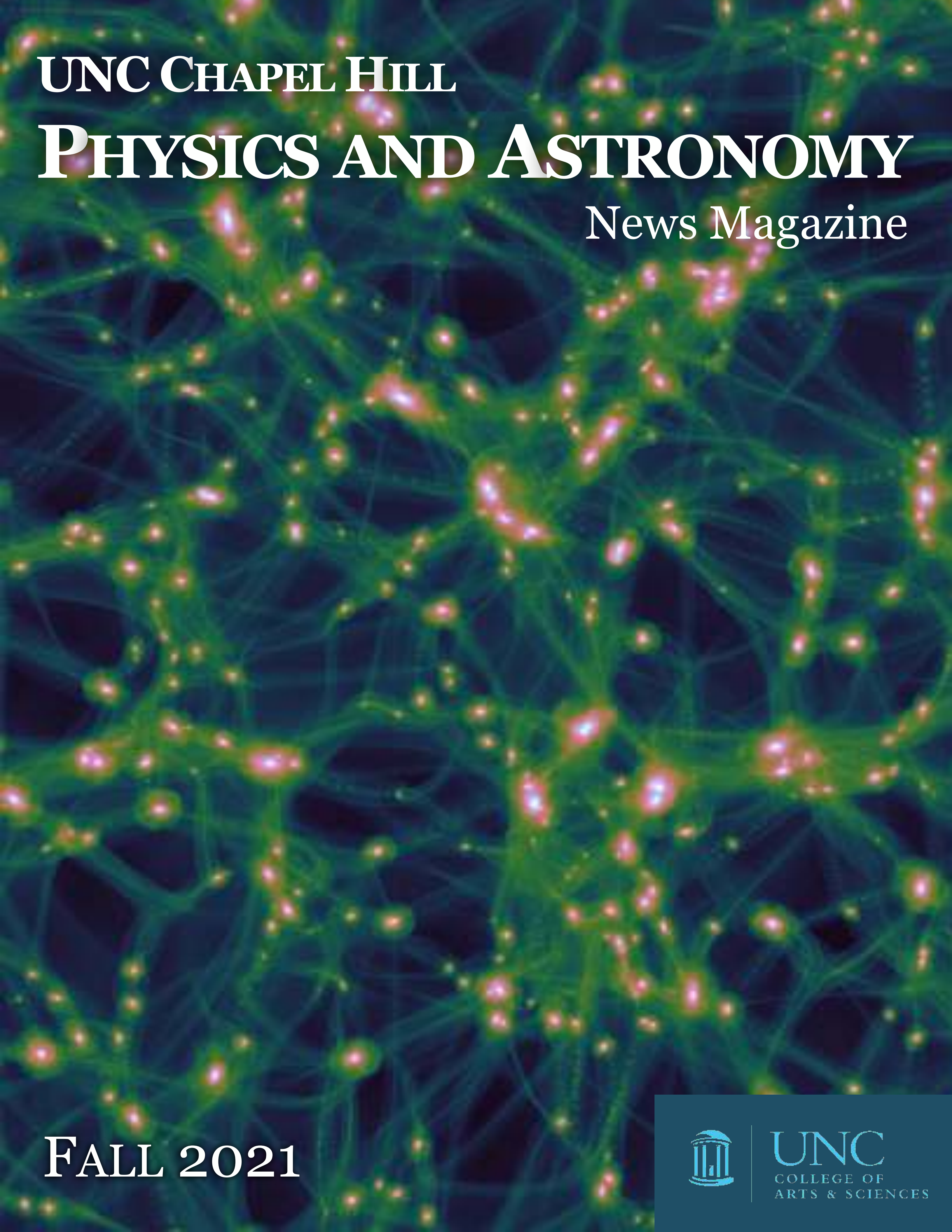
# UNC Chapel Hill
# Physics and Astronomy
## News Magazine



Fall 2021

UNC
College of
Arts & Sciences

# Fall 2021

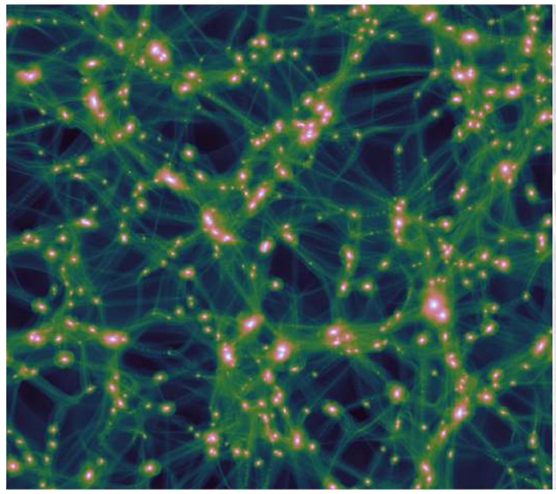
**online**
physics.unc.edu

**Our Department in numbers:**

| | |
|---|---|
| **33** | Tenure-line faculty |
| **5** | Teaching faculty |
| **5** | Research faculty |
| **11** | Academic support staff |
| **4** | Instrument shop personnel |
| **11** | Elected Fellows of the APS, AAAS, SPIE, or AIMBE |
| **$11.2M** | Annual Research Funding received in 2020-2021 |
| **87** | Graduate students |
| **8** | Postdoctoral scholars |
| **6974** | Annual course enrollment 2020-2021 |
| **13676** | Credit hours taught in 2020-2021 |
| **213** | Majors |
| **49** | Bachelor's degrees awarded in 2020 |

UNC COLLEGE OF ARTS & SCIENCES

# Physics and Astronomy
## News Magazine



***On the cover**: A simulation snapshot 17 million years after inflation in a scenario that includes an early matter-dominated era during the Universe's first thousandth of a second (see Adrienne Erickcek's article on page 4).*
***Credit**: Sten Delos*

## Contents



## Plus



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

# From the **Chair**

**Persevere in the age of pandemic**

By Frank Tsui

This past year has been the most challenging in our collective personal and professional lives. In the face of physical isolation and social distancing measures, severe budgetary constraints, and record high enrollments, we have become more focused on our mission. We as a community have found new ways to do research, teach and learn, and stay connected, and demonstrated the will and compassion to help each other.

As you read this issue of the magazine, you will find that our faculty and students have continued to make significant advances at the frontiers of fundamental physics and technology, from exploring the cosmos and its origin, to developing new paradigm to harness the power of the sun, to examining the basic building blocks of the universe, from building the most advanced telescopes, to producing FDA approved medical devices. Our faculty have continued to win prestigious awards and won record high amounts of research funding. We have taught record high number of students and credit hours in classes, and graduated record high number of physics majors, the highest within the state, among the top two in the entire southeast from Virginia to Florida to Louisiana.

One of the stories in this issue is the 50th reunion of physics class of 1971, an impressive group of graduates. I am so very proud of their professional accomplishments, contributions to the society, and dedication to public service. A common theme of their stories is how instrumental their Carolina physics education has been in shaping their careers. As a group, they also set an excellent example for other classes to emulate with a sense of comradery and genuine care for each other. Their collective experiences also reaffirm our mission. As we face the overarching challenge of our time, climate change, physics and astronomy research, education, and service are more important than ever, not only for the pursuit of knowledge, but also for building the workforce prepared to solve the world's problems.

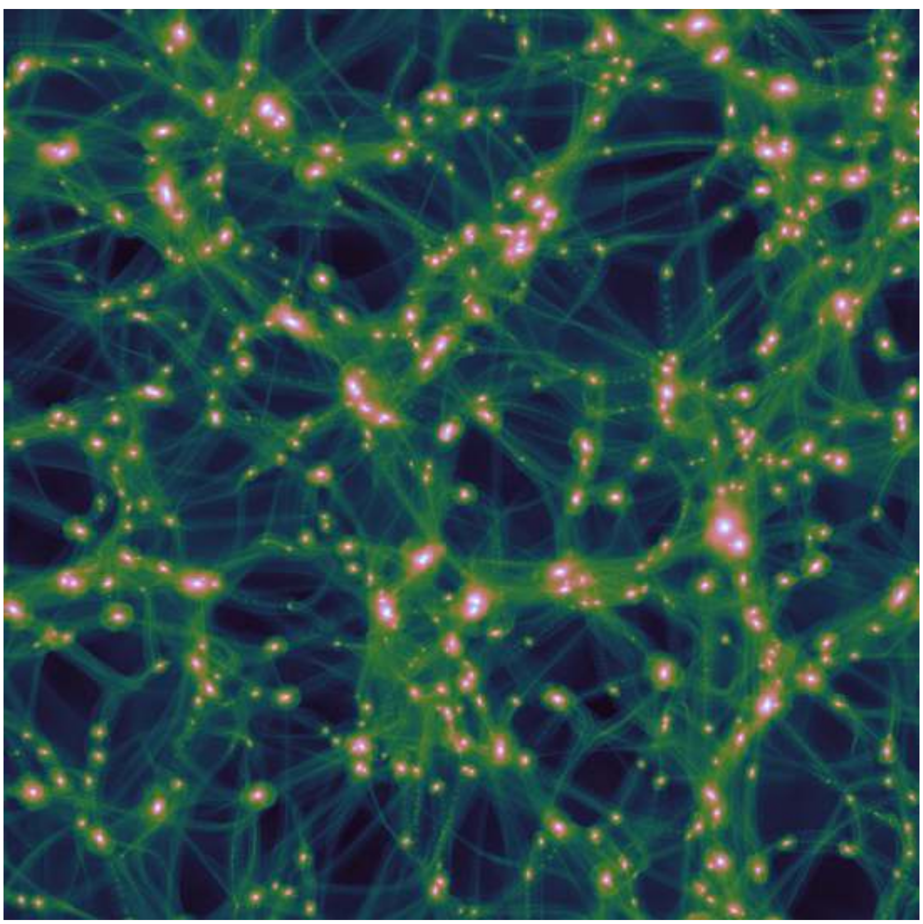
The challenges have taught us that we are resilient, we can persevere. I am excited about where we are and the future. Our dreams and actions moving forward will define our destiny.

Best wishes,
**Frank Tsui**
Chair, UNC-CH Physics & Astronomy

# Probing the Universe's First Second with Dark Matter

By Adrienne Erickcek

Half of a second after "the Big Bang," the Universe was filled with a hot plasma of photons, protons, neutrons, electrons, positrons, and neutrinos. The temperature of this plasma was 14 billion degrees Celsius – about 1000x hotter than the interior of the Sun. Remarkably, we know the composition of this plasma quite accurately because we can measure the amounts of helium and other light elements that were created by fusion within this plasma. Moreover, the photons within this plasma make up the cosmic microwave background (CMB), which provides a picture of the Universe when the protons and electrons in this plasma formed atomic hydrogen 380,000 years after the Big Bang. The CMB tells us that in addition to this plasma, the early Universe also contained dark matter – a mysterious long-lived particle that has no electric charge and is much colder than the neutrinos. For every kilogram of normal matter in the Universe today, there are 5 kilograms of dark matter.



*A simulation snapshot 17 million years after inflation in a scenario that includes an early matter-dominated era (EMDE) during the Universe's first thousandth of a second. The box size is 1.5pc on a side. You can see lots of dark matter halos – they would be very rare at this time if there had been no EMDE.*

What we don't know is where this plasma and dark matter came from. What happened during the Universe's first half-second? There is strong evidence that the birth of the Universe included a period of rapid accelerating expansion called inflation, during which quantum fluctuations in the density of the Universe were stretched to astrophysical scales, seeding the growth of galaxies and other structures. After inflation, the Universe would have been empty aside from the energy source that drove inflation. Somehow this energy must have been converted into other particles, but since we don't know much about the inflation, we don't know how this conversion happened. In most theories of inflation, this conversion created particles with energies greater than $10^{12}$ GeV, which exceeds the energy of the particles we can study in colliders by a factor of 100 million. The infant Universe is our only window into physics at these energies, but unfortunately, it is very difficult to probe the evolution of the Universe during the first half-second after inflation

The density fluctuations that were created during inflation manifest themselves as hot and cold spots in the CMB, but we can only see megaparsec-scale hot and cold spots. These regions are so large that they started to evolve many years after inflation ended, and they offer no insight into the dynamics of the Universe during its first second. Smaller-scale temperature fluctuations are obscured by dissipation within the primordial plasma. It is also impossible to probe the sub-kiloparsec fluctuations that grew during the Universe's first second using normal matter because star formation has thoroughly altered the distribution of gas on these scales. Only dark matter is inert enough to offer a pristine probe of density fluctuations on sub-galactic scales.

My research group studies how the evolution of the Universe during its first second affects the production and distribution of dark matter. If the primordial plasma dominated the energy density of the Universe during the first second, dark matter density fluctuations would grow slowly during this time, and the first gravitationally bound dark matter structures form about 50 million years after inflation. If unstable massive particles, possibly created at the end of inflation, dominated the energy density of the Universe during its first second, these particles would pull dark matter particles toward them, leading to an earlier formation of dark matter structures. Since the density of matter in the Universe decreases with time, earlier-forming clumps of dark matter are denser than their later-forming counterparts. Using both cosmological perturbation theory and simulations of dark matter particles, my group has demonstrated how the abundance and densities of the smallest dark matter clumps depend on the evolution of the Universe during its first second.

**"Using both cosmological perturbation theory and simulations of dark matter particles, my group has demonstrated how the abundance and densities of the smallest dark matter clumps depend on the evolution of the Universe during its first second."**

Detecting these clumps of dark matter is challenging: they typically have masses far less than the mass of the Earth, and even though they are the densest dark matter structures, they are still diffuse, with central densities around $10^{-15}$ kg/m$^3$. However, if dark matter originated via pair production within the primordial plasma, we expect that dark matter is composed of matter and antimatter in equal amounts. Therefore, when two dark matter particles collide, we expect them to annihilate and emit gamma-rays. The presence of dense clumps of dark matter makes it far more likely that dark matter particles will collide, so we can use gamma-ray observations to constrain their abundance, thus providing a window into the Universe's first second.

