instead.

Together with the earlier findings, this result suggests that any purportedly established AdS/CMT holographic duality should be calling for a critical inquiry into whether it really involves the systems in different dimensions ('It from Qubit', as per the popular holographic motto) or is it merely topological ('All from Hall', as per its counterpart proposed in my work). Contrary to the former, the 'HALLographic' correspondence would be relating pairs of systems of (de facto) same dimensionality. In the latter case, the intrinsically topological bulk gravity would offer an interesting alternative description but would be unlikely to provide an insight that could have not been gathered in the framework of the boundary model itself.

It remains to be seen as to which option is going to materialize. And this is what makes the general field of holography highly exciting while pursuing it remains a true adventure.

Prof. Dmitri Khveshchenko obtained his Masters degree at the Moscow Institute of Physics and Technology in 1985, and his Ph.D. at the Landau Institute for Theoretical Physics, also in Moscow, in 1989. He then became a Research Associate at the James Franck Institute in the University of Chicago from 1992-1993, from where he moved to the Physics Department at Princeton University, where he was a Research Associate until 1995. He then joined the Nordic Institute for Theoretical Physics (NORDITA) in Copenhagen. He joined the faculty of the Physics and Astronomy Department at UNC Chapel Hill in 1999.

Understanding and improving active learning

By Muxin Zhang

In the past decades, the active learning curriculum, sometimes referred to as the "flipped classroom", has been widely adopted by college-level physics courses in the US. Contrary to traditional lecture-based classes, active learning emphasizes student-centered learning activities, such as small group work, where students take charge of their own learning process and knowledge construction. These curriculum reform efforts are driven by existing education research demonstrating that, compared to traditional instruction, active learning curriculum significantly increases student engagement and performance, especially in science, technology, engineering, and mathematics (STEM) disciplines. However, much research is needed to understand how students navigate the different components of an active learning curriculum and how these components can be improved by instructors to better support multiple desired learning goals.

My research interest lies in understanding the mechanisms of physics learning and exploring ways of transforming college physics education to be more responsive to students' thinking and their socio-emotional experiences of the disciplinary practice. For my graduate thesis, I conducted research projects to understand and improve the active learning curriculum, utilizing both quantitative and qualitative methodologies. For different components of a typical introductory physics course, I attended to different learning mechanisms, learning goals, and support structures (see Figure 1).

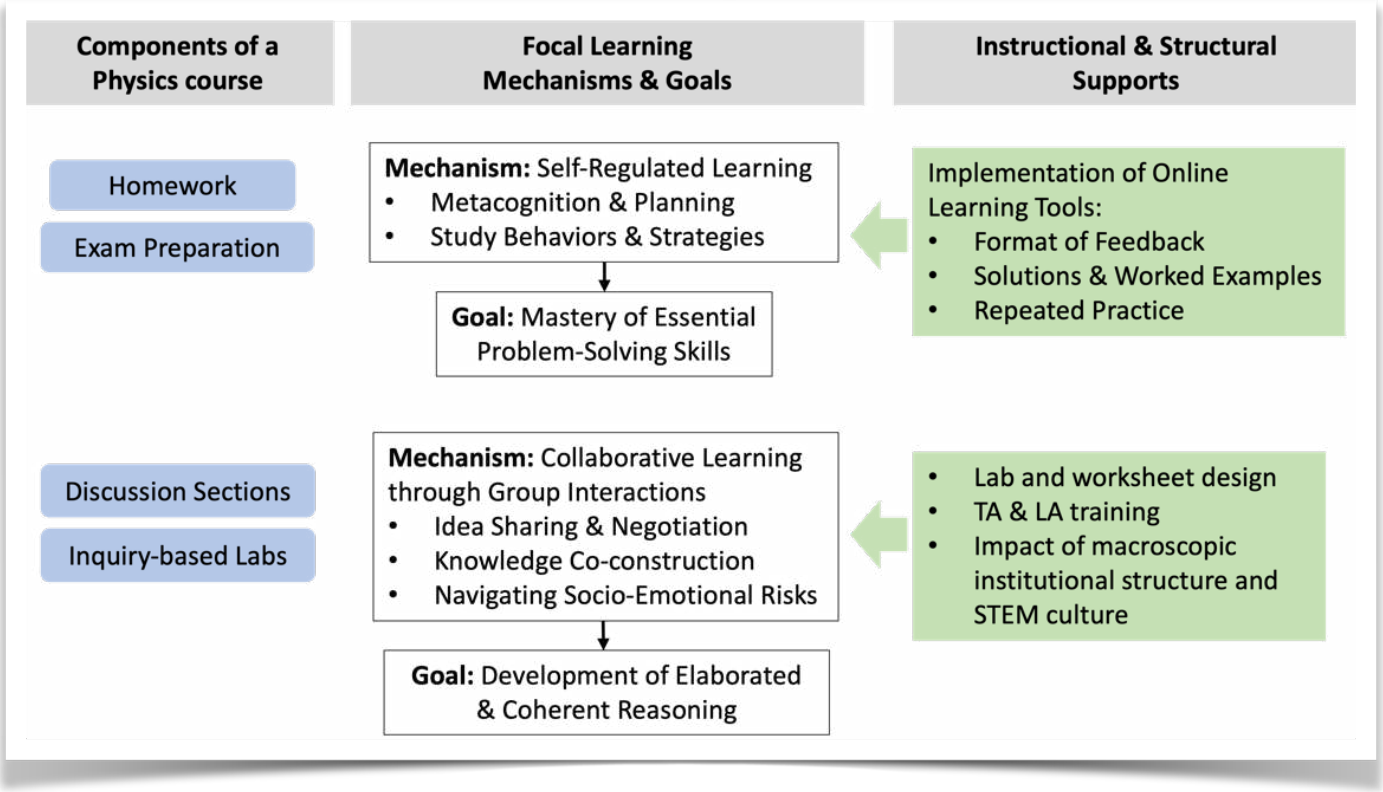


***Figure 1**: Examples of course components, learning processes, and support structures that I investigated in past research projects.*

Below, I briefly discuss two research projects.

First, to support students in mastering essential physics problem-solving skills, I conducted intervention studies to investigate the effects of online learning tools on students' self-regulated study behaviors and performance. My colleagues and I found that, compared to traditional homework, an in-situ implementation of the mastery-style online homework with delayed feedback, animated solutions, and multiple versions of practice significantly improved students' problem-solving performance and study behaviors in an introductory calculus-based electricity and magnetism course.

Second, to explore ways of supporting collaborative learning in discussion and lab sections, I collected video recordings of group work over the course of a semester in a classical mechanics course. By coding the different types of interactions that happened in a focal group, I identified patterns of group interaction over time on a macroscopic level. I also conducted case studies of particularly interesting interactions – when group members generated in-depth physics explanations and raised divergent ideas. My colleagues and I found that, in productive discussions of divergent ideas, students made moves to connect elements of reasoning from different group members. Through these moves, group members refined and extended the conceptual resources that were brought into the group, which allowed them to collaboratively build more elaborated and coherent explanations over time. In less productive cases, ideas and resources were dismissed because group members considered them wrong, too uncertain, or not being the right kind of idea, even though considering those ideas could have potentially led to fruitful conceptual discussions. Based on these case studies, we propose that instructors need to explicitly support the process of collaborative coherence seeking during group work.

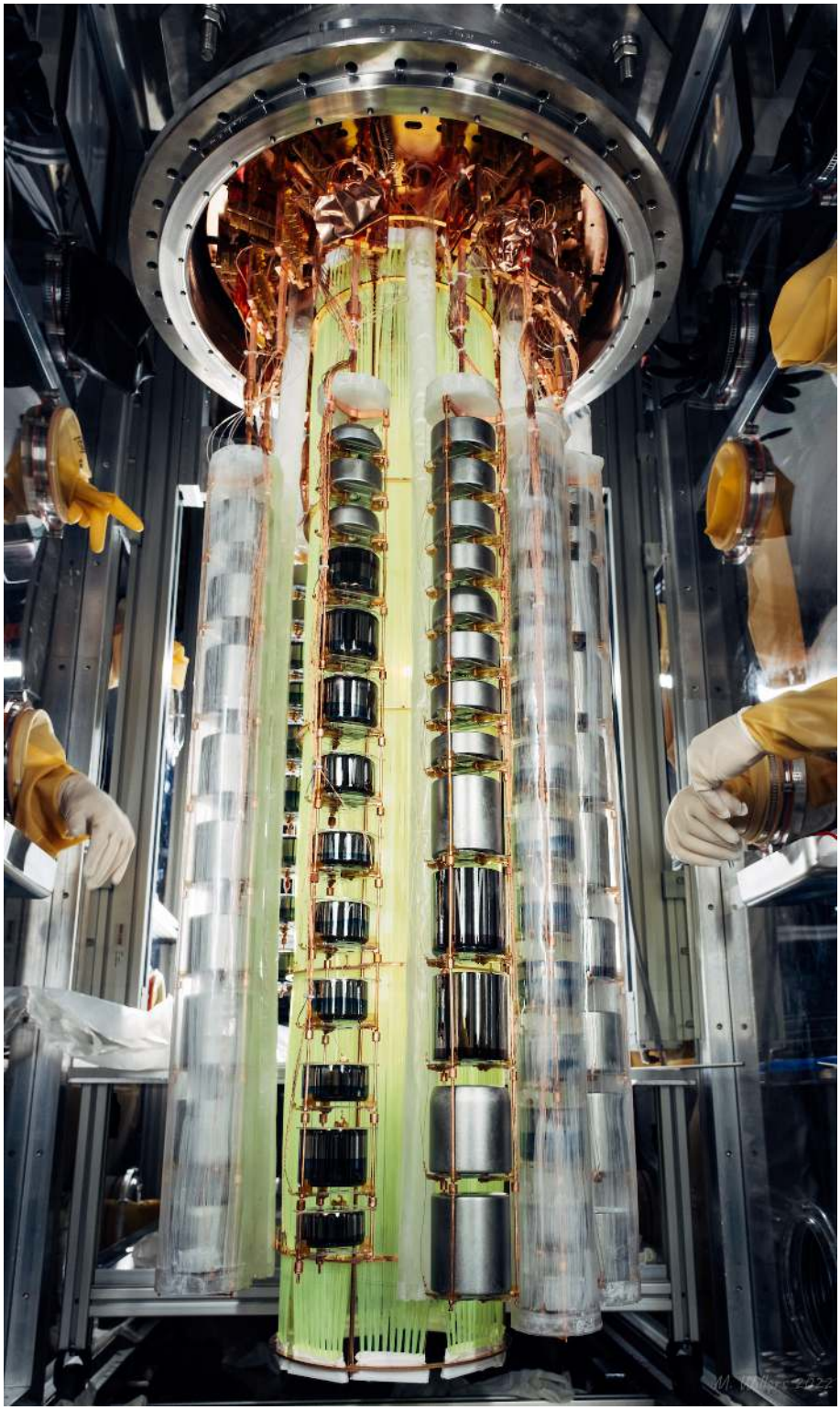
"My research interest lies in understanding the mechanisms of physics learning and exploring ways of transforming college physics education to be more responsive to students' thinking and their socio-emotional experiences of the disciplinary practice."

