Department of
PHYSICS *and* ASTRONOMY

UNC COLLEGE OF ARTS & SCIENCES

THE UNIVERSITY OF NORTH CAROLINA AT CHAPEL HILL

FALL 2017

GRAVITATIONAL WAVE ASTROPHYSICS

Aaron Zimmerman (CITA) gave an invited talk summarizing the status of Advanced LIGO and other ground-based gravitational wave detectors at the 20th Capra Meeting on Radiation Reaction in General Relativity in Chapel Hill on 19 June 2017.

The year 2015 marked the advent of gravitational wave astronomy, with detection of the event GW150914 by the US LIGO project signaling the merger of two heavy black holes (36 and 29 solar masses). Since then, two other confirmed black hole mergers have been detected, and LIGO (the Laser Interferometer Gravitational-Wave Observatory) has discovered a previously unexpected class of heavy stellar-mass black holes.

This year, LIGO operated until September in its second observing run, O2. Its twin detectors were joined on August 1, 2017, by the single European Virgo detector, located in Cascina, Italy. The ensemble of three detectors increases system sensitivity and improves the ability to localize sources on the sky. In future years, LIGO and Virgo will be joined by KAGRA (the Kamioka Gravitational Wave Detector) in Japan and LIGO-India. With the last published detection having occurred in January, we await word on what LIGO, and now Virgo, have discovered in the past nine months.

In related news, the European Space Agency announced in June that they will proceed with the LISA (Laser Interferometer Space Antenna) mission. To be launched after 2030, LISA will consist of three spacecraft separated by 2.5 million kilometers in a triangular formation in solar orbit. The approval of LISA follows the highly successful LISA Pathfinder mission, which demonstrated the ability to shelter the optical elements of LISA and keep non-gravitational accelerations on them to below a femto-g (10-15 gravity).

LISA is designed to detect gravitational wave events in the 0.1 mHz to 1 Hz range.

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New Introductory Physics Courses

All four of our introductory physics courses (PHYS 114/115,118/119) are now being taught in a lecture/studio format with improved learning gains and student perception. These new courses are revised versions of PHYS 104/105, 116/117, which were taught in the more traditional lecture/lab/recitation format. The new format provides better synchronization of topics by introducing a subject in lecture and then exploring this topic in greater depth later that same day or the next day, rather than having lectures and labs separated by a week or more in the traditional mode. This lecture/studio cycle repeats with two modules held each week as shown in figure 1 on page 3.

This lecture/studio model enables the majority of student contact time to be spent in the studio environment, where students engage in a variety of active-learning strategies, such as guided-inquiry laboratory investigations and tutorial-style activities that focus on conceptual understanding of fundamental physics principles. The motivation for this new teaching format comes from Physics Education Research (PER) findings that students learn more through active engagement with a subject when

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WHAT'S INSIDE

FROM THE **CHAIR**

"What do you do for a living?" This is the question I was recently asked by somebody I had just met at a party. My response was followed by, "What is that good for?"

I have heard these questions before, and I felt well prepared to provide answers: "Apart from teaching undergraduate students, we train graduate students in basic physics and astronomy research. They acquire valuable skills that they will not obtain elsewhere: expertise in microscopic and macroscopic physics, hands-on laboratory techniques, numerical modeling, and complex problem-solving."

Christian Iliadis

At this point, people I have just met usually reply with a polite "Nice to meet you" before making a dash for the bar. But this fellow clearly had an issue with the "basic" aspect of my work, where "basic" is defined as "research without a direct application." He said, "Sure, I get that. But explain to me how the people of our great state and the nation benefit from your line of work?"

It's a fair question. It is much easier to sell applied, application-driven research than basic, curiosity-driven research. To mention a few examples from our own department, nuclear magnetic resonance imaging is an interesting application for oil exploration, and optical coherence tomography is a promising technique for medical imaging. But how does society benefit from research in neutrinos? Or exoplanets? Or gravitational waves?

I continued my conversation by mentioning olive trees. This plant holds a magical fascination for me. My parents' village in northern Greece is full of olive trees. They are beautiful to look at. The symbolism of olive trees was important for both ancient and modern societies. On the Great Seal of the United States, an eagle grasps an olive branch with 13 olives in its right talon, representing the 13 original colonies. But does the olive tree have any practical uses? Of course - the economy of many ancient societies depended on olive oil. The size of today's annual olive oil world market amounts to several billion dollars.

I mentioned olive trees because of an interesting parallel: It takes more than 10 years from planting the seed to bearing the first olives.

I continued my parable with my new friend by saying, "In the same vein, it takes time for fundamental research to bear fruit." I mentioned a few examples. Albert Einstein published the theory of relativity between 1905 and 1915. Seventy years later, GPS devices, which rely on the theory of relativity for accuracy, became available to the public. Quantum mechanical tunneling was discovered theoretically in 1927 by Friedrich Hund. It took 60 years until the invention of flash memory, which utilizes quantum tunneling. Since our smartphones rely on flash memory, quantum tunneling literally happens daily in our pockets.