**Adrienne Erickcek** joined the UNC physics and astronomy department in 2013 after completing a joint postdoctoral fellowship at the Canadian Institute of Theoretical Astrophysics and the Perimeter Institute for Theoretical Physics. She developed an interest in cosmology while an undergraduate student at Princeton University: "I was captivated by the fact that we can use astrophysical observations to learn about the birth of the Universe." She went on to receive her Ph.D. from Caltech: her thesis explored how alternatives to general relativity and alternatives to the simplest models of inflation can be constrained by cosmological observations. For the past several years, her research has focused on dark matter in the early Universe, and in 2018 she was awarded an NSF CAREER grant to investigate how to use dark matter to probe the evolution of the Universe during its first second. Adrienne is an avid science fiction fan: "astrophysics is the way I fulfill my childhood dream of exploring the cosmos." She also enjoys hiking with her husband and sons and playing the flute.

# Toward a solar energy revolution

By René Lopez

Sunlight is clearly the most abundant and sustainable source of energy available to the world. A solar energy revolution based on direct solar energy conversion to electrical or chemical energy forms seems possible even with standard well-known silicon technology. However, only abundant, and low-cost materials stand a chance to surpass silicon's cost trajectory and enable a deeper, perhaps faster energy transformation. Such a step requires deeper understanding and developments in the physics light, interaction with novel materials.

My group is committed to a bet that alternative systems such as organic, hybrid, and quantum dot solar cells have indeed the potential bring out that solar energy revolution. The key is to comprehend and manage in the adversative problem common in all new and old solar material systems –light absorption vs. electrical charge carrier transport–, that is light needs a certain amount of material to be absorbed and create separate electrical charges, but those charges need to travel out to harvesting points before recombining and lose their energy in heat. The most obvious way to address this problem is by improving the intrinsic characteristics of materials by defect passivation and overall crystallinity and purity enhancement. Another way is by addressing the transport and light absorption characteristic lengths mismatch with new device structures.

An example of the latter approach is shown in Fig 1. In this work done in the Lopez group, a non-flat cell structure (Fig 1a) for a solar cell based in lead sulfide quantum dots is investigated vs. a conventional flat layer design. The proposed non-planar structure is conceived to enhance the light absorption of the material while acknowledging the limited charge transport one can obtain from this type of quantum dots. The comparison between the space distributions of charge generation between the conventional flat cell and the proposed design could not be more striking (see Fig 1b), which enable a potential doubling of the generated photocurrent in the same cross-sectional area exposed

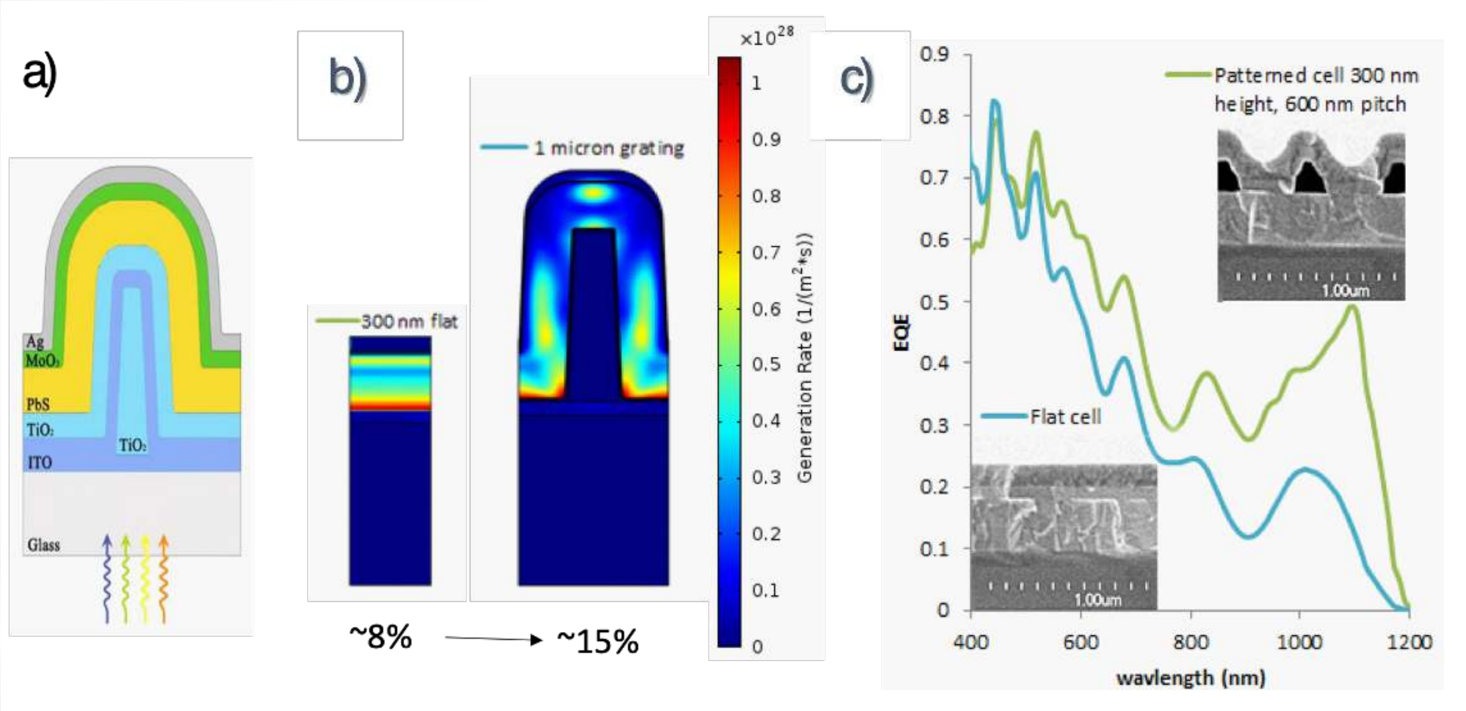



***Fig. 1.*** *a) Materials and structure of a non-planar design for PbS solar cells, b) Optical generation density projected improvement between a flat optimized cell vs. a non-flat 1 micron height patterned-grating structure. c) External quantum efficiency (EQE) vs. wavelength experimental comparison between flat and non-flat.*

to the sunlight. Experimental realization of this device requires though significant quality in nanofabrication. Fig. 1c shows a cross-section of the work realized in the Lopez lab toward realizing this type of solar cell design, at all colors of light the conversion of light into electrical current is enhanced, and the enhanced is maximum in the near IR region. This nanostructure can be shown to be an ideal to maximize the IR absorption capability of quantum dots which is far superior to silicon'.

Lately, my group has focused on combining semiconductor materials with organic catalysts to approach the related problem artificial photosynthesis. In other words, the storage of energy from the sun. The concept (Fig. 2) is intended to understand the fundamental mechanism and bottlenecks to be able to do direct conversion of sun light into liquid fuel. Specifically, utilizing a combination of pulse laser and magnetron sputtering deposition techniques, the goal is to create semiconductor nitride material with the adequate bandgap and band alignment to enable an interfaced catalyst to perform carbon dioxide reduction. This work is part of the new UNC Center for Hybrid Approaches in Solar Energy to Liquid Fuels (CHASE), one of the few nation-wide energy hubs funded by the Department of Energy. The goal of the center is to develop and study systems to mimic photosynthesis with inorganic semiconductors coupled with organic catalyst for direct conversion of light energy into liquid fuel products. The challenges to make this an efficient process are vast, besides the ideal specifications required for the semiconductor to cooperate with the catalyst, practical issues such as control of defects and surface passivation schemes are critically important to enable this potential sun energy storage technology.

In sum, materials improvements and novel microstructural design hold an important approach to improve solar energy harvesting and storage technologies. Both from the point of view of studying physical phenomena to bringing out the development of a practical technology, understanding of the physical processes in a integral form is essential to make solid progress to that anticipated true energy production revolution.

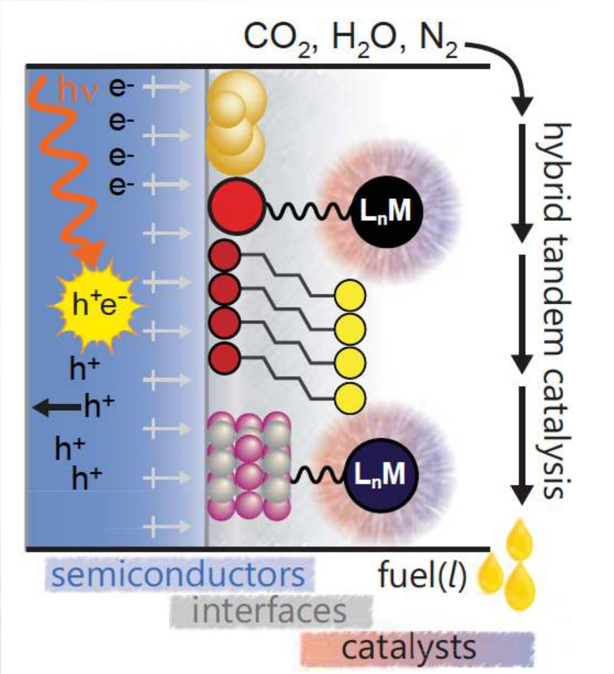



***Fig. 2.*** *Conceptual mechanism for artificial photosynthesis where inorganic semiconductor absorbs light to create electron and hole pair that are transferred to specially designed organic catalyst to convert $CO_2$ into a high energy value liquid fuel.*

**René Lopez** obtained his bachelor's degree from the Monterrey Institute of Technology (Mexico), and his Master and Doctoral degrees from Vanderbilt University (USA). He worked at the Oak Ridge National Laboratory and Vanderbilt University before joining the Faculty of the University of North Carolina at Chapel Hill (USA) in 2006. His research work at UNC has been centered in materials and nanostructures for harvest light energy with light trapping schemes that made use of photonic and charge transport concepts to minimize energy loses with alternative polymer, dye sensitized and quantum dot solar cells. When he is not teaching or doing research, Prof. Lopez studies classical guitar.

# Nuclear physics from quarks and gluons on the lattice

By Amy Nicholson

My research focuses on understanding low-energy properties of the constituents of matter (hadrons, nuclei, and nuclear matter) by solving Quantum Chromodynamics (QCD) using computational techniques. I am particularly interested in making theoretical connections with experiments searching for new physics beyond the Standard Model of particle physics (neutrinoless double-beta decay, direct dark matter detection, CP violation), as well as understanding the origins of matter in the Universe (baryogenesis, Big Bang and stellar nucleosynthesis) and phases of matter under extreme conditions, such as within the cores of neutron stars.

I largely use lattice methods, in which space and time are discretized, which allows for a non-perturbative solution of QCD. The theory is then solved numerically, requiring efficient use of state of the art high performance computers. I am a senior member of the CalLat collaboration, a collection of nuclear theorists with a research goal of forming a quantitative bridge between our understanding of nuclear physics and QCD. We are consistently awarded allocations to machines such as Summit at Oak Ridge National Laboratory through the US Department of Energy (DOE) Office of Advanced Scientific Computing Research, and Sierra at Lawrence Livermore National Laboratory.

**"Already at the precision level of the calculation performed by my group, we are able to place the most stringent bounds on right-handed Beyond the Standard Model currents when the result is combined with Effective Field Theory."**

With the CalLat collaboration and Henry Monge-Camacho, a former UNC postdoc, I have recently computed the axial charge of the nucleon, $g_A$, which may be directly related to the lifetime of the neutron, directly from the Standard Model to an unprecedented precision below the percent-level. Experimentally, the neutron lifetime and $g_A$ have been measured to 0.1% precision. However, values for the neutron lifetime disagree significantly when measured using neutron beams and counting only Standard Model decays, versus trapped ultracold neutrons, which allow one to measure the lifetime due to all possible decays

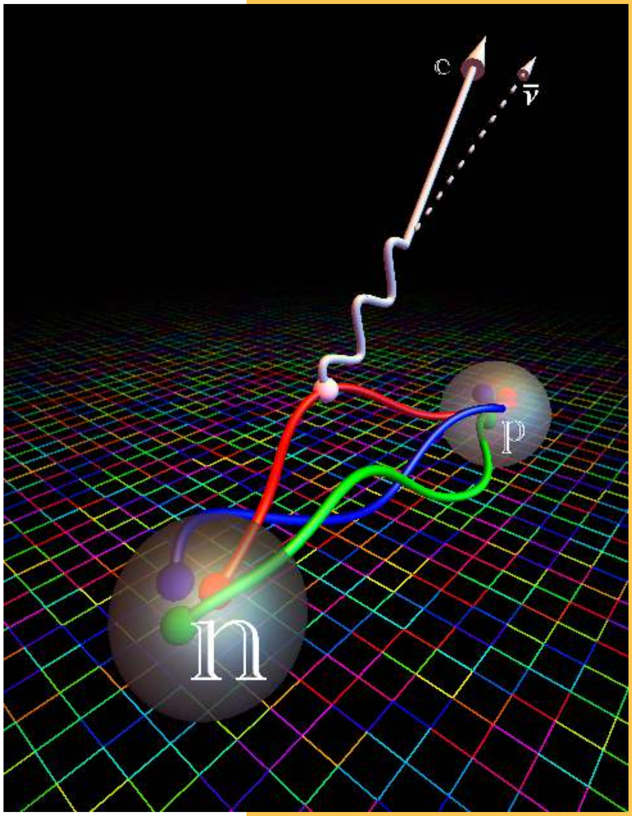
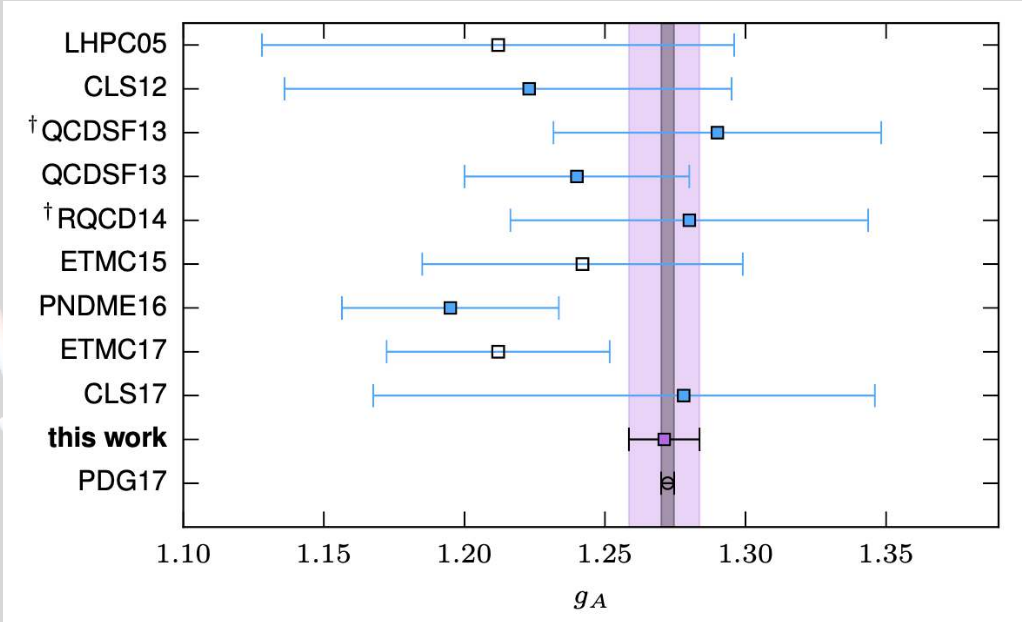