A few future research directions are interesting to me. In the context of group work, I want to investigate how task structures and group assessments can be designed to help group members learn to value each other's ideas and draw connections between contributions from different members. I am particularly interested in examining the effect of structured group reflection activities on the quality of group interactions. Additionally, I want to further investigate how student emotions are entangled with physics learning processes. For example, how are emotions connected to the development of epistemological beliefs about physics? How do students cope with their emotions during exam preparation, and how do their coping mechanisms impact their study behaviors? How can instructors support the construction of emotionally safe spaces for collaboration? Existing research in this area suggests that instructors and instructional designs can benefit from an understanding of students' diverse emotional experiences of physics learning.

Prof. Muxin Zhang received her B.A. in Physics from Cornell University and her PhD in Physics Education Research (PER) from the University of Illinois Urbana-Champaign with Dr. Eric Kuo. Her graduate thesis focused on analyzing cognitive and socio-emotional aspects of small group interactions in physics discussion sections and labs. She is particularly passionate about understanding the role of emotions in science education and scientific practices. Muxin joined our Physics and Astronomy Department in Fall 2023 and is currently teaching (and learning to teach) the Physics 114 course at UNC-CH.

The nature of the neutrino

By Reyco Henning



The LEGEND-200 detector showing the enriched germanium detectors (grey) surrounded by scintillating fibers that help reject radioactive backgrounds.

My research broadly focusses on the origin and fundamental nature of matter, addressing questions like: Why is the universe dominated by matter and not antimatter? What is the nature of the mysterious dark matter that makes up most of the universe? Are there special types of matter where particles and anti-particles are the same? These interconnected questions require techniques from experimental and theoretical physics, as well as astronomy to answer. My own contribution is building experiments that test various explanations and search for new processes that could elucidate these mysteries, leading me to work on experiments from the International Space Station to more than a mile underground in a working nickel mine in Canada.

My most significant involvement is with the LEGEND (Large Enriched Germanium Experiment for Neutrinoless Double Beta ($0\nu\beta\beta$) Decay) experiment. The observation of $0\nu\beta\beta$ decay would show that lepton number is violated and imply that neutrinos, a type of fundamental particles, are their own antiparticle. It is generically predicted by theories that explain of the excess of matter over anti-matter in the universe, as well as by Grand Unification Theories in theoretical physics. Simply put, it is a Nobel-worthy discovery that would change our understanding

of the fundamental nature of matter.

LEGEND is a collaboration of about 250 scientists from 50 institutions. I am a member of the LEGEND group at UNC that consists of myself, Prof. Wilkerson, and Prof. Gruszko. We are one of the largest groups in LEGEND and have several leadership roles. LEGEND has two phases. The first, LEGEND-200, is currently operating in an underground laboratory in Italy. LEGEND-200 consists of about 140 kg of germanium (Ge) detectors, enriched to ≥ 90% in ^{76}Ge, operated in a liquid argon (LAr) active shield, with plans to scale to 200 kg. It is planning to continue data-taking until about 2029. Naturally occurring radioactivity can mimic the signal we are searching for, and we take extreme measures in materials selection, purity, shielding and analysis to mitigate these in LEGEND.

The second phase, LEGEND-1000, is being proposed and will probe 0νββ with discovery sensitivity to ^{76}Ge half-lives beyond 10^{28} years, which is more than a trillion times the age of the universe! With an estimated total cost of $600 million, LEGEND-1000 will perform a quasi-background-free search and can make an unambiguous discovery of 0νββ decay. Constructing LEGEND-1000 is a truly international endeavor with significant contributions from the National Science Foundation, the Department of Energy Office of Science, and international partners in Canada, Italy, Germany, Switzerland, and the United Kingdom. LEGEND-1000 will directly advance Recommendation 2 of the 2023 Long Range Plan for Nuclear Science which states: *As the highest priority for new experiment construction, we recommend that the United States lead an international consortium that will undertake a neutrinoless double beta decay campaign, featuring the expeditious construction of ton-scale experiments, using different isotopes and complementary techniques.*

Experiments like LEGEND can search for more than just 0νββ decay. These exquisitely sensitive detectors can also search for different types of dark matter, probe fundamental properties of quantum mechanics, and search for exotic particles. I have personally worked on several of these efforts that also provided a rich playground for my students to contribute to truly fundamental research.

Prof. Henning grew up in South Africa and emigrated to the United States after completing high school. He attended the University of Denver, graduating with BS degrees in Physics and Mathematics in 1998. He completed his PhD at the Massachusetts Institute of Technology in 2003 working on the Alpha Magnetic Spectrometer cosmic-ray experiment. From 2003-2006 he was a postdoctoral fellow at the Lawrence Berkeley National Laboratory working the Majorana and Sudbury Neutrino Observatory experiments. He joined the Department of Physics and Astronomy at UNC in 2007.

Science is Awesome Day!

By Jennifer Weinberg-Wolf

Nearly every room in Phillips Hall on campus was filled with the sounds of 10-year-olds working together, laughing, and having fun. For one day each year, the department hosted local elementary school children, their teachers, and parent chaperones to get a little insight into physics and astronomy as well as a college campus, generously supported by the Stirling Foundation. In May we held the third annual event (with a few years off due to Covid-restrictions on field trips). Over the three years, we've hosted more than 700 children and approximately 100 chaperones (teachers, school support staff, and parents) with the help of over 70 volunteers (undergraduates, graduates, faculty, and department staff)! Each year, the day has been a great success - 99% of the students polled indicated they had fun, and we've received only positive feedback from the teachers, chaperones, and volunteers. The students attending the event came from four of the eleven elementary schools in the local school district and one school from a neighboring county's district. The specific schools were chosen to participate because of the high percentages of students on free and reduced lunch at the school.

"The consensus from our volunteers is that the day was fun, meaningful, and worth their time."

The students rotated through three stations (a reverse science fair, a demonstration show, and a hands-on activity-building challenge) before eating lunch on the quad at UNC-Chapel Hill and getting a sweet treat. For many of the students, this was their first time being on a college campus or seeing college classrooms. In the reverse science fair, faculty members presented their current research at the level that fourth graders can understand. Students heard three talks and then voted on who gave

the most interesting presentation. Dr. Law (methods to search for life on other planets) and Dr. Branca (how we use MRIs to see inside human bodies for medical diagnostics) currently have bragging rights for their presentations! In the demonstration show, we have the mantra, "It's not magic – it's physics" as we explain complicated topics through hands-on examples. And in the activity challenge, students work in small groups with volunteers to build their own Rube Goldberg device to move a marble or car across a table in a series of complicated, inter-connected steps. Everyone is successful, but more importantly, they have time to talk with current students about studying STEM at college and meet a diverse group of role models. In surveys before and after the event, we see increases in the numbers of students who say they are good at math, might choose a career in science, are interested in physics, and that they like science!

Similarly, teachers and chaperones request to come back in future years. The teachers feel comfortable asking questions themselves, to build their confidence in physics topics for future instruction. The consensus from our volunteers is that the day was fun, meaningful, and worth their time. Common themes from the volunteers' evaluations stressed the importance that science should be inclusive, that science should be fun, and that physics and astronomy should cover a broad range of topics. Important points that we're able to emphasize, due to lots of people working together and financial support from the Stirling Foundation.

The Stirling Foundation

In case you missed it...

Congratulations SPS National Council Inductee

The SPS National Council is proud to announce the 2023-24 SPS and Sigma Pi Sigma Council! **Em Chittenden** of the University of North Carolina-Chapel Hill is now the Associate Zone Councilor. Chittenden will represent the Physics and Astronomy Department in Washington DC at the SPS Conference!

The SPS National Council is the main governing body for the Society of Physics Students and Sigma Pi Sigma. The Council is composed of an elected faculty zone councilor (ZC) and an elected student associate zone councilor (AZC) from each of the 18 zones, and an elected council president and Sigma Pi Sigma president. The council composition was designed carefully with the student voice in mind. The Council meets face-to-face annually, usually in the fall in the Washington, DC, area and by video conference each spring.

SPS is a chapter based society that exists to help students transform themselves into contributing members of the professional community. Traditional coursework develops only one range of skills. Other skills needed to flourish professionally include effective communication and personal interactions, leadership experience, establishing a personal network of contacts, presenting scholarly work in professional meetings and journals, research experiences, and outreach services to the campus and local communities. Through its members, advisers, chapters, and leadership, SPS enables national initiatives and

local impacts within the community. SPS supports students, advisers, and departments to improve the overall community.

SPS wants to support every undergraduate student with an interest in physics and astronomy excel. SPS seeks to assist every undergraduate department help students succeed. Locally, regionally, nationally, and internationally, the SPS offers the opportunity for these important enrichments to the student's experience.

Congratulations Em!

"Nuclear Physics of Stars" textbook now published in Chinese by Tsinghua University press limited

Prof. Christian Iliadis's acclaimed textbook, "Nuclear Physics of Stars," has been published in Chinese by Tsinghua University Press Limited. This follows the global success of the second English edition, which was published by Wiley-VCH in 2015.

"Nuclear Physics of Stars" is an authoritative academic text that occupies a unique niche. It is the only nuclear astrophysics textbook in print and holds the distinction of being the only one to ever go to a second edition. This milestone acknowledges its sustained importance in the international scientific community.

Designed to educate and inform, the textbook has been employed across the globe, primarily to train graduate students in the specialized fields of nuclear physics and astrophysics. It presents comprehensive, detailed coverage of the subject, making it an invaluable resource for aspiring scholars in these areas.

The publication of the Chinese edition by Tsinghua University Press Limited marks an exciting development, as it will greatly facilitate the book's accessibility and reach within Chinese-speaking academic circles. This will extend the textbook's impact further, fostering a deeper understanding of nuclear physics of stars among a broader student and professional audience.

Recently published: Prof. Yusuke Kanai's research featured in Physical Review Letters

Professor Yosuke Kanai has recently published a paper in Physical Review Letters (PRL), the issue 11/2023, which has been selected as an Editor's Suggestion and featured in Physics Magazine of the American Physical Society (APS).

This week's issue of Physical Review Letters (PRL) features the article "Electronic Excitation Response of DNA to High-energy Proton Radiation in Water" by Professor Yosuke Kanai, Dr. Dillon Yost, and Mr. Chris Shepard as its co-authors. Professor Yosuke Kanai is an Adjunct Professor in the Department of Physics and Astronomy in addition to being a Professor in the Department of Chemistry at UNC.

Understanding the radiation-induced response of DNA is pivotal for human health. The electronic excitation induced in DNA by high-energy protons is central to understanding how DNA damage occurs in extreme conditions such as those experienced by astronauts. For instance, as much as 90% of galactic cosmic radiation (GCR) is high-energy protons, and human exposure to GCR is a great concern for space missions. The electronic response of DNA to high-energy protons is also the foundation of modern proton beam cancer therapy. The energy transfer rate from irradiating protons to electrons in the target matter is quantified by so-called electronic stopping power, and it plays a central role in understanding the electronic stopping phenomenon.

Starting with the seminal work by Hans Bethe in 1930, many researchers have developed linear-response models for calculating the electronic stopping power. Over the last ten years, Prof. Kanai's group has developed a new computational formalism such that quantum dynamics responsible for electronic stopping is directly simulated from first-principles quantum mechanical theory[1]. Building on their earlier work on water[2], the new PRL discusses how sugar-phosphate side chains of DNA respond strongly to irradiating protons due to the lone-pair electrons when DNA is solvated in water. As a result, positively charged holes are formed with a greater probability on the DNA side chains than on the nucleobases.

This work advances our understanding of how the exposure of DNA to highly energetic protons can result in double-strand breaks in DNA, which are particularly important in inducing cell death.

[1] *First-Principles Modeling of Electronic Stopping in Complex Matter under Ion Irradiation*
C. Yost, Y. Yao, Y. Kanai
Phys. Chem. Lett. **11**, 229 (2020)
[2] *K-shell Core Electronic Excitation in Electronic Stopping of Protons in Water from First Principles*
Yao, D. Yost, Y. Kanai,
Phys. Rev. Lett., **123**, 066401 (2019)

UNC Physics graduate Tyler Kay has won an award for poster presentation at the SPIE conference

One of our recent physics graduates, Tyler Kay, has been recognized for his outstanding work at the 2023 SPIE Medical Imaging conference in San Diego recently. Tyler's poster presentation on his undergraduate research project completed at UNC, "Comparing multi-view synthetic radiography derived from tomosynthesis with standard bitewing radiography", was awarded at the event.

The SPIE Medical Imaging conference is a highly respected platform that brings together researchers, scientists, and medical professionals from around the world to share their latest findings and innovations in image processing, physics, computer-aided diagnosis, perception, image-guided procedures, biomedical applications, ultrasound, informatics, radiology, and digital and computational pathology.

Physics Students Win National Recognition for Fourth Consecutive Time

The NC Museum of Natural Science in Raleigh is a weekend destination for many families and science lovers. But visitors to the museum the weekend of Jan. 28-29 had an even more fantastic experience as Astronomy Days returned offline for 2023. This is one of the nation's premier annual events on cosmology, offering a unique opportunity for outer space enthusiasts of all ages to explore and learn. This year's Astronomy Days theme is Humans in Space: Past, Present, and Future.

"Want a sticker of the solar system planets? Which planet is your favorite? "Mars!", "Saturn!", "Neptune!" Conversations like these continued to occur at the UNC Physics and Astronomy booths throughout the two days.

As is customary, UNC Physics and Astronomy is an active contributor and strong supporter of Astronomy Days. This year UNC's booth was set up on the third floor of the museum and was divided into two themed booths. All exhibits were designed and organized by graduate and undergraduate volunteers from the UNC Department of Physics and Astronomy. Over the course of two days, 16 student volunteers welcomed hundreds of visitors.

Of course, the students didn't just share their knowledge and love of physics and astronomy through spreading stickers. At the "UNC Physics and Astronomy" booth, they designed fun little experiments to explain scientific principles such as Angular Momentum and Cartesian Diver. At the "Planet Hunters and Investigators" booth, visitors can use models to simulate planetary motion and learn about the Earth's rotation, revolution and the creation of the day, night and seasons.

"I've always felt that knowledge about the universe is very grand and complex, and my child is still too young for her cognitive abilities to possibly understand these

concepts." a mother of Hailey, a six-year-old girl, shared with us, *"But this form of sharing, this design, through little experiments, you feel like your common sense is being challenged then you want to learn more, and it's an amazing experience. I think she's starting to enjoy learning about the universe."*

Hailey's Mom was not alone; many parents stopped at the booths and were pleasantly surprised by the enthusiasm and curiosity that erupted from their children. "I could feel the love and pride these students from UNC have for their field of study, and their passion was passed on to my children," commented a mother of two boys and a toddler girl.

UNC Physics and Astronomy has been dedicated to spreading scientific knowledge to the general population and sharing the fascination and beauty of physics and astronomy. As more events return offline this year, it will also have more opportunities to connect with the public and sow the seeds of love for science.

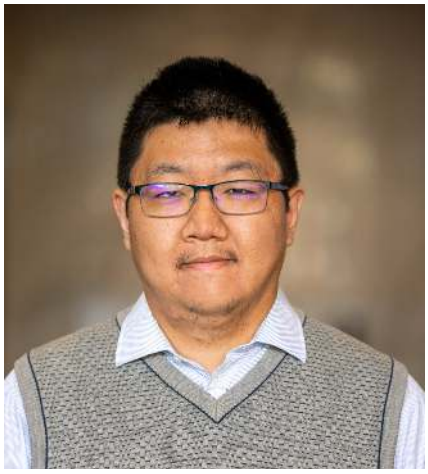
Recently published: Professor Hugon Karwowski and Dr. Aobo Li are the contributors to an article published on Physical Review Letters and featured in Physics Magazine's "Editor's Suggestion"

This week's issue of **Physical Review Letters (PRL)** features the article "Search for the Majorana Nature of Neutrinos in the Inverted Mass Ordering Region with KamLAND-Zen" with Professor Hugon Karwowski and Dr Aobo Li as its co-authors. The piece was also highlighted in **Physics Magazine** and chosen as an "Editor's Suggestion".

In her evaluation of the significance of this article, Laura Baudis, the editor of the Physics Magazine and professor in the Department of Physics of the University of Zurich, believes that the research will help physicists further uncover the mystery of neutrino.

Professor Hugon Karwowski's research interests include photofission, few-body physics, neutrinos and applied nuclear physics. Some of his representative publications include the First measurement of the strange axial coupling constant using neutral-current quasi-elastic interactions of atmospheric neutrinos at KamLAND (Nov 2022); Abundances of Uranium and Thorium Elements in Earth Estimated by Geoneutrino Spectroscopy (Aug 2022); Exploring the multi-humped fission barrier of 238U via sub-barrier photofission (Apr 2013); Measurements of the ^{48}Ca (γ, n) reaction (Sep2011); Precision measurements of H2(d,p)H3 and H2(d,n)He3 total cross sections at Big Bang nucleosynthesis energies (Apr 2006). To learn more about Professor Karwowski, visit his Department of Physics and Astronomy faculty profile.

Dr. Aobo Li is an interdisciplinary experimentalist of artificial intelligence (AI) and

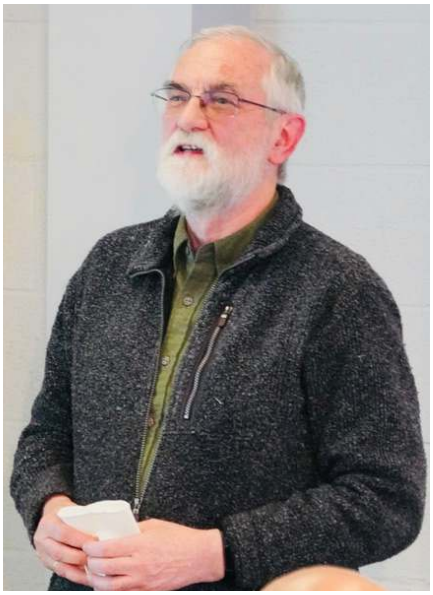


neutrino physics. He received his B.S. in physics at the University of Washington in 2015 and then completed his graduate work at Boston University. After receiving his PhD in 2020, Aobo joined the University of North Carolina at Chapel Hill as a Postdoctoral Research Associate and COSMS Fellow, working with Professor Julieta Gruszko on Germanium detector experiments while maintaining his partial involvement in KamLAND-Zen. Aobo initiated and led the Germanium Machine Learning (GeM) group, bringing AI solutions to two Germanium detector experiments: Majorana Demonstrator and LEGEND, while leveraging resources to educate domestic and international collaborators to acquire AI experience. His research work has recently been honored with the **APS 2023 Dissertation Award in Nuclear Physics** and the **UNC Postdoctoral Award of Research Excellence (PARE)**.