*Illustration of beta decay showing quarks on the lattice.*

allowed by nature. This has raised the exciting possibility that there may be new, unknown physics contributing to the neutron decays which gives rise to this difference. A direct calculation of $g_A$ and the neutron lifetime from the Standard Model at a comparable precision to experiment would help to resolve this puzzle. Already at the precision level of the calculation performed by my group, we are able to place the most stringent bounds on right-handed Beyond the Standard Model currents when the result is combined with Effective Field Theory.




*Summary of select LQCD calculations of gA along with the result of this work and the experimental determination (PDG17). The vertical magenta band is our full uncertainty to guide the eye, while the vertical gray band is the experimental uncertainty. Results with closed symbols have also included an extrapolation to the continuum limit, while results with open symbols have only included an extrapolation/interpolation to the physical pion mass.*

Decades of efforts from other collaborations to compute this quantity theoretically led to unclear control over systematic effects, resulting in differences of quoted values at the level of two sigma at a precision of a few percent. Cracking the subpercent-level of precision relied on the use of a novel computational method, the so-called Feynman-Hellmann method, in which the matrix element is extracted directly from a two-point correlation function (the usual method for extracting spectra in lattice QCD calculations), as opposed to the more complicated three-point functions used in traditional methods. The use of two-point functions allows for the much simpler extrapolation to the physical limit in a single parameter, while the three-point method requires multiple (computationally expensive) calculations to allow for a tricky extrapolation in two parameters.

The exponentially increased computational speed of this method furthermore allowed for more computation time to be dedicated to increasing statistics. An improved lattice QCD action also allowed for more refined control over systematics due to spacetime discretization. This combination of novel computational methods and improved control over systematics was chosen as one of six finalists internationally for the 2018 ACM Gordon Bell Prize for “Innovations in applying high-performance computing to science, engineering, and large-scale data analytics”. The research was published in Nature in 2018.

**Amy Nicholson** joined our department in Fall 2017, following a postdoctoral position with the Nuclear Theory group at UC Berkeley. Previously, she had been a postdoc in the Theoretical Quarks, Hadrons, and Nuclei group at the University of Maryland. She received her PhD from the University of Washington in 2011 under advisor David B. Kaplan, and her BS in Physics from New York University in 2004. She was recently awarded a 2021 NSF CAREER award for her research, “Grounding Nuclear Physics in the Standard Model for New Physics Searches”

# Magnetic Fields and Ultrasound Waves: a New Biomedical Imaging Modality

By Amy Oldenburg

From pre-natal care to cardiology, ultrasound scanners, which send ultrasound waves into tissue and read out the reflected waves (or echoes), are a mainstay for safe and easy-to-use biomedical imaging. Unfortunately, interpreting ultrasound images, which are confounded by speckle, an artifact of the interference between waves reflected from different points, can be challenging and often requires a trained specialist. Other imaging modalities like MRI and CT employ **contrast agents** that can be ingested or injected to label tissues of interest, like cancers or clots. Contrast agents are comprised of macromolecules or nanoparticles that are small enough to be readily cleared from the human body, accumulate at the tissue of interest, and provide a physical mechanism for being detected by the imaging modality. However, ultrasound cannot detect these types of agents due to their small size; because they are much smaller than the ultrasound wavelength of ~0.5 mm, they are very inefficient at reflecting ultrasound waves. We would say that these agents lack **echogenicity**.

To overcome this limitation and address the need for contrast-enhanced ultrasound, the Coherence Imaging Lab at UNC has been advancing a method for magnetic nanoparticle imaging with ultrasound called **magnetomotive ultrasound (MMUS)**. Basically, we put strong electromagnets around the ultrasound transducer that are modulated at a specific frequency, and the fringe field, i.e., the magnetic field gradient that extends into the ultrasound view, acts to pull on any magnetic nanoparticles labelling the tissue in a modulated fashion. While the nanoparticles are not echogenic, we are interested in using them to label tissues such as blood clots, which are comprised of platelets and other materials already visible in the ultrasound scans. Our detection software looks for evidence of tissue motion at the same frequency and phase as the magnetic field (frequency- and phase-locking). We then form a "contrast-enhanced" ultrasound image of the tissue where the relative density of the nanoparticles is inferred from the modulation amplitude (typically in nanometers) of the induced motion.

From a technological point of view, this is exciting because we can now detect nano-sized particles, by virtue of their mechanical coupling with the tissue, using an imaging method with a much coarser resolution (typically 10s of microns). It is also interesting to note that the motion

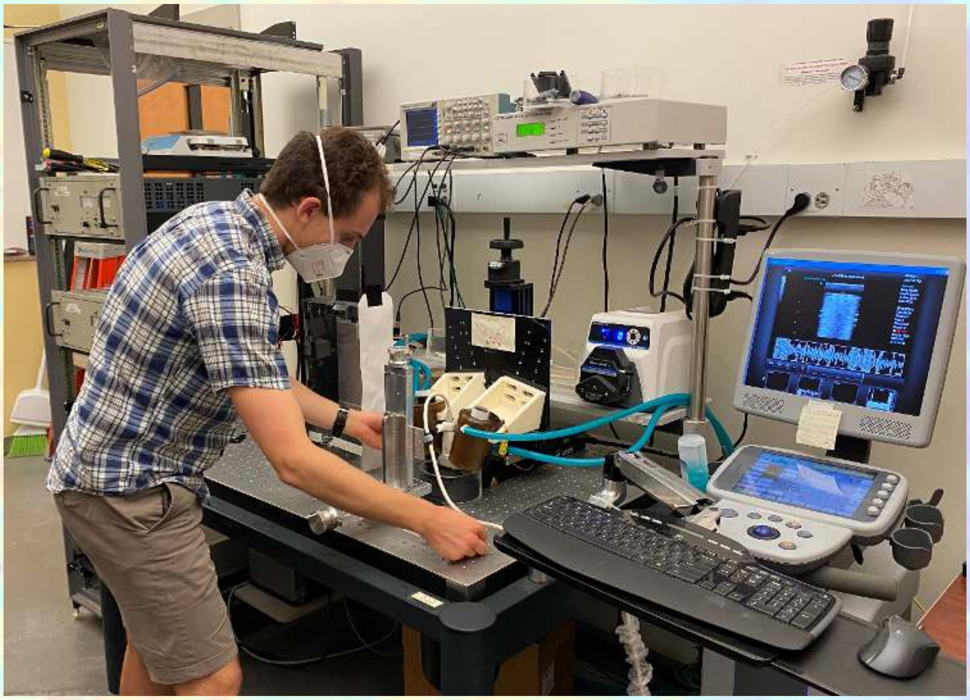


***Fig. 1.** Physics graduate student Ben Levy aligns the water-cooled electromagnets surrounding the clinical ultrasound scanner on the MMUS system.*

detection method exploits the wave-like nature of the ultrasound to sense relative phase changes in the echoes corresponding to displacements on the scale of 10s of nanometers. Sometimes it gets a little tricky to keep the physics straight, because in our system we have both mechanical waves being generated by the magnetic field modulation, typically at 1 – 30 Hz frequencies, and ultrasound waves being used to image the mechanical motion, typically at 1 – 5 MHz frequencies.

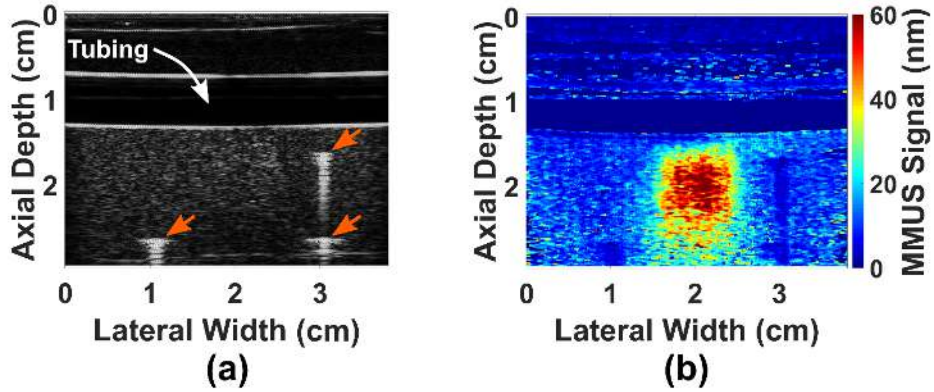



***Fig. 2. Left**: Standard ultrasound image of a simulated artery of flexible tubing in an echogenic gel, and fiducial markers (arrows) surrounding a cubical magnetic particle-labelled inclusion; the inclusion exhibits no contrast against background. **Right**: Corresponding MMUS image showing how the inclusion is now contrasted by merit of the magnetically-induced motion coupled into the echogenic gel.*

MMUS is also exciting from an applications point of view. For eventual human use, we note that magnetic iron oxide nanoparticles are already ubiquitous in MRI and have a safe profile. In our early-stage development, physics graduate student Ben Levy (Fig. 1) has been exploring the utility of MMUS to detect and accurately size blood clots in arteries and veins. This could be useful for detecting or monitoring the growth of potentially harmful clots before they fully occlude the blood vessel, or, alternatively, their dissolution while undergoing therapy. Currently, it is difficult to detect clots that have not already occluded a blood vessel, and methods for sizing clots are qualitative because they can blend into the background. Our results show that MMUS can readily see simulated clots next to a simulated artery (Fig. 2). Importantly, Ben showed that, even if the artery is pulsing as it would in the human body from cardiac motion, the frequency- and phase-locking method can specifically detect the magnetic particle motion and reject the simulated heartbeat.

**"...we can now detect nano-sized particles, by virtue of their mechanical coupling with the tissue, using an imaging method with a much coarser resolution."**

Going forward, we are investigating methods for using MMUS to measure the elasticity of clots, which might be inferred by the mechanical frequency response of a clot in conjunction with mechanical models. Clot elasticity is an important indicator of clot age, which indicates to a clinician how dangerous it might be and whether intervention is necessary.

**Amy Oldenburg** earned a BS in Applied Physics from the California Institute of Technology, a PhD in Physics at the University of Illinois at Urbana-Champaign (UIUC), and worked as a postdoc at the Beckman Institute at UIUC. She joined the faculty of the University of North Carolina in 2008 where she directs the Coherence Imaging Laboratory, which focuses (pun intended) on novel biomedical imaging modalities based on light and ultrasound waves. In her spare time, she does amateur auto racing and answers spectator questions about the physics equations decorating her BMW race car.

# Recently published

## Efficiency Enhancement of Organic Thin-film Phototransistors due to Photo-assisted charge injection

Laurie McNeil's group has determined that thin-film transistors made from the organic compound diF-TES ADT are more than 100% efficient at converting absorbed light into electric current.  Each photon absorbed by the device generates multiple charge carriers due to enhanced injection of carriers from the electrodes.  The enhancement occurs because each absorbed photon creates an exciton: a negatively-charged electron and a positively-charged hole bound together.  The electron and hole separate, and the hole contributes to the current while the electron remains trapped. The presence of the trapped electrons reduces the barrier for charge injection from the electrodes and increases the current.  As a result, this device has one of the highest photoresponsivities ever recorded for an organic transistor. The findings were published in **Applied Physics Letters 119, 073302 (2021)**.

The lead author on the paper, Zafrullah Jagoo, received his PhD from UNC in the summer of 2020 and is now a Process Engineer at Intel.

## Evolution of Non-Gaussian Hydrodynamic Fluctuations

Gökçe Basar and Postdoctoral Associate Xin An, in collaboration with Mikahil Stephanov and Ho-Ung Yee from the University of Illinois at Chicago, recently derived the evolution equations for non-Gaussian measures of thermal fluctuations in hydrodynamics. Fluctuations play a key role in the ongoing search for the quantum chromodynamics (QCD) critical point and this work describes how these fluctuations evolve dynamically within the hydrodynamic framework. They introduced a novel generalization of the Wigner function to higher point correlation functions and developed a diagrammatic technique to organize the expansion in the magnitude of thermal fluctuations. Their findings were published in **Physical Review Letters 127, 072301 (2021).**

## The Evolution of Physics Education: How Undergraduate Departments are Transforming

Laurie McNeil writes about the many changes in the ever evolving methods of teaching Physics and how they are being implemented in undergraduate programs.