Colloquium honors Professor Hugon Karwowski on retirement

On January 9th, 2023, the Department of Physics and Astronomy held a colloquium on Measurements of Fission Product Yields Using Monoenergetic Neutron and Gamma-ray Beams in honor of Professor Hugon Karwowski on the occasion of his retirement.

The colloquium celebrated Karwowski and his many years of service to the Department of Physics and Astronomy and UNC. In introducing Karwowski's remarks, Yue WU, Kenan Distinguished Professor and the colloquium host, laid out his colleague's prestigious career at UNC, which began in 1984 as an assistant to the associate professor of Physics. Wu said, "Hugon was very strict with the students, but they loved him very



much. Students and young faculty alike found him to be the person to seek when they needed advice. We appreciate his wisdom, insight, empathy, and being steadily logical, rational, and humorous."

Dr. Jack Silano from Lawrence Livermore National Laboratory (LLNL), who graduated from the Department of Physics and Astronomy at UNC six years ago and was supervised by Prof. Hugon, was the guest speaker for the colloquium. He has given an overview of a joint LLNL-LANL-TUNL research program aimed at performing high-precision FPY measurements using quasimonoenergetic neutron and gamma-ray beams at Triangle Universities Nuclear Laboratory. At the beginning of the presentation, Dr Silano also paid tribute to the impact of Professor Karwowski's work in the field and the instruction and guidance he has received and benefited from.

After the presentation and Q&A, a celebratory cake was shared, and a cordial, friendly and fun exchange took place. Before an audience of colleagues, current and former students, as well as honored guests, Karwowski delivered a very brief speech reflecting on his teaching and research career and looking forward to his upcoming retirement life. He would also go on to keep a focus on his research area.

Professor Karwowski is loved by his students. On the RMP (rate my professors) website, previous students have left comments such as "one of the best professors you could get to know", "Dr K is the coolest professor ever", "Professor K is an incredible teacher and is more than just an instructor", and "Love the man, he has a heart of gold."

Professor Branca's research featured on cover ChemPhysChem

Professor Branca and her co-workers' research titled *Low-boiling Point Perfluorocarbon Nanodroplets as Dual-Phase Dual-Modality MR/US Contrast Agent* is the subject of a cover story in the 24/2022 issue of ChemPhysChem magazine.

Ultrasound and Magnetic Resonance Imaging (MRI) are often combined to diagnose and treat cancer. These two techniques use very different contrast agents to enhance detection sensitivity. With MRI, the researchers generally use gadolinium-based or iron oxide-based contrast agents that affect the rate at which nuclear spins lose their phase coherence or relax back to their thermal equilibrium state after inducing perturbation of their state with radiofrequency waves. These contrast agents are generally safe, but some individuals may negatively react to them. With ultrasound, the team use microbubbles, a biocompatible gas-phase contrast agent that effectively scatters ultrasound waves. Low boiling point perfluorocarbons (LBPF) based microbubbles are a new class of ultrasound contrast agents. These are delivered to the body in a nanodroplet liquid form and can then be vaporized into microbubbles with localized acoustic energy. In addition to providing ultrasound contrast when converted into microbubbles, they can be used for targeted delivery of oxygen and drugs to specific tissues.

In this publication, in collaboration with Paul Dayton from BME, Professor Branca and her co-workers demonstrated that this new class of contrast agent can also be detected with MRI by using spin-polarized xenon and a combination of cleverly select radiofrequency pulses that enhance the sensitivity of MRI to both its ultrasound-invisible nanodroplet liquid form as well as its ultrasound visible microbubble form, effectively making them a dual-phase dual-modality contrast agent for MRI and US.

ChemPhysChem showcases ground-breaking international research combining chemistry and physics. It is published on behalf of Chemistry Europe, an association of 16 European chemical societies.

CoSMS Institute 2023: A year of transformation and enlightenment

The CoSMS Institute (Institute for Cosmology, Subatomic Matter & Symmetries) at the University of North Carolina has had a successful year marked by renewal and revival as the world emerged from the grips of the pandemic.

Renovation and Transformation

One of the most striking changes within the CoSMS Institute was the rejuvenation of the Phillips Hall's west wing, which houses the institute. Room 207, formerly an aging lab space, is undergoing a remarkable transformation and by January will be in use as a vibrant seminar room. This renovation will significantly enhance the Institute, providing a conducive space for academic discussions, presentations, and fostering an environment that encourages meaningful interactions among researchers and students.

Room 200 is now available as a sleek and modern conference room equipped with state-of-the-art teleconferencing facilities. This upgrade not only enhances the institute's ability to engage in virtual collaborations with experts worldwide but also accommodates offline gatherings, enabling cutting-edge research and international collaboration.

Moreover, the CoSMS Institute's commitment to its visitors and staff is evident through aesthetically and functionally revamped visitors' and staff offices. These rejuvenated spaces ensure a welcoming and conducive environment for productive work.

Distinguished Speakers and Cutting-Edge Insights

The CoSMS Institute welcomed distinguished speakers in 2023, enriching its academic environment and propelling the pursuit of knowledge forward.

Professor Edward (Rocky) Kolb, the Arthur Holly Compton Distinguished Service Professor of Astronomy & Astrophysics at the University of Chicago, graced UNC and the CoSMS Institute on March 27th and 28th as the New Horizon's Distinguished Speaker. During his visit, Professor Kolb, who was recently honoured as the APS 2024 Lillienfeld Prize for his exceptional contributions to physics and the ability to communicate these results, met with faculty and students, delivering captivating lectures and presentations. He also made science accessible to the general public by delivering a compelling speech titled "The Quantum

***Top**: Professor Edward (Rocky) Kolb, the Arthur Holly Compton Distinguished Service Professor of Astronomy & Astrophysics at the University of Chicago*

***Bottom**: Professor Christian Weiheimer from the Institute for Nuclear Physics at the University of Münster.*

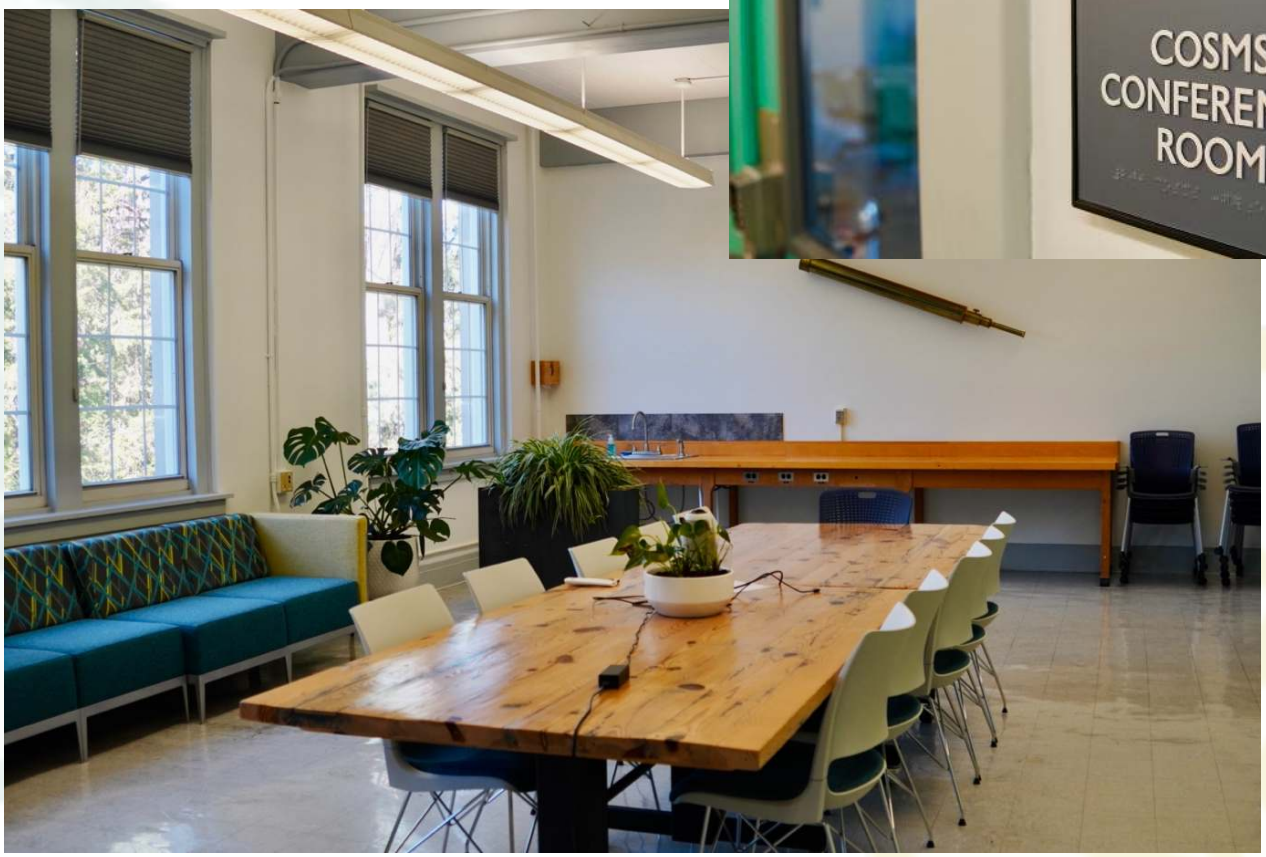
and the Cosmos," demystifying complex concepts and inspiring the curious minds of all ages.

Following Professor Kolb's visit, April saw the arrival of Professor Christian Weiheimer from the Institute for Nuclear Physics at the University of Münster. He described the latest advancements in The Dark Matter Experiment XENONnT and announced highly anticipated first results related to the experiments search for Weakly Interacting Massive Particles (WIMPs). This visit provided an invaluable opportunity for students and researchers to engage with the frontiers of dark matter research, leaving them inspired and better informed about the enigmatic substance that constitutes a significant portion of the universe.

Outlook for the Future

As the CoSMS Institute looks ahead to the coming year, there is a firm commitment to continue its tradition of hosting distinguished scientists and scholars. The Institute aims to bring in experts who can not only contribute to cutting-edge research but also effectively communicate their knowledge to the general public. The intent is to elevate science literacy and kindle people's curiosity and interest in the enigmatic realms of physics and the universe.

2023 has been a year where the CoSMS Institute emerged stronger and more vibrant than ever. Looking forward, the Institute remains dedicated to promoting outstanding discovery science, public science literacy and engagement, ensuring that the wonders of physics and the universe are accessible to all.



The newly renovated room 200, now a modern conference room, fully equipped with state-of-the-art teleconferencing facilities.

2023 The Nobel Prize in Physics

By Laurie E. McNeil

The 2023 Nobel Prize in Physics is awarded to **Anne L'Huillier** of Lund University in Sweden, **Pierre Agostini**, of The Ohio State University, and **Ferenc Krausz** of the Max Planck Institute of Quantum Optics (Garching) and Ludwig-Maximilians-Universität (München) in Germany. They are honored for their studies of the movement of electrons in atoms, molecules and condensed matter by means of attosecond spectroscopy. L'Huillier is the fifth woman to receive the physics prize (of 288 laureates), and the first to receive an equal share (the other four women[1] each split half the prize with a male recipient, with the other half going to a man).

Understanding of the energetics of electrons in atoms and in condensed matter is by now well developed, but the dynamics of electron motion has remained largely obscure because the motion occurs on timescales of attoseconds (10^{-18} seconds). Probing phenomena at such short times requires the ability to generate laser pulses at similar timescales. One of the crucial breakthroughs came in the 1980s when Anne L'Huillier and coworkers used a Nd:YAG laser that produced 1064 nm light in pulses a few picoseconds (10^{-12} s) in duration. They focused that light onto argon gas, producing very high local intensities (10^{13} W/cm^2). The illuminated gas emitted coherent radiation at many higher harmonics of the laser radiation, integer multiples of the fundamental frequency like the overtones of a vibrating string. In a subsequent paper they were able to explain the spectrum of these high harmonics by solving the time-dependent Schrödinger equation numerically and then accounting for collective effects in the medium using Maxwell's equations. In a simplified, semi-classical picture (see figure below) the infrared radiation from the laser ionizes the gas atom via tunneling and the free electron is then accelerated by the intense electric field of the laser. When the electric field reverses in the next half-cycle the electron is accelerated back to the gas ion and can recombine with it. The kinetic energy the electron gained from the field while it was free is then converted into high-frequency photons in the extreme ultraviolet (XUV) range. In order to use these short pulses to study electron dynamics it was necessary to develop a method to measure them. This next step was taken by Pierre Agostini and his group, using frequency modulation in a two-wavelength photon field. The method, called "reconstruction of attosecond beating by interference of two-photon transitions," or RABBIT, makes it possible to measure the pulse duration of a train of attosecond pulses by focusing the XUV pulse together with the infrared light from the drive laser onto a rare-gas target and analyzing the photoelectrons emerging from the target.

Meanwhile, in the late 1990s a group led by Ferenc Krausz made technical advancements in generating femtosecond (10^{-15} s) pulses by compressing laser pulses in a hollow optical fiber filled with noble gas. These pulses could then be focused onto a noble gas jet to produce higher harmonics as L'Huillier had done and thus generate much-shorter pulses. By 2001 both Krausz and Agostini's groups had documented pulses in the range of hundreds of attoseconds duration.

Now that laser pulses at these very short timescales were available, it became possible to address a long-standing question in physics: what is the timescale of the photoelectric effect? In this phenomenon an atom or surface absorbs energy from a photon and an electron is emitted. There had never been a way of determining the time delay between absorption of the radiation and ejection of the electron, so the process was

[1] Marie Curie (1903), Maria Goeppert-Mayer (1963), Donna Strickland (2018), and Andrea Ghez (2020).

Pierre Agostini, Ferenc Krausz, and Anne L'Huillier

"for experimental methods that generate attosecond pulses of light for the study of electron dynamics in matter."

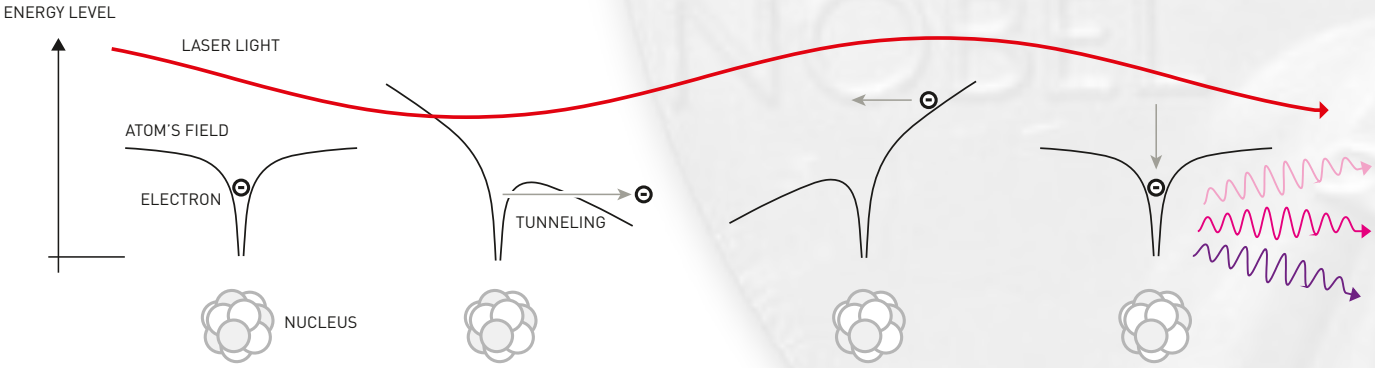
assumed to be instantaneous. In 2010 Krausz and his group determined the photoemission delay in neon, a signature of collective dynamics of the electron cloud. L'Huillier's group then further refined the experiment and were able to resolve a factor-of-two discrepancy between the measured and predicted values of the delay.

The work of these three groups over thirty years has made it possible to use high harmonics to generate attosecond pulses throughout the UV and soft X-ray region of the electromagnetic spectrum, all on a table top, opening up a wide range of studies of complex electron interactions and collective electronic motion now underway. The three 2023 laureates were, as is usually the case, caught by surprise when the phone call from Stockholm came. L'Huillier was teaching a class (remarkably, she continued with the lesson). Agostini (who has retired from Ohio State) could not be reached initially by the Nobel Committee and instead received a call from his daughter asking if what she had read on Goggle was true. Krausz was getting ready to lead a lab tour. All will be remembered for making it possible to probe phenomena in matter at the time scales at which they occur, opening up new understanding of the motion of electrons.

For more information, scan the QR code below.

Laser light interacts with atoms in a gas

Experiments that created overtones in laser light led to the discovery of the mechansim that causes them. How does it work?



1 An electron that is bound to an atom's nucleus cannot normally leave its atom; it does not have enough energy to lift itself out of the well created by the atom's electrical field.

2 The atom's field is distorted when it is affected by the laser pulse. When the electron is only held by a narrow barrier, quantum mechanics allow it to tunnel out and escape.

3 The free electron is still affected by the laser field and gains some extra energy. When the field turns and changes direction, the electron is pulled back in the direction it came from.

4 To reattach to the atom's nucleus, the electron must rid itself of the extra energy it gained during its journey. This is emitted as an ultraviolet flash, the wavelength of which is linked to that of the laser field, and differs depending on how far the electron moved.

Two NSF Graduate Fellows

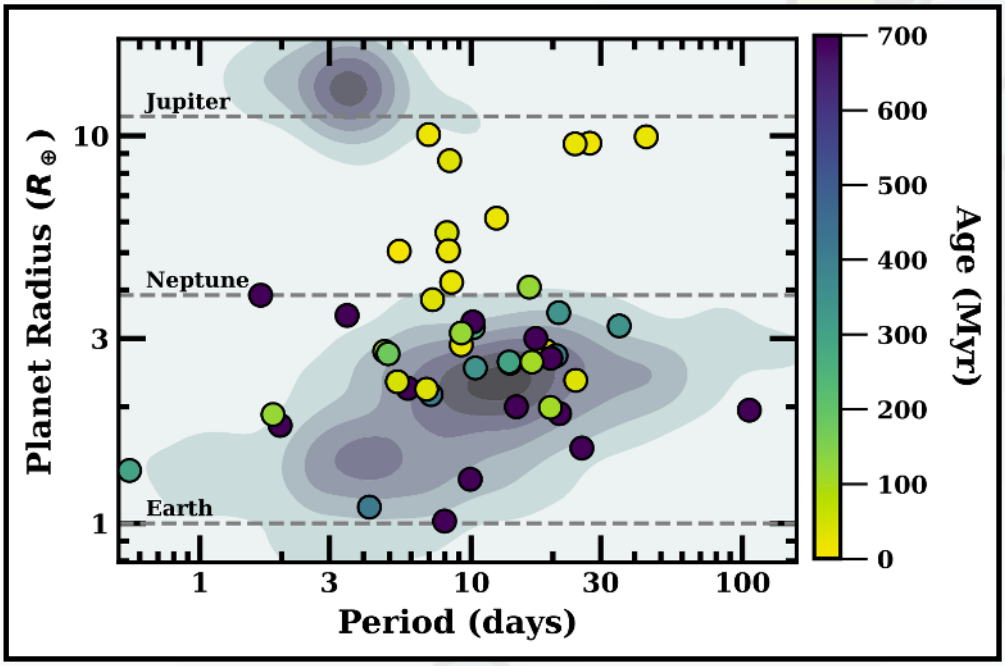
Madyson Barber

I am a second-year graduate student and the recipient of an NSF Graduate Research Fellowship. I work with Dr. Andrew Mann in the Young Worlds Lab, where we primarily study young (<1 billion years old) stars and exoplanets. My project focuses on conducting an in-depth search for transiting planets to better understand how planet properties, such as size, orbit, and atmosphere, evolve over their lifetime.