She begins by citing a model that explains how the traditional lecture hall model of teaching physics can often fall short when it comes to overall comprehension and retention by students.

A newer model that includes cooperative and hands-on learning may be more effective. Many institutions are evolving their teaching methods to include the professor asking students many questions throughout their lectures for students to discuss with partners than answer via a clicker to gauge where the overall class stands. Their is also the hands-on component where large classes are broken down into smaller lab groups (say about nine) that sit together and work on more hands on experiments, pencil and paper tutorial activities and cooperative group problem solving.

Reports are showing that potential employers are looking for people with physics-based knowledge (gained through the traditional teaching methods), scientific and technical skills (including coding, data analytics, and instrumentation as well as the ability to solve ill-posed problems) communication skills (for all types of audiences) and professional and workplace skills (such as working in diverse teams, project management, and knowledge of career opportunities and job seeking) amongst other things, though many are not covered in

traditional physics instruction. The hope is that students will gain the necessary knowledge through the ever evolving methods of teaching.
Find the full article at:
***https://www.sigmapisigma.org/sigmapisigma/radiations/spring/2021/evolution-physics-education***

## Active-learning Teaching Strategies Outperform Highly Regarded Traditional Instructor

It's no secret that active learning helps students learn and retain more information than they would from traditional, lecture-only instruction. A new paper by Colin Wallace and his colleagues at the University of Arizona, reveals the extent to which an entire semester of active learning benefits students. Their paper, which was just published in the Journal of College Science Teaching, describes a semester-long experiment comparing two introductory physics courses, one taught by an experienced and popular instructor who only lectured, and the other taught by a first-time instructor who made extensive use of active learning pedagogies.

Both classes enrolled over 200 students and covered the same content. Students in the two classes took identical exams. The first-time instructor sacrificed one of his three weekly lectures to make room for small breakout sessions of approximately 25 students each. During these breakout sessions, students worked collaboratively on activities informed by physics education research that were designed to improve student's conceptual understandings and problem-solving skills. Additionally, the first-time instructor used the technique of Think-Pair-Share (a.k.a. Peer Instruction) in a novel way during lecture to improve students' problem-solving skills.

The results were dramatic: On almost every question on every exam, students of the first-time instructor outperformed students of the experienced instructor. These results held for both conceptual and quantitative questions. By the final exam, students of the first-time instructor were outperforming their peers by as much as two letter grades on some questions. Because the final exam was a cumulative exam, this result suggests that the effects of active learning may be cumulative: As students spent more time actively engaged with the material, they experienced increased abilities to recall, apply, and synthesize what they learned, even in contexts that were prima facie novel.

The findings were published in **Journal of College Science Teaching, Vol. 50, No. 4, p. 48 (2021).**

## TESS Discovers New Worlds in a River of Young Stars

Using observations from NASA's Transiting Exoplanet Survey Satellite (TESS), a team of astronomers has discovered a trio of hot worlds larger than Earth orbiting a much younger version of our Sun. Called TOI 451, the system resides in the newly discovered Pisces-Eridanus stream, a collection of stars less than 3% the age of our solar system that stretches across one-third of the sky.

The planet was identified and validated by the THYME collaboration, which is led by our own Andrew Mann and Elisabeth Newton of Dartmouth College. THYME includes UNC graduate students Mackenna Wood and Pa Chia Thao, both of whom were co-authors on the study. The collaboration focuses on identifying planets much younger than the Sun to study how planets change with time.

"This discovery was only possible because of TESS's wide field of view, which is essential to surveying the whole stream" said Dr. Mann. Jessie Christiansen, a co-author of the paper and the deputy science lead at the NASA Exoplanet Archive added, "TESS data will continue to allow us to push the limits of what we know about exoplanets and their systems for years to come."

The findings were published in **Astrophysical Journal, Vol. 161, p. 65 (2021).**

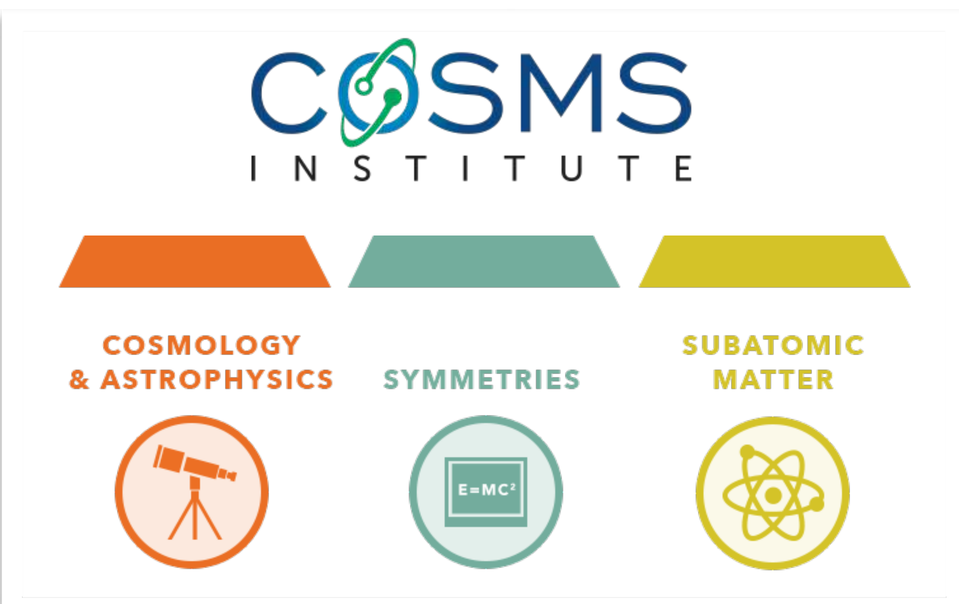
# Happenings at CoSMS

By John Wilkerson

Although many Institute of Cosmology, Subatomic Matter, and Symmetries (CoSMS) activities were put on hold because of the pandemic, we can report substantial progress on renovating the second floor wing in Phillips Hall that will serve as the physical home for CoSMS. This occurred thanks to the efforts and leadership of Prof. Christian Iliadis, who also had assistance from a number of other staff and faculty.

***Phillips Hall 200****, recently painted and renovated, now features glass white boards, custom wooden conference tables with tops built from reclaimed lumber, and modern comfortable furniture. An early brass telescope discovered in the attic of Phillips Hall, seen here on top left, adds a distinctive historical touch.*

The large seminar room, which was painted and renovated, now includes glass white boards, custom wooden conference tables with tops built from reclaimed old lumber, and modern comfortable furniture. An early brass telescope, discovered in the attic of Phillips Hall is mounted on one of the walls adding a distinctive touch. Renovation, painting, and outfitting of the wing's hallway and three offices for visitors is also now complete. We are very much looking forward to using these bright and attractive spaces for hosting upcoming CoSMS and departmental functions.




Remaining future renovations include converting a storage space into a large seminar room, establishing an office - meeting preparation space, and setting up a common area room to provide space for more informal meetings and discussions. Preparatory work on these rooms is continuing, with renovations dependent on further funding.

Plans to launch our New Horizons distinguished speaker series unfortunately continue to be delayed, now by uncertainties associated with the Delta variant. However, we are planning two more focused series for CoSMS faculty that can be held either in-person, remote, or as hybrid meeting. The first series is *Communicating Science — How to effectively convey science to the public*. The goal is to encourage CoSMS members to strengthen their communication skills with the expectation that CoSMS will in the future be hosting a regular series of public lectures. We are also planning retreats on faculty research topics to both inform CoSMS members of current activities and to explore potential new collaborations.

Finally, CoSMS is working with local faculty in preparing to host two international science workshops. Both were originally scheduled to be held in 2021, but are now rescheduled to be held in 2022. Prof. Joaquín Drut is leading the organization of the *XXI International Conference on Recent Progress in Many-Body Theories,* which will bring together over 100 participants from around the world to present and discuss advances in quantum many-body theory across all areas of physics. As a bridge to the conference, planned to be held in the Chapel Hill area in September of 2022, a virtual seminar series, the Quantum Many-Body Days (QMBD2021) is underway this Fall.

Planning is also moving forward for hosting the 7th Symposium on Neutrinos and Dark Matter in Nuclear Physics in May of 2022. This symposium brings together a broad group of researchers from both fields, unified by similar experimental techniques and challenges, and common theoretical motivations to explore physics beyond our current standard model of fundamental interactions. Prof. Jon Engel chairs the local organizing committee that includes CoSMS members from UNC, Duke, NCSU, and NCCU. We anticipate around 80 speakers and around 120 attendees for the symposium which is currently planned to be held in Asheville, NC.


***Phillips Hall 205*** *is one of the most recently painted and renovated rooms, featuring new furniture as well, which now serve as offices for CoSMS visitors.*

**"…we can report substantial progress on renovating the second floor wing in Phillips Hall that will serve as the physical home for CoSMS."**

# 2021 The Nobel Prize in Physics

By Joaquín E. Drut


The Nobel Prize in Physics for 2021 was announced on October 5th. This year the prize was awarded *"for groundbreaking contributions to our understanding of complex systems"* and it was divided among three awardees: one quarter to **Syukuro Manabe** (Princeton University) and one quarter to **Klaus Hasselmann** (Max Planck Institute for Meteorology) *"for the physical modelling of the Earth's climate, quantifying variability and reliably predicting global warming";* and one half to **Giorgio Parisi** (Sapienza University) *"for the discovery of the interplay of disorder and fluctuations in physical systems from atomic to planetary scales."*

The balance of incoming radiation from the sun absorbed by the atmosphere, and not reflected back to space, is essential for life on Earth and is what we call the greenhouse effect. Although carbon dioxide is a tiny fraction (0.04%) of the atmosphere's volume, it plays a crucial role as it partially regulates the amount of water vapor, giving rise to a feedback mechanism that can drastically change the temperature of the atmosphere.

In the 1960's **Syukuro Manabe** developed some of the first physical models that explain this mechanism by capturing the convection effects of air masses and the latent heat of water vapor. He showed that carbon dioxide concentration can have a substantial impact on the surface temperature of the Earth, while oxygen and nitrogen have negligible effects. These insights came from a simplified one-dimensional model, but paved the way for more sophisticated models in three dimensions.

The vast array of weather patterns of our planet is largely a result of the uneven distribution of solar radiation, which in turn is due to differences in latitude (the

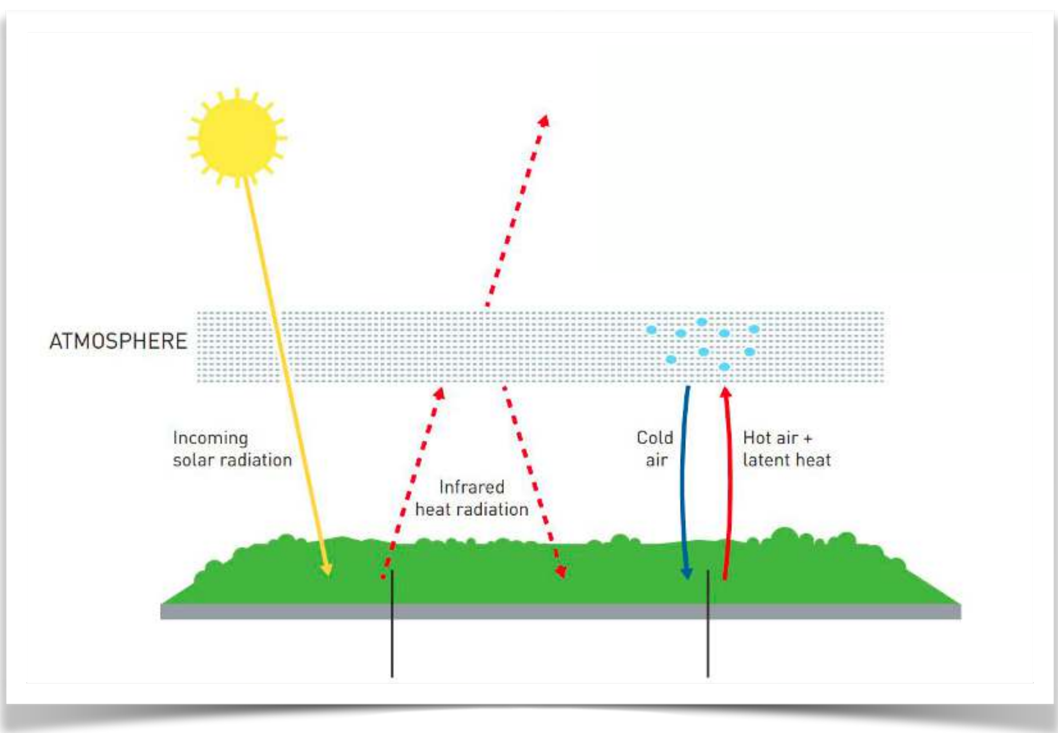



*Illustration of Manabe's climate model.*
***Credit:*** *nobelprize.org*

**Syukuro Manabe** and **Klaus Hasselmann**
*"for the physical modelling of the Earth's climate, quantifying variability and reliably predicting global warming."*

**Giorgio Parisi**
*"for the discovery of the interplay of disorder and fluctuations in physical systems from atomic to planetary scales."*

Earth is round) and the fact that we have seasons (the Earth's axis is tilted relative to the plane of its orbit). The result, namely climate, is in principle governed by the laws of hydrodynamics, but is in practice a chaotic system whose future state is very challenging to predict.

Around 1980, **Klaus Hasselmann** showed that such chaotic systems can be described using rapidly changing noise. He created a stochastic climate model that showed that fast changes in the atmosphere, such as wind strength and air temperature, can lead to slow changes such as melting ice sheets and warming seas. He also developed methods to identify human impact on climate, leading the way in determining that, coupling together theories and observations, one could distinguish the separate effects of changes in solar radiation, volcanic particles, and levels of greenhouse gases, demonstrating unequivocally that human emissions are the reason for the Earth's increasing temperatures.

Statistical mechanics is the area of physics that deals with systems of many interacting particles. Pioneered by giants such as Maxwell, Boltzmann, and Gibbs, it is largely concerned with systems in thermodynamic equilibrium and in homogeneous or periodic spatial arrangements. Several classes of materials, however, present features attributed to them being away from equilibrium, in metastable, disordered states, displaying an amorphous arrangement with no discernible long-range pattern. This behavior is often due to the phenomenon of frustration, where for instance in magnetic materials (e.g. a spin glass) spins appear randomly aligned or misaligned yet frozen in place.

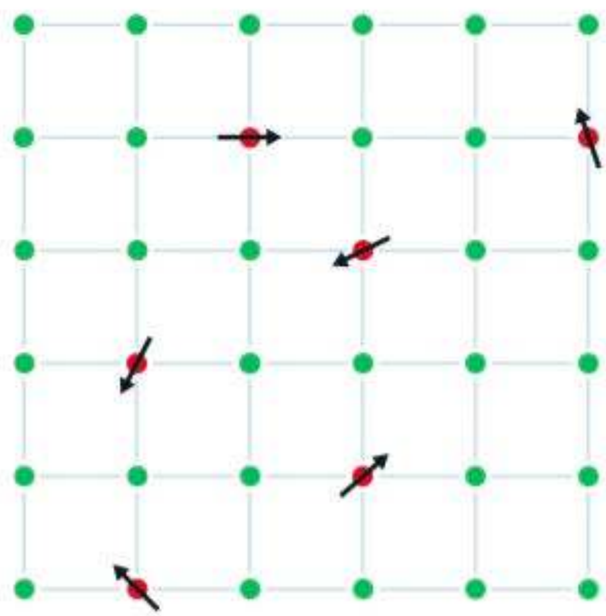


*Illustration of a spin glass.*
***Credit:*** *nobelprize.org*

**Giorgio Parisi** contributed to our understanding of these systems with groundbreaking findings on how to apply a mathematical trick: the so-called replica trick, to solve a spin glass problem, which is a paradigm for a class of disordered complex systems. In the 1980's he found a hidden pattern in the replicas, which allowed him to solve the problem. His method has since then been used in many disordered systems and has become a cornerstone of the theory of complex systems. These fundamental discoveries were so deep that they reached well beyond physics to mathematics, biology, neuroscience, and computer science, where some of the challenges are directly connected to the phenomenon of frustration.

In addition to the above, Parisi made important contributions to other areas in physics ranging from biophysics to surface growth (he is the 'P' in the KPZ equation) and quantum chromodynamics (he is the 'P' in the DGLAP equation). More in tune with this year's Nobel prize, it is worth mentioning the concept of 'stochastic resonance,' which Parisi and collaborators applied toward understanding the features of power spectra of paleoclimatic records.

# Focus on Grad Research

## Finding 5x as many Massive Black Holes in Small Galaxies

By Mugdha Polimera and Sheila Kannappan

Galaxies come in a variety of flavours, but a common distinction made is based on their mass -- high-mass galaxies (like the Milky Way) are called 'giants' and low-mass galaxies (like the Magellanic Clouds) are called 'dwarfs'. The exact separation between these two types is fuzzy, but we define the dwarf-giant divide as $M_{stars}$ ~ $10^{9.5}$ $M_{sun}$, the mass below which galaxies start to have very different properties. Typical local dwarfs have low metallicity (ratio of elements apart from H or He with respect to H), high ratios of atomic hydrogen gas to stars, and high star formation (SF).

Over the years, astronomers have gathered evidence to show that almost all giants have Super Massive Black Holes (SMBHs) in their centers, with masses in excess of 1 million Suns. Depending on how you search, up to half of these SMBHs can show signs of actively accreting material onto a glowing hot disk -- these SMBHs are called Active Galactic Nuclei or AGN. Recent work with gravitational waves has proven the existence of black holes (BHs) with 5-10x the Sun's mass, but the mass gap between these stellar-mass BHs and SMBHs is very large. We suspect that the missing link might be a class of Intermediate Mass BHs (IMBHs) that may be hosted in the centers of the low-mass dwarf galaxies.

One of the most popular methods of identifying AGN is by using optical emission-line diagnostics. These diagnostics examine the relationships between metal-to-Balmer-line ratios (e.g., [N II]/Hα) of galaxies, which change depending on the shape of the spectrum creating excitation. By comparing observed galaxy line ratios to the highest theoretical line ratios that can be produced by SF alone without the higher-energy excitation of an AGN, these diagnostics classify galaxies as SF, AGN, or a 'Composite' combination of the two. The most famous emission-line diagnostic used is the BPT plot (named after its creators Baldwin, Phillips, and Terlevich), but the choice of line ratios used in this diagnostic biases it against finding AGN in low-metallicity hosts. Our modelling and testing have shown that other diagnostics using different metal emission lines are better at identifying AGN activity in galaxies with low-metallicity and high spectral contributions from SF, typical characteristics of dwarf galaxies.

Our team recognized the need for an AGN identification method that simultaneously uses multiple diagnostic plots in order to account for potential dwarf AGN activity. Thus, we modified an existing galaxy classification scheme using three diagnostic plots (including the famous BPT plot) to systematically classify all galaxies into distinct categories, leaving no galaxy unclassified. Figure 1 shows representative galaxies in each category of our new scheme.

*By systematically classifying galaxies, our method has uncovered a hidden population of star-forming AGN (abbreviated as SF-AGN).* These galaxies are classified as SF by the famous BPT plot, but as AGN by

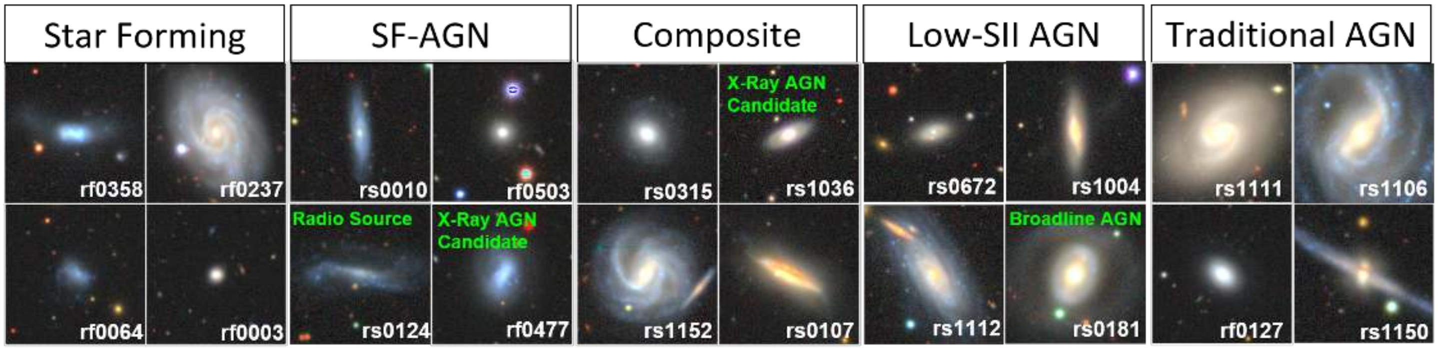



***Fig.1***: *Representative galaxies in each category of our new galaxy classification scheme.*

two other diagnostics. We extensively tested whether other scenarios could be the origin of the unique trend in emission-line ratios of SF-AGN, and we concluded that AGN activity is the most likely source of emission. One of the most convincing pieces of AGN evidence came from spatially resolved emission-line measurements of a SF-AGN (Figure 2). If a central BH is responsible for the observed emission lines, the emission should be present only in the central region around the BH and not all over the galaxy. In Figure 2, we can see that the AGN-like neutral oxygen emission (red pixels in bottom panel) is indeed centralized, providing strong evidence for BH activity.

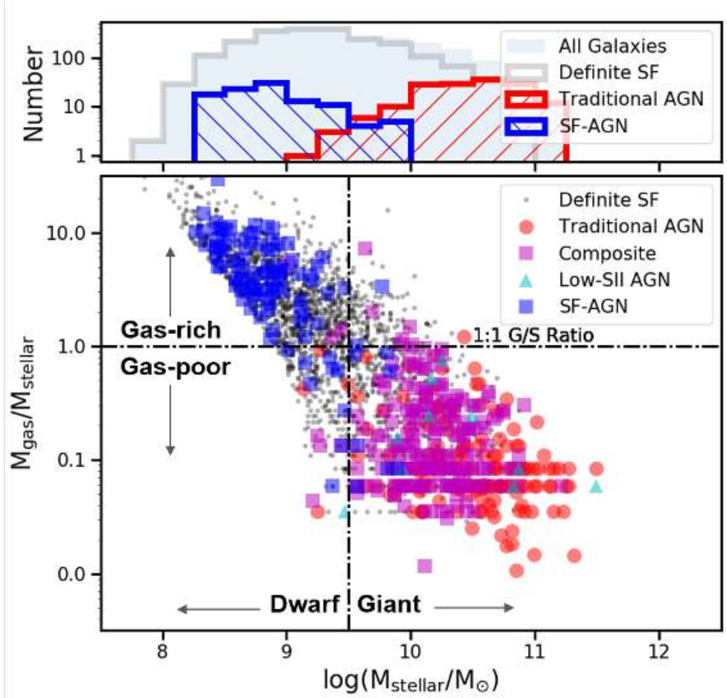



***Fig 3**: Newly identified SF-AGN (blue squares) are mostly gas-rich dwarfs whereas previously identified Composite (purple squares) and Traditional AGN (red circles) are mostly gas-poor giants.*

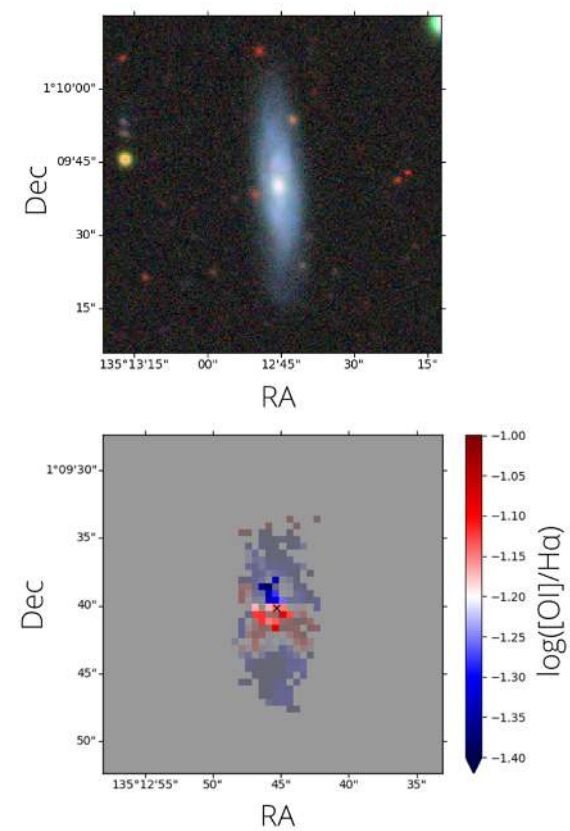



***Fig. 2**. Top: Image of one newly identified SF-AGN, rs0010. Bottom: Centralized emission indicative of AGN activity (red pixels) in rs0010.*

The newly identified SF-AGN (blue squares in Figure 3) are almost exclusively found in gas-rich dwarfs that also have low metallicity and high SF. These new SF-AGN are found in a region of parameter space that is barely populated by Traditional AGN identified by the BPT plot.

Upon including the new AGN categories, we find that our method uncovers AGN in ~3-15% of dwarf galaxies with strong optical emission lines, which is much higher than previous estimates using optical emission lines (<1%). The large percentage range in our study reflects systematic uncertainties in spectral modelling. Considering the entire population of dwarf galaxies in our statistically complete survey, our new method yields a dwarf AGN percentage of ~1-2% in the full galaxy population. This number is ~3-6x higher than estimates from previous optical studies (<0.3%) and at least 2-5x higher than previous mid-IR estimates (<= 0.4%).

Finding this hidden population of AGN in typical local dwarfs is a huge step toward understanding how dwarf galaxies co-evolve with their BHs. In the future, we will compare properties of AGN identified by multi-wavelength detection methods and investigate whether there is a difference in the physics of AGN feedback via gas outflows AGN in dwarf vs. giant galaxies.

# Focus on Undergrad Research

## Peering into the many-body problem by eigenvector continuation and algebra automation

By Austin Blitstein

Unknown to the naked eye, the world around us is a vibrant collection of interacting quantum particles. Life as we know it is the result of various emergent properties of matter that arise when you gather a great number of these quantum particles together. For instance, the concept of temperature and heat flow is really just the result of an exchange of kinetic energy between systems on the particle level. In the Computational Quantum Matter Lab headed by Dr. Joaquin Drut, we aim to study such systems from first principles, assisted by computers to carry out calculations that could otherwise be done by hand if allotted enough time.

One way to approach such a problem is to start by understanding the dynamics of a few interacting quantum particles, then using what we learn to generalize to larger systems. This is where I have focused my efforts over the past year. In particular, I am working to compute the energy of few-body systems of spin-1/2 fermions that interact via a short-range contact interaction. Once found, we tune the parameters of the model via a process called renormalization to match the physical regime in which the particles are just about to bind together, referred to as the unitary limit.