Despite NASA's Kepler, K2, and TESS missions discovering over 5,000 exoplanets thus far, only around 40 are known to be young. Therefore, we lack statistical information about the early stages of planet formation and the environmental conditions that give rise to planets like those in our Solar System.

The challenge in our work lies in the nature of young stars, where high photometric variability makes identifying these planets much more difficult. The transit method of planet discovery involves examining a star's brightness over time, searching for small, periodic decreases in the observed brightness as an object orbits the star and passes between the star and the observer. Natural fluctuations of the star generate signals 10-100x greater than the signal of a transiting planet. To help overcome these challenges, I employ new statistical methods, improved strategies for reducing instrumental and stellar noise, and new data from the TESS telescope. These efforts will improve our ability to detect young planets.

In addition to making statistical comparisons between young and old planetary systems, we anticipate that our discoveries will be ideal targets for further exploration using instruments like JWST. Our catalog of young planets will also aid in testing theories of how planets form and evolve.



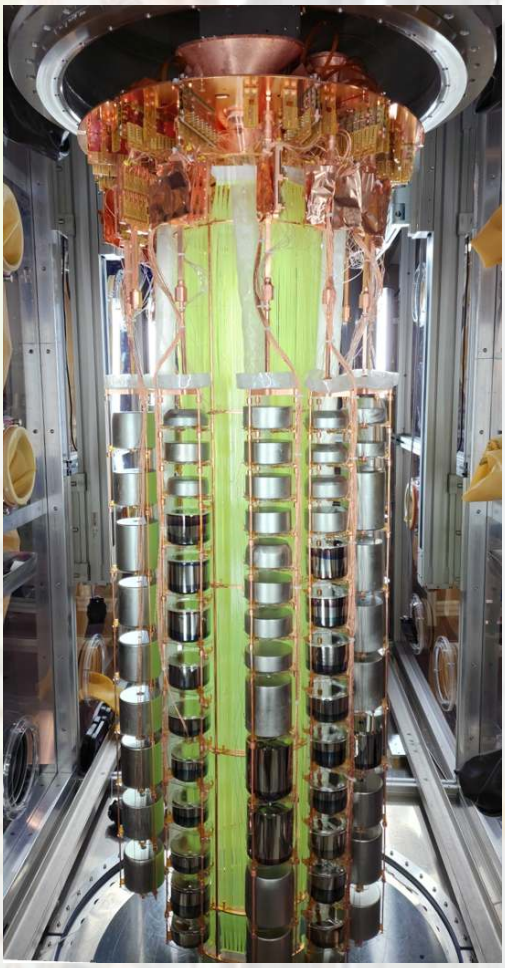
The distribution of known transiting planets, shown as the grey density contours, overlaid with planets in young stellar associations with precise ages, shown as the circles colored by age.

Guadalupe Duran

I am a third-year graduate student and a recipient of an NSF Graduate Research Fellowship. I am currently working with the Experimental Nuclear and Astro-Particle Physics group on the LEGEND experiment, which is searching for neutrinoless double-beta ($0\nu\beta\beta$) decay in ^{76}Ge. If this rare decay is observed it would confirm that the neutrino is its own antiparticle. This would provide important information about the mass of the neutrino, insight into the matter-antimatter asymmetry of the universe, and prove that lepton number is not a conserved quantity.

Currently, LEGEND is in the LEGEND-200 phase, where 200kg of high purity germanium detectors are deployed underground at Gran Sasso National Laboratory (LNGS) in Italy. I will be working on the characterization of some of the remaining detectors to be installed for this phase, and later, on their deployment at LNGS to complete the installation of detectors for L-200.

The characteristic signal of a $0\nu\beta\beta$ decay is a monoenergetic peak resulting from single site energy deposition of the electrons. Therefore, during analysis all single-site events should be retained, while all multi-site events can be rejected as background events. The parameter used for this rejection is called A/E. This cut parameter is tuned using the double-escape peak of ^{208}Tl, from the ^{228}Th decay chain. However, there is only one visible energy value of double escape peak, thus it is not possible to know what the acceptance and rejection rate of A/E is at different energies. One of LEGEND's predecessors, the MAJORNA Demonstrator, incorporated a ^{56}Co calibration in order to measure how the A/E efficiency varies with energy. I propose to implement this calibration in the remaining detectors for LEGEND-200, which will not only allow energy-based correction for A/E and improved background rejection, but will also create a valuable dataset for training and testing machine learning models.



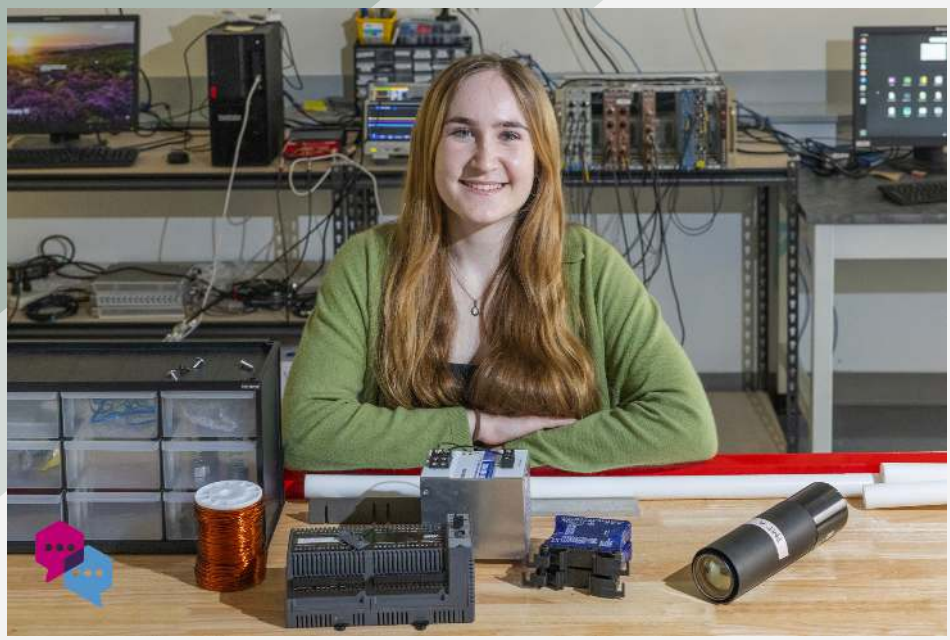
An image of the LEGEND-200 detector installation.
***Photo credit**: Brady Bos (UNC).*

NSF and DOE graduate fellowships are highly competitive national awards that support outstanding graduate students above and beyond regular teaching (TA) or research assistantships (RA). Our department is committed to providing funding for our graduate students in the form of such TAs and RAs, supplemented by competitive Department-, College-, and University-level awards and fellowships. You can contribute to our research mission by helping us support our excellent students. Gifts of any size will greatly increase our ability to do so. See the "JOIN US!" page below for details.

Focus on Undergrad Research

NuDot and the Search for Neutrinoless Double Beta Decay

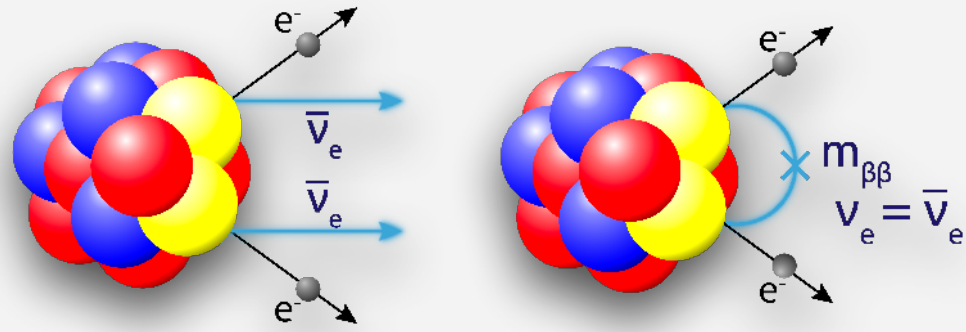
By Sarah Vickers



Since the proposal of the elusive particle by Wolfgang Pauli nearly a century ago, the neutrino has been at the heart of many long-standing questions about the Standard Model of particle physics, astrophysical phenomena, and the beginning of our universe. The latter of these contains the mystery of the Majorana nature of the neutrino: is the neutrino its own anti-particle? What would be the implications of such a discovery?