So far, this problem is only exactly solvable for one spin-up and one spin-down fermion, called the 1+1 problem. To address the N+M problem, with N spin-up and M spin-down fermions, one must get crafty with their approach. Such calculations are usually done by exploiting a small parameter (perturbation theory) or by associating each particle with an excitation of some underlying continuous field (quantum field theory). Under the guidance of Dr. Drut, I set out to explore a new technique called **Eigenvector Continuation** (EC) that has surfaced in the nuclear structure community over the past couple years. In that area, the few- to many-body problem is the whole challenge: all nuclei are made out of strongly interacting protons and neutrons.

In short, the EC method involves solving the easier problem of weakly interacting fermions for various coupling strengths, then using the resulting “directions” of the vectors that represent the state of the system to infer where to look for the solution of the harder problem of strongly interacting fermions (see figure below). It turns out that using only a few such “directions” leads to remarkable agreement with exact solutions (where available). The explanation for why EC works has to do with a concept called analytic continuation, which is notoriously responsible for slightly imprecise statements such as 1+2+3+… = -1/12.

The actual implementation of EC for a few-body problem can be done in many ways, usually entirely numerically. This project aims at a largely analytic implementation, with numerical evaluation at the very end. For that purpose, I have broken up the problem into algebraically tractable pieces, whose derivation can be automated as it consists of algebra manipulation and Gaussian integrals. That is currently the focus of my efforts, to obtain both the states and energies of the system at various coupling strengths, which are then fed into the EC algorithm. Results from this process are expected by the end of the year, and will be analyzed in collaboration with Dr. Tom Dooling at the University of NC at Pembroke.

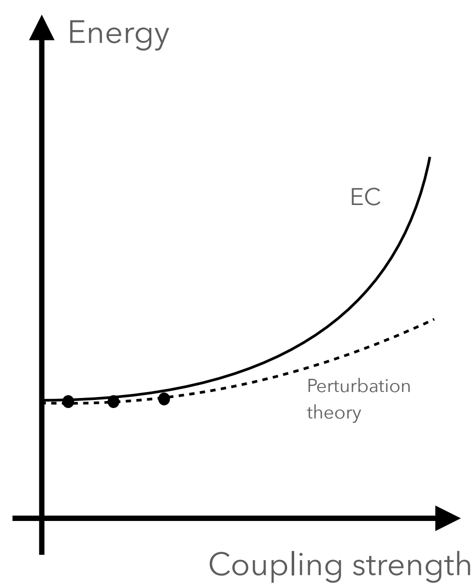
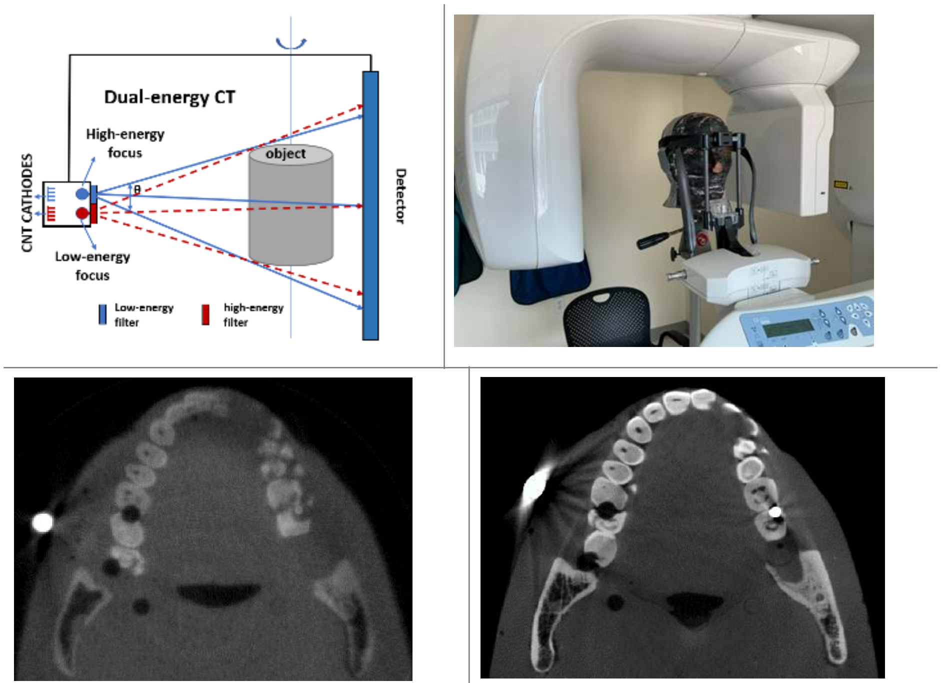



*Illustration of the eigenvector continuation method. A few samples are taken at weak coupling, using other approaches, that are then re-used to solve the strongly coupled problem.*

## Toward low-cost computed tomography. By Alan Li

Since Hounsfield took the first Computed Tomography (CT) scan 50 years ago, much research has been done on CT and many variations of CT have emerged. Cone-beam computed tomography (CBCT) has become a widely used imaging technique in dentistry and a growing area of medical imaging. CBCT can provide three-dimensional information, rather than the two-dimensional information provided by conventional X-ray radiography while having a lower radiation dose compared to other CT exams.

However, the presence of strong metal artifacts is a major concern of using CBCT, especially in dentistry because of the common presence of highly attenuating dental restorations, fixed appliances, and implants. These metal artifacts appear as dark streaks across images and thus degrade the image quality. Virtual monoenergetic images (VMIs) synthesized from dual-energy CT (DECT) scans are known to reduce metal artifacts. Diagnostic x-ray beams are usually generated from a spectrum of energy. DECT is a CT technique that uses two separate x-ray energy spectra. VMIs are synthesized from the two scans generated from two x-ray energy spectra, to simulate images taken with a single energy x-ray beam. Although several techniques exist for DECT, they all come with a significantly increased equipment cost which is not suitable for dental use.




***Top left**: A drawing illustrating the proposed DE-CBCT; **Top right**: A clinical CBCT scanner (Carestream CS9300); **Bottom left**: VMI at 140keV; **Bottom right**: image from clinical scanner*

One major objective of the research I'm doing with Dr. Zhou's lab is to develop a low-cost dual-energy CBCT (DE-CBCT). We aim to achieve this by retrofitting a regular CBCT scanner with a carbon nanotube X-ray source with dual focal spots and using filters to produce two x-ray spectra. Although this approach has the benefit of reduced equipment cost to achieve DECT, it has the disadvantage of reduced energy separation between the two x-ray energy spectra and decreased dose efficiency. It has been shown in the past that larger energy separation between the spectra produces better metal artifact reduction. Therefore, we have been designing set-ups to mitigate these disadvantages and evaluate the feasibility of this idea.

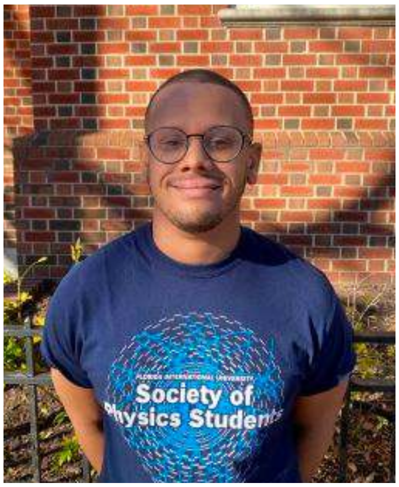
We have imaged a head phantom with a metal bead at the two x-ray energy spectra using two filters at 120kVp. Two sets of projection images were reconstructed separately using an iterative volumetric CT reconstruction algorithm. VMIs were synthesized from them using the image-domain basis decomposition method and showed significantly fewer metal artifacts at high virtual energies. The required X-ray output was achieved. We have written a manuscript that is under review and the abstract has been selected for poster presentation at a national imaging conference next year.

We are currently building a prototype device with similar setup to simulate a carbon nanotube source array to battle against the limitations of CBCT.

The Department of Physics has collaborated with Adams School of Dentistry on these projects. These projects are supported by NIH and NC Biotech.

# Two NSF Graduate Fellows and a DOE Awardee

## Joseph Moscoso




I am a second-year graduate student specializing in nuclear astrophysics and the recipient of an NSF Graduate Research Fellowship. My work focuses on understanding the nuclear processes that occur during stellar evolution and generate the vibrant universe observed today. Thermonuclear reaction rates are the key to understanding the role of nuclear reactions in stellar evolution and we investigate these reaction rates both in the laboratory and through large-scale simulations of nucleosynthesis.  At the Triangle Universities Nuclear Laboratory (TUNL), I work in the Laboratory for Experimental Nuclear Astrophysics (LENA), a world-class facility for experimentation on nuclear reactions where measurements are taken at unprecedented precision. Specifically, I will be using proton beams to shed light on the unexplained elemental abundance correlations observed in globular clusters, collections of stars in the galactic halo that form very early in galactic evolution. For this, we are developing an ion implantation system to create targets for nuclear fusion experiments created possible with the world's highest beam intensity at LENA. In Tandem, we use Bayesian methods to calculate thermonuclear reactions rate with Monte Carlo sampling, using these rates in large-scale nucleosynthesis simulations. These simulations can enlighten us on how individual nuclear reactions affect observed abundances. In addition to my research, I serve as senator of the Physics & Astronomy Department in the Graduate Student and Professional Government.

## Taylor Stevenson

I am a third-year graduate student in the Astrophysical Fluid Dynamics Lab and the recipient of an NSF Graduate Research Fellowship. My work seeks clarity on the origin of the r-process elements, some of the heaviest metals in our universe. Binary neutron star mergers could be a source of r-process elements; however, within old stellar populations, r-process abundances vary greatly. Numerical models predict that ejecta will have different chemical compositions depending on their direction of ejection, and so the presence of imperfect mixing in observed abundance patterns suggests two separate scenarios. The neutron star ejecta could enrich the surrounding ISM with these abundances before it can fully mix, leading to chemical asymmetry, *or* these light and heavy r-process elements stem from different sources. Developing magnetohydrodynamical models of ejecta mixing can

discern between these two scenarios. My first step was completing a Bhatnagar-Gross-Krook solver to handle the problem's near-vacuum conditions with high physical fidelity. Currently I am expanding the hydrodynamics code Athena++ to include multiple fluids. The resultant code will provide predictions for kilonovae mixing and nucleosynthesis, the evolution of r-process abundances, and their influence on stellar populations. Knowledge about the origin of heavy elements is knowledge about our own origin, and our place in the universe.

# Morgan Clark

I have been named an outstanding graduate student by the DOE Office of Science Graduate Student Research Program (SCGSR). SCGSR awardees spend 3 to 12 months at a DOE National Laboratory working closely with experts at world-class facilities on research projects that address scientific challenges central to the Office of Science's six research programs. The program enables students to conduct part of their dissertation research while providing access to the expertise, resources, and capabilities available at the DOE laboratories and facilities.

I have been working with John Wilkerson as part of the Experimental Nuclear and Astro-particle Physics group at UNC since 2018 which plays a leading role in both the Majorana Demonstrator and LEGEND experiments searching for neutrinoless double-beta decay in $^{76}$Ge. If found, neutrinoless double-beta decay would confirm that lepton number is not conserved, provide important information about the mass of the neutrino, and could give additional insight into the matter-anti-matter asymmetry in the universe. The Large Enriched Germanium Experiment for Neutrinoless double-beta Decay (LEGEND), is a tonne-scale experiment consisting of two phases. The first, LEGEND-200, will deploy ~200-kg of $^{76}$Ge detectors in existing infrastructure at Gran Sasso National Laboratory in Gran Sasso, Italy. I will spend 6 months at Oak Ridge National Laboratory (ORNL) studying the detectors manufactured by ORTEC in Oak Ridge, TN for LEGEND. These detectors will be in the novel Inverted Coaxial Point Contact (ICPC) geometry which was developed by David Radford at ORNL to increase the mass of the detectors used in the experiment without sacrificing their excellent pulse shape discrimination capabilities or energy resolution. The goal of this project is to determine the important parameters of the detectors fabricated by ORTEC and fully characterize each one before the detectors are installed in LEGEND-200, the first phase of the LEGEND experiment. Understanding the performance of each detector is vital to the success of LEGEND.

**NSF and DOE fellowships a**re 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.

# Diversifying Departmental Diversity Work

By Sheila Kannappan
**Associate Chair for Diversity and Mentoring**

Pandemic times have highlighted many diversity, equity, and inclusion (DEI) challenges, including disparate impacts on people of color, increased gender violence, strain on international and low-income students, and animosity toward people of Asian descent. The Physics & Astronomy Department Diversity Committee has expanded its membership and its mission over the last year and a half to address these challenges.

Early in the pandemic, we interviewed multiple international students and postdocs and appointed an international diversity liaison to identify and address concerns and improve communication. Then, in the wake of multiple police killings of unarmed Black people in summer 2020, many in the department became energized to engage with racial and social justice issues. The Diversity Committee sought to channel that energy by holding an open house that summer, inviting the whole department to join in our efforts and/or propose new efforts. An outgrowth of that meeting was the new PHYSAST-DIVERSITY Slack space, open to all in the department, which currently has 79 members and 11 projects with dedicated channels. Anyone in the department could become a member of the Diversity Committee "extended family."

One exciting result, a year in the making, is our new Grad-to-Undergrad (G2U) mentoring program for underrepresented racial minorities. Initiated by graduate student Zack Hall and inspired by the American Physical Society TEAM-UP report, the G2U program launched in fall 2021 with two active mentoring groups bringing together five graduate student mentors and five undergraduate mentees between them. G2U is supported by ten faculty advisors and graduate student coordinators, who contribute to a larger community interacting with mentees via social gatherings, study halls, and professional development workshops. The G2U program complements other new mentoring efforts, including the launch of Graduate Achievement through Mentorship (GrAM), started by AM-WISE in fall 2020, and the revamp of our faculty mentoring program in academic year 2020-2021 to provide broader and more consistent mentoring options for all faculty at all levels.

We have also sought to address sexual harassment in multiple ways. Training in university Title IX policies, already mandatory for faculty, is now a required part of the first-year graduate student seminar. We regularly invite the Gender Violence Service Coordinators (GVSCs) to hold confidential meetings with our undergraduate and graduate students and give us aggregate feedback. This process led to a campaign to provide HAVEN (Helping Advocates for Ending Violence Now) training for all faculty, and after several in-house trainings, we can report that 75% of Physics & Astronomy faculty members have been exposed to HAVEN best practices

*Mentors, mentees, and organizers in the new G2U program* for supporting survivors of harassment or violence.

A new project of the Diversity Committee, bridging concerns about sexual and racial harassment, is developing a custom Bystander Intervention workshop to empower students and faculty to go beyond supporting survivors to actually preventing harassment. All members of the 2020-2021 Diversity Committee participated in trainings at ***http://ihollaback.org*** (with varying themes, including prevention of workplace harassment, street harassment, and harassment of Asians/Asian Americans). This team is now actively working on a custom training for Physics & Astronomy, also drawing on training materials generously shared by MIT and Yale.

Another in-house effort, the brainchild of undergraduate Xiao-Ming Porter, was designing an LGBTQ Allyship in the Classroom workshop for Physics & Astronomy faculty and graduate student TAs. A team of undergraduate and graduate students, staff, and faculty worked together to make the workshop shorter and more relevant than standard trainings. In January 2021, 17 faculty members and 11 TAs attended the new workshop in time to incorporate the suggestions in spring classes. As then-Chair Christian Iliadis wrote to the department, "I was stunned by how much I learned. The workshop will make you self-aware, question some of your basic assumptions, and help you improve the atmosphere in your classes." The workshop was offered again in August 2021 for 5 more faculty members and 10 more TAs, including some from Math.

An ongoing initiative to improve classroom teaching is being led by undergraduate Melissa Kissling, who launched a new series of one-page bulletins on "Diversity, Equity & Inclusion in Teaching Physics" with the help of other students and faculty. Emailed to the whole department and posted online at ***https://go.unc.edu/uncpa-dei-bulletin***, (see QR code below) these bulletins are handy quick references with topics such as "Low-Cost Course Planning," "Imposter Syndrome," and "Pronouns" (dovetailing with the LGBTQ Allyship workshop). The next bulletin will be on "Microaffirmations," an antidote to microaggressions.

Beyond the classroom, the Diversity Committee welcomed the opportunity to collaborate with Professor Laurie McNeil on implementing the recommendations of the APS/AAPT report "Phys21: Preparing Physics Students for 21st Century Careers," which she co-authored. With input from many students and faculty, Dr. McNeil assembled a database of current employment information for over 200 graduates and former postdocs of the department (send her your info at mcneil@physics.unc.edu). In April 2021 she organized a well-attended panel discussion on careers in manufacturing, featuring alumni now at Intel, Ionbond, and TechFit. She plans to work with students to plan and advertise more panel discussions (for example, on data science, biomedical technology, finance, and/or K-12 education) and to create flyers explaining how students can prepare for various career sectors. We are excited that Dr. McNeil has now been named Director of Career and Professional Development for the department, recognizing that her efforts go way beyond the Diversity Committee in impact.

To celebrate our achievements, staff diversity liaison Jhon Cimmino has led the charge in putting diversity front and center on the department webpage and in department communications, working with students to diversify the images and news stories on our website and promoting allyship trainings in the department's calendar. He created the Ally Spotlight series, first interviewing Graduate Affairs Coordinator Maggie Jensen (who has completed Mental Health First Aid, HAVEN, SafeZone, Greenzone, Carolina Firsts, and UndocuCarolina trainings, making her a superhero ally) and more recently new Diversity Committee faculty Joaquin Drut (watch for this to be released soon).

The Diversity Committee is excited to keep expanding departmental involvement. We recently held another department-wide gathering in which participants stressed the need for more support for mental health, social engagement, and reducing work pressure. Contact us to learn more or to join in!

# THE SHOP PAGE

Whether you are hunting for exoplanets, searching for the origin of the elements, or disentangling neutrino signals from background noise, you are probably building your own detectors from the ground up, and for that you need help from expert machinists and instrument makers. Thankfully, our Department has its own machine shop, which is in fact the only machine shop on campus. From Phillips Hall 115, Phil Thompson and his crew (William Harris, David Norris, and Cliff Tysor) offer complete professional instrument construction through a variety of services including CNC (programming, turning, milling), manual and electric-discharge machining, welding, sheet metal fabrication, and plastic fabrication. The team machines essential parts for world-class research in multiple areas such as time-domain astronomy (Nick Law's Evryscope), nuclear astrophysics (Christian Iliadis' LENA device), and neutrino detection (John Wilkerson's Majorana experiment).

# STAFF NOTES

## Service awards

These awards are given to faculty and staff for years of service to the University and the Department.

**30 years**

Art Champagne
Louise Dolan
Sean Washburn
Yue Wu

**25 years**

Christian Iliadis
Phil Thomson
Frank Tsui
Otto Zhou

**15 years**

Shane Brogan
David Hill
Cassandra Houston
Laura Mersini-Houghton
Paige Tingen

**10 years**

Josh Haislip
Stefan Jeglinski
David Norris

**5 years**

Jeremy Cribb

## New staff member

**Shannon Rossi**

Grant and Research Coordinator

I grew up and went to school in Albany, NY but moved to Chapel Hill at the end of January 2021, upon accepting a position with UNC. I moved with my partner Elijah and Border Collie Pup, Asher. I have a financial background working for University at Albany prior to this and Ayco, A Goldman Sachs Company prior to U. Albany. I also teach yoga part time. Although I started with UNC working fully remote, the energy and inclusiveness from my colleagues made my transition very easy. I look forward to meeting more people along the way and learning what's in store for the future!

# The Awards

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.

### Paul E. Shearin Outstanding Senior Award
**2021**
Kate Richardson
Max Kremer

### Daniel C. Johnson Memorial Award
**2021**
Alexander Stewart
Zelong Yin

### Robert N. Shelton Outstanding Research Award
**2021**
Dylan Owens

### Outstanding Graduate Teaching Assistant Award
**2021**
Britta Gorman
Mugdha Polimera

### Outstanding Undergraduate Teaching Assistant Award
**2021**
Henry Nachman

**Graduate program 2020 (continued from previous issue)**

**Ph. D.**

R. Isaac
C. Munna
J. E. Olander

**M.S.**

A. Glazier
M. E. Kern

**Graduate program 2021**

**Ph. D.**

Y. An
T. Dombrowski
C. M. Hobson
W. S. Howard
C. Moakler

**M.S.**

N. J. Bryden
D. Dutton
N. W. Galliher
D. A. Hervas Aguilar
J. J. Marincel
K. Morrell
S. Song

**Undergraduate program 2020 (continued from previous issue)**

**B.S.**

L. T. Fox
M. Nik Akhtar
M. A. Pack
G. Shi

**B.A.**

J. B. Andrews

**Undergraduate program 2021**

**B.S.**

A. R. Alberti
O. V. Apte
M. C. Brockmann
E. R. Castelloe
M. Elliott
E. Fenwick
K. S. Kempthorn
K. Leung
M. Lightfoot
D. A. Owens
K. A. Richardson
E. Wilson
A. C. Wood III
K. Yang
K. Yu

**B.A.**

L. T. Black
M. Chen
A. T. Cuomo
I. B. G. Ford
L. T. Fox
S. P. Galvin
J. C. Garside
V. Grover
H. L.-J. Head
E. L. Hornback
K. S. Kempthorn
P. H. Kozlowski
A. Mcentarffer
M. C. Pasca
D. M. Schimtzek
L. E. Scott
J. P. Snyder
W. G. Tyler
D. A. Wollensak

**Nick Law** is one of the recipients of the prestigious **Hettleman Prize for Artistic & Scholarly Achievement by Young Faculty**. The late Phillip Hettleman, a member of the Carolina class of 1921, and his wife Ruth, established the award in 1986 to recognize the achievements of outstanding junior faculty. The recipients of the $5,000 prize are recognized during the Faculty Council Meeting. This year, four promising faculty members who exemplify groundbreaking and innovative research along with future career promise received the award. Law is an experimental astrophysicist who works on building new astronomical instruments and uses them to search for and understand new astronomical phenomena. His research group is currently focused on ongoing science programs with the Evryscopes, the first all-sky gigapixel-scale telescopes.

**Laurie McNeil** is one of twelve APS members selected as **Five Sigma Physicist** awardees for their outstanding advocacy work that included taking multiple actions during the past year and maintaining communication with APS Government Affairs staff. This year's awardees participated in various initiatives centered on contacting Congress and the Executive Branch to help advance APS's science policy priorities, including: ensuring the US scientific enterprise fully recovers from the pandemic, supporting visa and immigration policies that attract and retain talented international students to the US, addressing the helium crisis, and ending sexual harassment in STEM. Laurie is being recognized for her many actions throughout the year including sending a letter to congress supporting international students who faced having their F-1 visas revoked if they did not take in person classes during the pandemic. "The benefit from our communal effort far outweighs the very minor cost in time, especially since APS staff provide everything one needs to communicate effectively," McNeil said.

**Robert V.F. Janssens** is the new **Director of the Triangle Universities Nuclear Laboratory (TUNL)**, which is one of the U.S. Department of Energy's Centers of Excellence. Prof. Janssens joined the Department of Physics and Astronomy in 2017. Prior to coming to UNC, he spent his entire career within the Physics Division at Argonne National Laboratory, and served as its director from 2008 until 2017. He now is the Edward G. Bilpuch Distinguished Professor at UNC. He is a Fellow of the American Physical Society (APS) and served as the Chair of the Division of Nuclear Physics in 2019-2020. Since coming to Carolina, he has helped establish a research program in nuclear structure combining experiments at TUNL's High Intensity Gamma-ray Source (HIGS) with measurements carried out at national and international accelerator facilities. His research interest is in the evolution of nuclear structure with the number of protons and neutrons and the impact this has on global nuclear properties such as the nuclear shape, the binding energy, radioactivity and nuclear astrophysics processes. Professor Janssens becomes the seventh Director of TUNL and is the second director with a primary faculty appointment at UNC.

**Amy Nicholson** has been awarded a **National Science Foundation CAREER Award** to support her research in search for physics beyond the standard model. These 5-year awards support junior faculty who exemplify the role of teacher-scholars through research and education. While the Standard Model (SM) of particle physics stands as one of our most well-tested physical theories, it is expected to break down under certain conditions, and unexplained observational evidence and theoretical puzzles call for understanding of physics beyond the SM. Where and how this new physics originates are some of the biggest outstanding problems of physics; therefore testing the limits of the SM is a primary goal of many high-profile experimental programs in nuclear physics. Nicholson's research involves calculations supporting these high-impact nuclear experiments, utilizing some of the largest supercomputing facilities worldwide.

**Dan Reichart** has been selected to receive a **$3M grant from the Department of Defense's National Defense Education Program (NDEP)**. Reichart directs "Skynet", which is a globally distributed network of fully automated, or robotic, telescopes, developed by his team at UNC-Chapel Hill. Skynet currently numbers approximately twenty visible-light telescopes, spanning four continents and five countries, and one significantly larger radio telescope (pictured) at Green Bank Observatory in West Virginia. Skynet is used by hundreds of professional astronomers, who publish Skynet-collected data in peer-reviewed journals every approximately twenty days. But it has also been used by approximately 40,000 students, of all ages. This includes over 2,000 survey-level undergraduate students per year from nearly two dozen institutions across the US and Canada, who are using a curriculum called "Our Place In Space!", or OPIS!. OPIS! was originally developed by Reichart for UNC-Chapel Hill's ASTR 101 labs. It is now being adopted on a national scale, funded by over $2M from the National Science Foundation. The Department of Defense (DoD) has now decided to fund a $3M expansion of Skynet, paired with the development of a follow-on curriculum to OPIS!. Skynet will now integrate up to eight more radio telescopes into Skynet. These telescopes are located in the western mountains of North Carolina, Puerto Rico, and at two sites in Australia. They are comparable in size to Skynet's 6-story, 150-ton, radio telescope in West Virginia. Radio telescopes look like giant satellite dishes, and are used to study the invisible universe. They are expensive to build, and are located in remote, radio-quite locations, so it is rare for students to gain access to them. That said, this effort will fund approximately thirty educators to develop eight new observing experiences, collectively called "Astrophotography of the Multi-Wavelength Universe!". These observing experience will use both Skynet's visible-light telescopes and Skynet's new radio telescopes to explore stars and galaxies, and to study light-emitting mechanisms. This curriculum will be integrated into second-semester, but still introductory, astronomy courses at OPIS!-adopting colleges and universities across the nation. Skynet will also be working with Geneva Lake Astrophysics and STEAM (GLAS), to make these curricula and observing experiences accessible for deaf/hard-of-hearing and low-vision students.

# Learning physics together - the tie that binds for 50 years

By Andy Stanley and Tom Clegg

***Top:** Faculty and students attending 35-yr reunion (2006). (l-r) Front Row: Milton McNatt, Robert Reiman. 2nd row: Lewis Leinenweber, Rick Matthews, Paul Woodard, Stewart Crumpler, Andy Stanley, John Fredricks, Roger Peele. 3rd Row: John Roberts, with faculty, Steve Shafroth, Wayne Bowers, Larry Rowan, Everett Palmatier, Morris Davis. 4th row: l-r: Vic Briscoe, Dietrich Schroeer, Sang-il Choi, Tom Clegg, Eugen Merzbacher. **Bottom:** Faculty and Students attending 50-yr reunion (2021). (l-r) Front Row: Tom Clegg, Andy Stanley, Paul Woodard, Bob Gorlow. Middle row: Frank Tsui, Roger Peele, Lewis Leinenweber. Back row: Robert Reiman, Milton McNatt, Rick Matthews, Stuart Crumpler.*

Undergraduates commonly build close lifetime friendships with classmates. Faculty also befriend some students and occasionally stay in touch with them for many years. But the BS physics Class of 1971 is highly unusual. For 50 years they maintained such enduring contacts, both among themselves and with their former professors. Nine of their original 12 returned to campus this month for their 4th such reunion gathering at 5-year intervals since 2001.