Today, many current and next generation experiments are being carried out across the world, all working to understand the properties of this ghostly particle. My involvement with this effort began in Fall 2020, amid the turmoil and instability of the pandemic. Coming in, I was intrigued by the work of the Experimental Nuclear Astroparticle Physics group and got in contact with Dr. Julieta Gruszko, who I have been working with ever since. The ENAP group is focused on one of the top priorities in particle physics: the search for neutrinoless double beta decay (0νββ). Experimental measurement of this process would be the first observation of mass creation without the balancing antimatter, the first instance of lepton number violation, and instantly confirm the Majorana nature of the neutrino.

There are many approaches to the search for 0νββ, but they all have one thing in common: the need to get bigger and better. The lower limits on the half-life for 0νββ are greater than 10^{25}-10^{26} years, meaning that experiments need massive amounts of candidate isotope to have a chance of seeing this theorized process. The NuDot experiment, led by Dr. Gruszko, is a half-ton prototype for the future of kiloton-scale liquid scintillator searches. New techniques for background reduction are needed for the success of this new generation, and the central aim of NuDot is to demonstrate the separation of Cherenkov and scintillation signals for 1-2 MeV beta particles. This combats otherwise irreducible backgrounds such as ^{8}B solar neutrino scattering and allows us to filter data based on the



2νββ decay (left) vs 0νββ decay (right)
***Credit**: Henry Nachman.*

distinctive Cherenkov signal of a double beta-decay event.

The smaller scale of NuDot allows us to conduct trials on many new techniques, technologies, and materials towards the pursuit of 0νββ. As a tight-knit collaboration, I have been able to be involved in numerous aspects of the experiment throughout my time at UNC. One of these is investigating the light yield of new perovskite nanocrystal quantum dot liquid scintillators, a brighter and highly tunable alternative to traditional scintillators. They also provide the opportunity to stably load tons of candidate isotope directly into the scintillator, a significant advantage when active isotope mass is such an integral component to success.

Towards the overall effectiveness of NuDot, I have designed an electromagnetic coil system for countering the geo-magnetic field. The detector sphere is composed of 59 8" and 112 2" photomultiplier tubes, with the former being un-shielded from the Earth's magnetic field, reducing detection efficiency along certain axes by ~ 30%. This requires the implementation of a shielding system, tailored to the location of the experiment and designed to fit around the other necessary components. In the summer of 2021, I aided in the initial installation of the calibration system at MIT Bates Laboratory with former UNC undergraduate Ravi Pitelka. Now, I am using my knowledge of the system to optimize and improve the functionality of the calibration system for NuDot, essential for testing directional reconstruction.

Very soon I will be defending my senior honors thesis on hardware design and improvements for NuDot, a culmination of my work on the experiment.

Sarah working on installing the NuDot calibration system at MIT Bates Laboratory, August 2021.

Awards & Graduations

The **Paul E. Shearin Award** was established by W. E. Haisley, Professor Emeritus of Physics, to honor Paul E. Shearin, Professor of Physics, member of the faculty for 36 years, and for 12 years Chairman of our department. This monetary award is given to the member of the senior class majoring in Physics who is judged most outstanding on criteria of scholarship, scientific insight and professional seriousness. The recipient is selected by the departmental faculty from candidates nominated by the undergraduate major advisors.

The **Daniel Calvin Johnson Memorial Award** in Physics. This award, established in 1960 by Mrs. Mildred Johnson in honor of her husband, Daniel C. Johnson, a former graduate of the department, is awarded annually to the physics major who is judged by the faculty to be the most outstanding student of the junior class.

The **Robert N. Shelton Award**, established in 2001, is given to one or more Physics and Astronomy undergraduate students for excellence in research. The award was first established by Provost Robert N. Shelton.

Outstanding Teaching Assistant Awards
Each year our department recognizes the most outstanding Teaching Assistants (TAs) for their exemplary work. Most TAs provide assistance teaching and grading for our introductory physics or astronomy courses, but some assist with more advanced or specialized courses. In a typical semester we employ approximately 40 graduate students and about 15 undergraduate students to serve as TAs, and we recognize the top 2 or 3 for the department TA award.

Undergraduate Excellence and Achievement Awards
The "Excellence" and "Achievement" awards are two new awards starting in 2022, given respectively for "demonstrated excellence in academics, leadership, and community involvement" and "demonstrated academic resilience."

2023 Awardees

Paul E. Shearin Outstanding Senior Award
Aaron Matthew Miller

Daniel C. Johnson Memorial Award
Ma Haouyu

Robert N. Shelton Outstanding Research Award
Logan Selph and Stephen Chesser

Outstanding Graduate Teaching Assistant Award
Liam Jones and Jon Carney

Outstanding Undergraduate Teaching Assistant Award
Dawson Brown

Undergraduate Excellence Award
Ravi Pitelka

Undergraduate Achievement Award
Joy Harrison

Graduate program 2022 (continued from previous issue)

Ph. D.

Ryan Hegedus
Joshua Reding
Brandon Yost

M.S.

Ramses Gonzalez Chavez
Zackary Hutchens
Alexander Sobotka
Pa Chia Thao

Graduate program 2023

Ph. D.

Nicholas Bryden
Henry Corbett
Nikolaos Dokmetzoglou
Britta Gorman
Benjamin Kaiser
Michele Kelley
Megan Kern
Kaitlyn Morrell
Mugdha Polimera
Tristan Swartz
Mackenna Wood

M. S.

Hwan Bae
Jonathan Bush
Derrick Carr
Joseph Karlik
Alisa Turchaninova
Jackson Waters

Undergraduate program 2022 (continued from previous issue)

B.S.

Magnus Fonda
Claire Harmon

B.A.

Samantha Machinski
Tomson Nystrom
Kaden Westphal

Undergraduate program 2023

B.S.

Lauren Behringer
Adrian Bruno
Stephen Chesser
Landon Colvell
Halona Dantes**
Matteo Fulghieri
Shriya Haravu
Benjamin Johnson
Jackson Lawrence
Zyad Lohavichan
Connor Magoon
Michael Metcalf
Luke Meyer
Aaron Miller**
Emma Modesitt
Henry Nachman**
Luka Noronha
Matthew O'Brien-Pifer
Landon Overall
Yifeng Peng
Ravi Pitelka
Xiao-Ming Porter
Cade Rodgers
Miguel Schott
Madeline Stratton
Benjamin Sykes
Nicholas Walton**
Turner White
Shiqi Zheng

B.A.

Nathan McCarley
Jacob Otte
Cy Pair
Jaden Passero
Megan Pramojaney
Kyra Pudol
Jamie Roberts
Emma Rowe
Meghana Sankaran
Caleb Schilly
Tyrese Smith
William Stiff
James Toole
Gary Zhang

Congratulations to our most recent Phi-Beta-Kappa inductees!

Ethan Michael Crook
Abigail Hailey Dunnigan
Rachel Elizabeth Emrick
Andrew Hanan Mattson
Ethan Joshua Meyerhoffer
Shourya Mukherjee
Alexander Orion Prakken

Phi Beta Kappa is the oldest academic honor society in the United States. It promotes and advocates excellence in the liberal arts and sciences, and inducts the most outstanding students of arts and sciences at select American colleges and universities.

** with highest honors

Prof. John F. Wilkerson, distinguished Professor of Physics, joined the **American Physical Society's (APS) Board of Directors**. The APS is pleased to announce the incoming Board of Directors members.

These incoming Board members will be joining 2023 officers President R. Rosner, President-Elect Y.-K. Kim, Past President F. Hellman, Treasurer D. Seiler, and returning Board members K. Hallberg, B. Karplus Hartline, R. McKeown, L. McNeil, P. Schiffer, and L. Williams. For more information on the Board of Directors, visit the APS website.

The American Physical Society (APS) is a nonprofit membership organization working to advance and diffuse the knowledge of physics through its outstanding research journals, scientific meetings, and education, outreach, advocacy, and international activities. APS represents more than 50,000 members, including physicists in academia, national laboratories, and industry in the United States and throughout the world.

The **American Astronomical Society's Division on Dynamical Astronomy (DDA)** announced that the 2023 recipient of the **Vera Rubin Early Career Award** is **Prof. Carl Rodriguez**, for his novel and sustained contributions to our understanding of dynamics of stars in dense stellar systems as well as his pioneering considerations of dynamical scenarios for gravitational wave sources originating from globular clusters. The detection of GW signals by LIGO in 2015 opened a new era in astrophysics, advancing our understanding of compact object mergers. Merging compact binaries are known to form dynamically in dense globular clusters. Dr. Rodriguez's gravitational modeling predicted LIGO's first GW detections, involving heavier black hole mergers. This established dynamical processes as a key formation mechanism. The model's enhancements revealed the significance of relativistic effects in forming even more massive black holes through repeated mergers, providing a theoretical explanation for high-mass coalescence events observed by LIGO. Dr. Rodriguez's work also contributed to comprehending spin distribution in binary black holes, particularly highlighting the unique emergence of significant spin-orbit anti-alignment from dynamical formation, along with predicting mergers with non-negligible eccentricity.Dr. Rodriguez will be invited to give a lecture at the 55th annual DDA meeting in the spring of 2024.

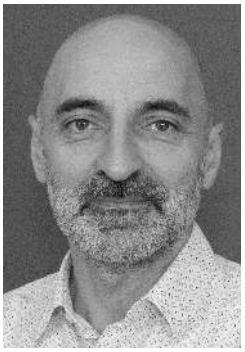
Prof. Charles Evans has been appointed **Visiting Full Professor in its University College Dublin's School of Mathematics and Statistics**, starting in October 2023 and continuing through September 2028. The Relativity Group within the School is one of the largest such programs, with three permanent faculty, two long-term PhD Fellows, two PhD visiting or adjunct faculty, several postdocs, and a number of PhD students. Professor Evans's research in gravitational waves, black holes, and gravitational self-force is shared in common with many of his Dublin colleagues. He and his students and collaborators are studying the orbital dynamics of extreme-mass-ratio

black hole binaries and their attendant emission of gravitational waves, as a prelude to the eventual launch of the LISA space mission.