Two of them, John Fredricks and John Roberts, were the driving force behind these enduring events. On each occasion, classmates invited their former physics teachers to join them for a reunion dinner at the Carolina Club in the Hill Alumni Center. Spouses were invited too. Old friendships were refreshed, stories were told, and new, lasting memories were enabled by many photos taken. Who are these graduates? What subsequent careers followed their physics training at Carolina?

The selective service draft and likely military service were important considerations for students 50 years ago. In addition, many physics advances since then have potential military applications. Thus, several in the class have military backgrounds.

The Navy provided John Fredricks an opportunity to pursue his BS in Physics at UNC. After graduating, he specialized in telecommunications, both while a career Naval officer and later as a civilian. Milton McNatt predicted, while on active duty with the Army, the effects of nuclear weapons on the survivability of Army systems, work he later continued as a civilian physicist for the Naval Weapons Laboratory. Andy Stanley performed similar work on internal electromagnetic pulse damage to space and missile systems caused by nuclear weapons detonation, first at the Air Force Weapons Laboratory while serving on active duty with the Air Force. Later as a civilian with the Department of the Army, he participated in an underground nuclear detonation at the Nevada Test Site to evaluate these effects on several specific military systems.

Andy, Roger Peele, and Paul Woodard had all been undergraduate Air Force ROTC cadets at UNC. Upon graduation, Roger entered active duty as an Air Force navigator, while Paul spent his time in the Air Force in computer systems operations. Lewis Leinenweber went into the Naval Nuclear Power Program as a Naval officer and served on nuclear submarines. After leaving the Navy he worked in the defense industry supporting nuclear submarine systems and geospatial technology software and standards.

Eleven of these 12 BS physics class members received advanced degrees that assisted their careers. Lewis Leinenweber received an MS Degree in Computer Science while Milton McNatt earned his MS in Systems Engineering. Rick Matthews remained at UNC to receive his physics Ph.D. and joined the physics faculty at Wake Forest University, where he eventually became the Department Chair and Associate Provost.

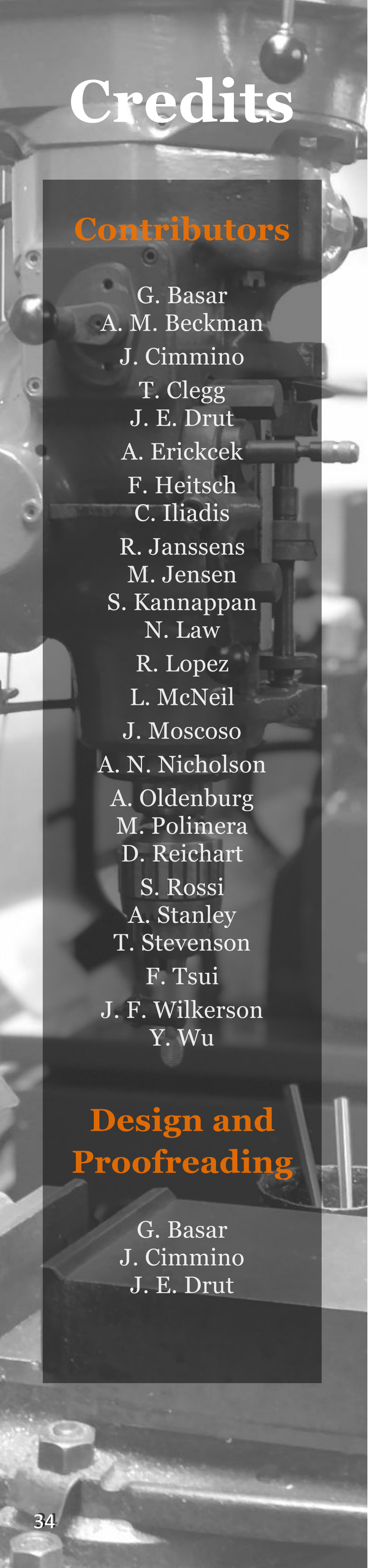
Paul Woodard, Robert Reiman, Andy Stanley, and Stewart Crumpler participated in a cooperative venture between UNC's School of Public Health and the NC State's Department of Physics, receiving MS degrees in Radiological Hygiene and Physics. Paul and Robert then entered medical school. Paul became an anesthesiologist, spending 30 years in private practice while also serving as an adjunct professor in the UNC-G School of Nursing and Medical Director/ Board President for the Raleigh School of Nurse Anesthesia. Since retiring, he has served as a general practitioner in a clinic for the uninsured. Robert specialized in internal and nuclear medicine. He currently teaches at Duke University and is Associate Director of Duke's Radiation Safety Division. Andy studied the deleterious effects of inhaled radioactive materials at the Inhalation Toxicology Research Institute (ITRI). Shortly afterwards, serendipity acted to bring Roger Peele and Andy together again, when Roger accepted a position as an aerosol physicist at ITRI.

Stewart Crumpler spent 43 years in quality assurance and regulatory affairs, first as a commissioned officer in the US Public Health Service and later as a pharmaceutical company executive. His experience included both enforcement of safety regulations for radiation-producing products and software control of medical devices, including co-authoring a book on global medical device regulatory strategy. Helen Roxlo Delp, who held the distinction of being the only woman in the class, earned an MS degree in Electrical Engineering and pursued a career in color research, first with Dupont and later with IBM. Her work on color management software helped provide the capability to display accurate color images on computer monitors.

Several class members gained degrees and/or experience in non-science related fields. Bob Gorlow pursued a career in architecture. John Roberts earned a Master's in Business Administration and spent 22 years developing Wendy's franchises. Andy Stanley earned a law degree and practiced law for 7 years. Later, as a consultant to the Department of Energy, he combined his technical and legal backgrounds to participate in the opening of the Waste Isolation Pilot Plant in New Mexico for disposal of defense nuclear waste and to support work on Nevada's Yucca Mountain Project for disposal of commercial nuclear waste. Roger Peele became an FBI agent and ended up at the FBI Crime Lab working in forensic analyses.

Throughout all of the various career paths taken by class members, their undergraduate physics training received at UNC has been the key to success. For some it provided the tools they needed to move directly into their chosen fields. For others, it provided a stepping stone to further technical education. Even for those who did not pursue technical careers, their physics training provided analytical skills that helped them succeed.

Finally, the class owes their professors a debt of gratitude for providing the solid physics and analytical training that enabled this wide variety of careers. The number of their former teachers has steadily declined, with only three remaining and only one of those healthy enough to attend this year's reunion. Classmates John Fredricks and John Roberts have also both passed away and are sorely missed. As they met with each other at this month's reunion, they reflected with satisfaction on their long friendships with both classmates and professors that have remained in place for 50 years, and celebrated the lives of those no longer here.



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# Q&A with Frank Tsui

*In this Q&A section of the Magazine, our new Department Chair reflects on his new role and the state of our Department.*

**How are you adjusting to your new position? Is there anything in particular that surprised you when you first started?**
**Frank Tsui:** Being a new chair during a pandemic is no business as usual, but thanks to my predecessor, Prof. Iliadis, who put together a "user's manual" for me, the transition was quite smooth. As for surprises, there were some. For example, less than 3 weeks before the first day of classes of the fall semester, the administration informed me that we were experiencing unexpectedly high demand for our introductory courses, and we were asked to increase the number of seats for these courses substantially. We discovered then that enrollment in some of our courses was already maxed out, in some cases 200% over previous records. Our leadership team sprang into action, assembling and implementing a plan, which involved numerous logistic challenges. The plan worked. The record-high demand was met. Our efforts were deemed "heroic" by the administration. However, the real heroes are those who are teaching those large courses, enabling students to experience in-person learning at Carolina for the first time. We are resilient thanks largely to our "frontline" colleagues who are directly impacted by the record high enrollments. We are grateful that they are the face of the Department.

**What do you see as the challenges for our Department looking forward? What are the most pressing matters we face?**
**FT**: Lack of resources, particularly those stemming from state budgetary constraints, repeated budget cuts, continue to be the biggest challenges for us, especially in the face of rising demand of our teaching, research, and service needs. Increasing interests in STEM fields put increasing stress on our teaching capacity and instructional budget to adequately staff the courses based on sound pedagogical requirements and best practices. We desperately need resources to upgrade and modernize our teaching labs, where the experimental apparatuses are deteriorating and becoming obsolete in the nascent age of quantum information. We urgently need to update inadequate, dilapidated research infrastructures. One of our colleagues is building a groundbreaking instrument in need of lab space, but the only space available was one without air conditioning, sufficient lighting, or even a door lock. We need substantial endowment funds to recruit and retain world-class faculty, as well as scholarships and fellowships to recruit a diverse and talented pool of students. Last Fall, we underwent a decadal external review. The committee of renowned experts concluded that "the Department is 'hitting above its weight', doing a great job in science, education, and service at all levels." We aspire to step up to the next "weight class" in excellence. In the absence of massive increase in state funded investments, we must raise funds elsewhere to support this goal.

**How can we help you?**
**FT**: We are all in this together. Our collective strength and talent are far greater than the sum of our individual's. So, get involved, participate, and contribute … do all you can do. The pursuit of our mission is not a spectator sport, and you may need to go outside of your comfort zone to help out where it's needed. I was pleasantly surprised that we have supporters who have been making annual contributions year after year and over time such pledges have turned into something quite substantial. I salute these and other generous efforts.

# JOIN US!

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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.

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***Background***: *A look inside the NuDot experiment.*
***Image credit***: *Julieta Gruszko*
*Find out more at jgruszko.web.unc.edu*

**Thank you!**

**UNC CHAPEL HILL**

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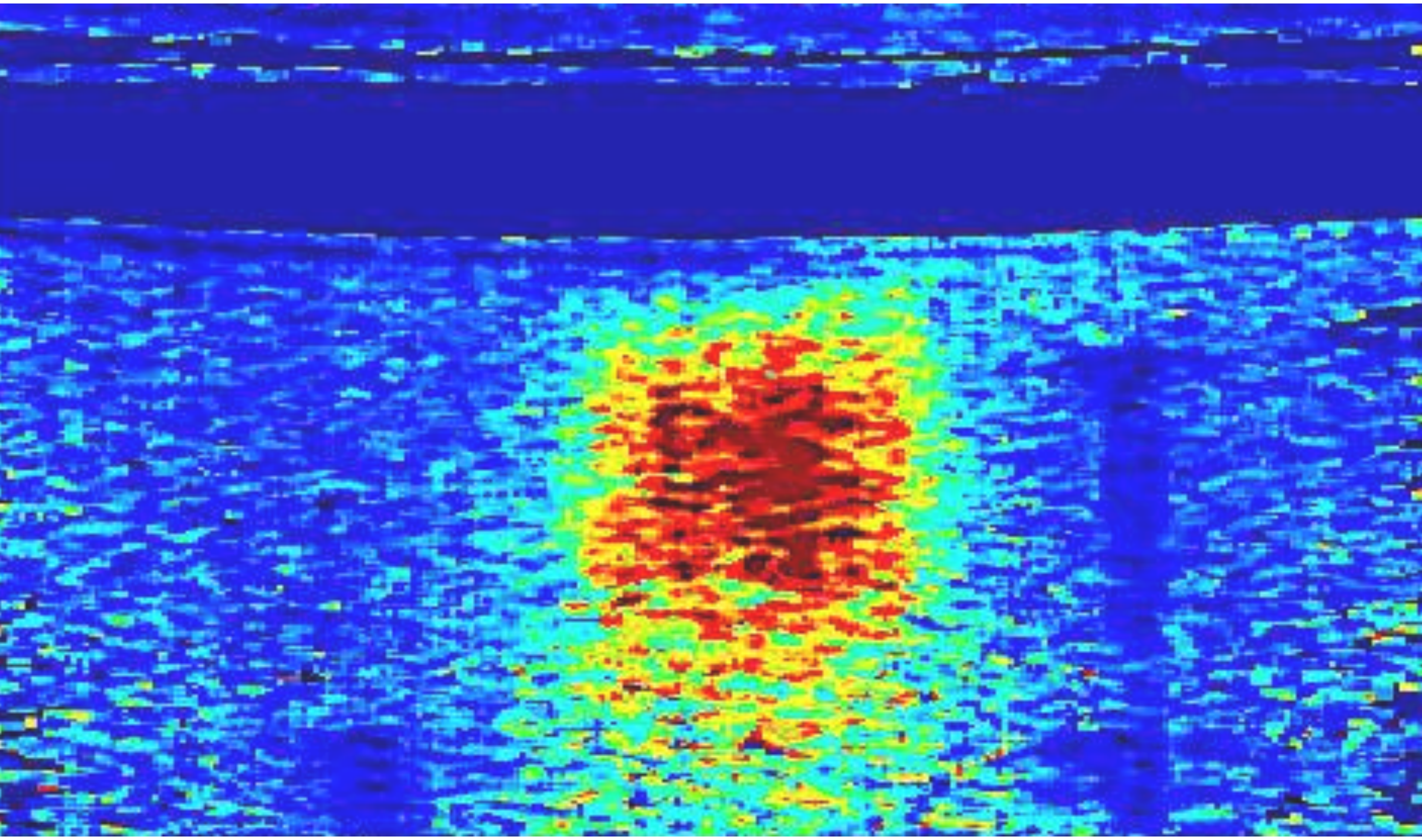

*Magnetomotive ultrasound image showing the contrasted of magnetically-induced motion coupled into an echogenic gel. See article inside:* **Magnetic Fields and Ultrasound Waves: a New Biomedical Imaging Modality***, by Amy Oldenburg*.

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