The **Retired Faculty Association (RFA)** Executive Committee is pleased to announce the selection of four outstanding recipients of the **2023 RFA Leadership Award**. Originally established to recognize those who provided leadership to the RFA, eligibility was expanded in 2013 to include additional individuals whom the RFA wished to honor for their distinguished service to the university (Bill Friday in 2013, Tom Ross in 2015, Shirley Ort in 2018). The award is given in alternate years. This year's recipients are Prof. Emeritus William Andrews (English); **Prof. Emeritus Tom Clegg** (Physics and Astronomy); Prof. Emeritus Jack Evans (Kenan-Flagler Business School); and Prof. Emerita Jan Yopp (Hussman School of Media and Journalism). All four were recognized and were presented the award at the RFA general membership meeting on April 20 at the Friday Center.

Tom Clegg is the V. Lee Bounds Distinguished Professor of Physics Emeritus. He joined the UNC faculty in 1968 and began 50+ years of research with students and faculty at the Triangle Universities Nuclear Laboratory located at Duke. There he led multiple teams in designing and building devices used for accelerator-related research into forces that bind atomic nuclei and fuel stellar nucleosynthesis.

Beginning while Tom was chair of UNC's Department of Physics & Astronomy, he led teams of UNC faculty from 1994 until 2010 through early campus land-use planning, and later during several phases of design and construction of UNC's new Science Complex. He served as chair of the Provost's Appointments, Promotion and Tenure Committee, Interim Dean of the College of Arts and Sciences, and later Interim Senior Associate Dean of Science and Mathematics. After retiring in 2016, Tom collaborated with the Retired Faculty Association and over 30 faculty retirees, most importantly Barbara Wasik and Marila Cordeiro-Stone, to produce a new *UNC-Chapel Hill Faculty Retirement Planning Guide*. At The Cedars retirement community where he now lives, he currently leads residents' planning to understand and mitigate future campus impacts of global warming.



Adrienne Erickcek and **Christian Iliadis** have been elected to the **American Physical Society's Fellows**, respectively *"For theoretical contributions spanning cosmology, including inflation, cosmic acceleration, and dark matter, with a key focus on understanding primordial density perturbations on small distance scales,"* and *"For pioneering direct measurements of stellar nuclear reactions and fundamental contributions to our understanding of stellar evolution and explosions."*

Fellowship is a distinct honor signifying recognition by one's professional peers. Each year, no more than one half of one percent of the APS's membership is recognized by their peers for election to the status of Fellow of the APS.

Credits

Contributors

M. Barber
T. Branca
S. Brogan
P. Cheng
L. Dolan
J. E. Drut
G. Duran
F. Heitsch
R. Henning
J. Hurst
M. Jensen
D. Khveshchenko
L. E. McNeil
F. Tsui
S. Van Heusen
S. Vickers
J. Weinberg-Wolf
J. F. Wilkerson
M. Zhang

Design

J. E. Drut

Q&A with Fabian Heitsch

In this Q&A section of the Magazine, our director of graduate studies (DGS) tell us about his role.

In your position as DGS, you have to pay attention to several key aspects of the graduate experience in our Department. Which of those do you find to be the most important or challenging ones?

Fabian Heitsch:
The low graduate student stipends pose the main challenge. They not only affect the department's ability to recruit students (for whom we compete with other departments across the country), but also to keep students in the program. We have made substantial progress, especially - thanks to very generous donations - regarding summer funding, but the reality is that we are still “outbid” by most competitors. National fellowships and some funding agencies are already envisioning substantially higher stipends, allowing us to request funds for increased RA stipends in grant applications.

From your experience as DGS, can you share any insights or trends that we should keep in mind, as a department, when thinking of the next, say, 3 to 5 years?

FH: The pandemic coincided with a move to abandon standardized test scores (GREs) in admissions. This has led to a range of student preparedness that is now even wider than before (which is already an issue at the undergraduate level). Revisiting an appropriate use of standardized test scores in combination with other criteria may be useful. Given the strong interest in computational physics (e.g. new BA track), exploring a 5-year MS degree in computational physics (for which we already have a lot of courses) may be of interest.

If you had to give a crucial piece of advice to the next DGS, what would it be?

FH: No advice, but here are the two guiding principles I have tried to adhere to. First, the DGS position is one of service to the graduate students and the faculty. Second, I assess any initiative against whether it simplifies the work for those served. There is a natural tendency to develop more rules, yet more rules entail more constraints.

JOIN US!

At the forefront of physics and astronomy with a financial gift to the department.

The Department of Physics and Astronomy Excellence Fund helps enhance our world-class programs in research and education by providing seed funds for new instrumentation, expanding research and teaching experience of our students, and supporting visiting speakers. Gifts of any size will greatly increase our ability to support outstanding students and faculty.

To give online, visit **physics.unc.edu/donate/**

To give via check, make your check payable to "The Arts and Sciences Foundation" and include "**101281 – Physics and Astronomy Excellence Fund**" in the memo line. Please mail your check to:

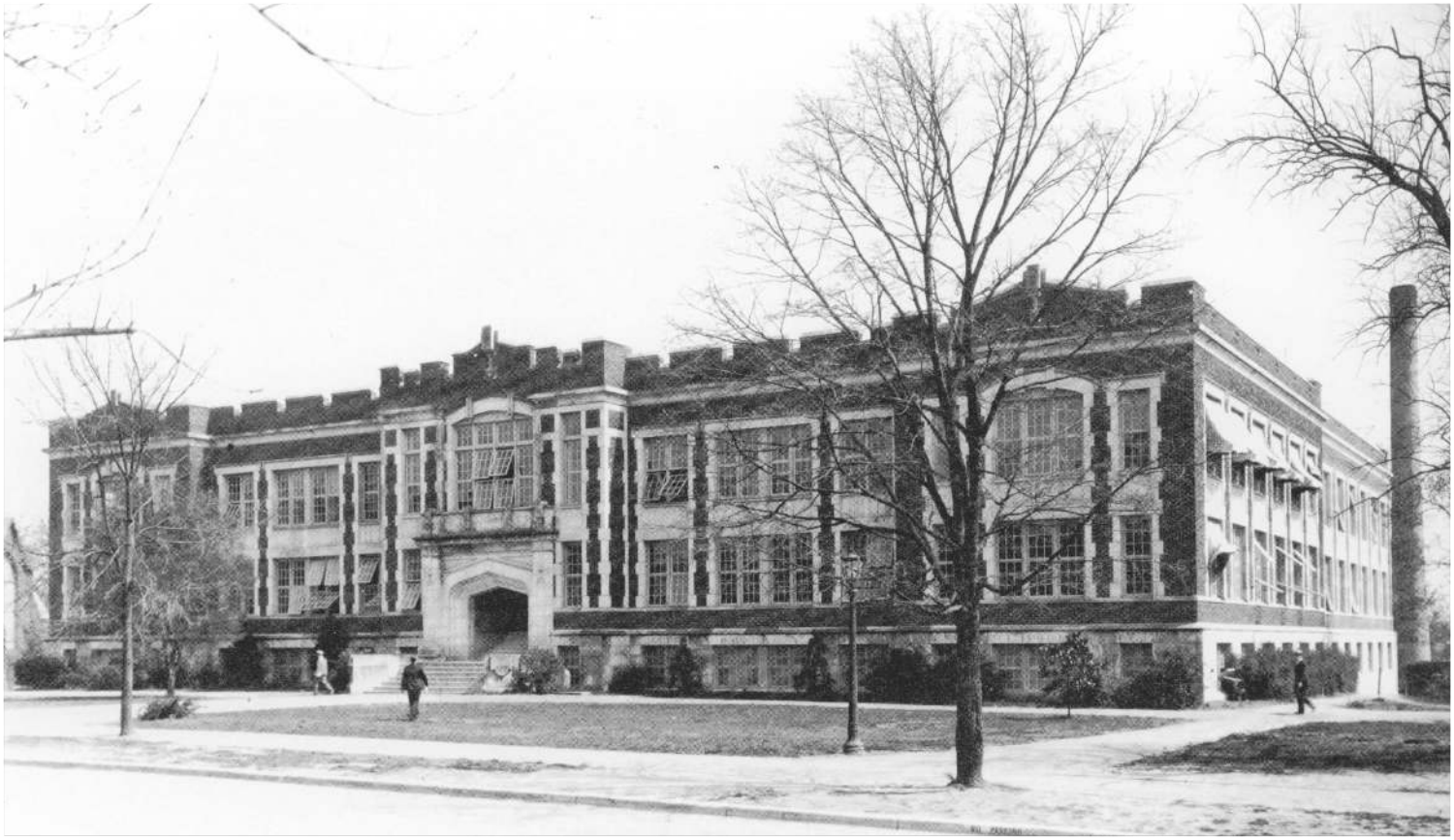
The Arts and Sciences Foundation
134 E. Franklin Street
CB# 6115
Chapel Hill, NC

***Background**: Young visitors listen closely to a Physics demonstration during **Science is Awesome Day** (find the full article by Jennifer Weinberg-Wolf on page 12).*

Thank you!

UNC CHAPEL HILL

PHYSICS AND ASTRONOMY



Did you know? *Phillips Hall, home to our Department, was built in 1918 and opened in 1919. It was constructed to house the university's science departments, which were previously scattered around campus. The first occupants were the Departments of Math, Physics, and Engineering. Phillips Hall was named after three members of the Phillips family who taught at the university during the nineteenth century. One of these members was James Phillips, who taught mathematics and served as a pastor in the New Hope Presbyterian Church. Later, James' son Charles taught mathematics and engineering at Carolina.*

UNC
COLLEGE OF
ARTS & SCIENCES

physics.unc.edu