"But these examples seem to be rare exceptions," was the reply from my sparring partner.

I mentioned more examples: electricity, lasers, superconductors, X-rays. All of these were discovered by basic, curiosity-driven research, without any applications on the minds of the researchers at the time of discovery. At this point, we parted ways. Thinking about the encounter the next day, I could not shake off the feeling that he was not alone in thinking that basic research is merely a hobby of university professors and of little practical use. I will continue my thoughts on this subject in the next newsletter.

Meanwhile, I hope you enjoy the current edition. It was so nice to hear back from a number of you after the last newsletter was published. Your stories, impressions, or simply a short note are always appreciated.

Best wishes,

Christian Iliadis
Chair, UNC-CH Physics & Astronomy

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It will observe sources such as galactic white dwarf binaries and more distant compact objects spiraling into the massive black holes residing in the centers of other galaxies. One such source, called an extreme-mass-ratio inspiral (EMRI), consists of a stellar mass black hole in orbit about, for example, a million solar mass black hole. Any EMRIs that LISA detects will be unique probes of general relativity, as the small black hole will orbit hundreds of thousands of times, skimming close to the event horizon of the larger hole.

Dr. Charles R. Evans' group theoretically models binary black hole mergers, especially EMRIs. With a small mass ratio, EMRIs can be calculated using black hole perturbation theory. Graduate students Zach Nasipak and Chris Munna use this technique to study inspirals into Schwarzschild and Kerr black holes. Graduate student Kyle Slinker models encounters between comparable mass black holes using numerical relativity. Past students working in these areas have included Thomas Osburn (PhD 2016, now assistant professor at Oxford College of Emory University), Erik Forseth (PhD 2016, now with Graham Capital Management), Roseanne Cheng (PhD 2012, now Metropolis Fellow at Los Alamos National Laboratory), and Seth Hopper (PhD 2011, now assistant professor at Earlham College).

Coincident with the recent gravitational wave discoveries, Evans' group, with the support of the CoSMS Institute, hosted the 20th Capra Meeting on Radiation Reaction in General Relativity during the week 19-23 June, 2017. The annual Capra meetings bring together 50 to 60 of the leading experts in the world on theoretical modeling of EMRIs and binary black holes. Recent meetings have been held in Paris, Kyoto, Caltech, and Dublin; next year's will be in Berlin. The meeting in Chapel Hill featured 33 speakers, including eight invited talks, and lengthy workshop discussion periods.

PHYSICS CORNER

COMPUTATIONAL QUANTUM MATTER: A WAY THROUGH A STATISTICAL CATASTROPHE ACROSS THE COMPLEX PLANE

By Prof. Joaquin Drut

The behavior of nuclear matter inside stars, the structure of atomic nuclei, and the electronic properties of materials may seem to have little in common. Those are, in fact, some of the central problems of modern physics, and they share the same formidable computational challenge: They are matter completely governed by the laws of quantum mechanics. Solving such problems requires computers with huge amounts of memory (scaling exponentially with the number of particles) or astronomical amounts of statistics (growing exponentially with the volume of the system). We certainly cannot afford the former — can we tame the latter?

This quantum statistical catastrophe, often called the "sign problem," has confused several communities and stalled computation for a long time. Over the last few decades, ingenious solutions were attempted on simple test models (small systems, few particles), but none survived realistic applications: the vexing statistical problem keeps reappearing as noise obliterating the calculations.

The computational quantum matter group led by Dr. Joaquín Drut is exploring new ways to address this long-standing predicament. By combining advances and insights from different areas of physics and chemistry, the group develops new computational tools and uses them to study realistic quantum matter problems.

In fact, there have recently been intriguing developments toward tackling the sign problem. As it happens, the issue can be traced back to the appearance of complex probabilities in the mathematics. By definition, a probability should be a positive real number, so most attempts tried to avoid complex numbers at all costs. The novel development is the realization that complex numbers are not a bug but an unavoidable feature. Such an approach was actually attempted a few times before, only to be later abandoned … So, what has changed?

This time around, it is not an isolated effort: there is a global community simultaneously tackling the mathematical underpinnings and solving the practical problems that appear along the way. This concerted effort has created enough momentum to push applications to high-energy, atomic (led by Dr. Drut's group), and condensed-matter physics. The back-and-forth between mathematical theory and computational experiment seems to be opening a way across the complex plane. This time around, we just might be able to unlock the long sought-after computations required to understand and predict the true complexity (pun intended) of quantum matter.

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passively receiving information from lectures. While there are many physics departments that have adopted active-learning strategies, our department at UNC-CH is one of only a few to do so for all of the introductory physics courses. As evidence of the effectiveness of these new courses, figure 2 is a graph that shows learning gains on a conceptual survey administered to students at the beginning and end of the Physics 105 and 115. Note the dramatic improvement in learning gains with the new format!

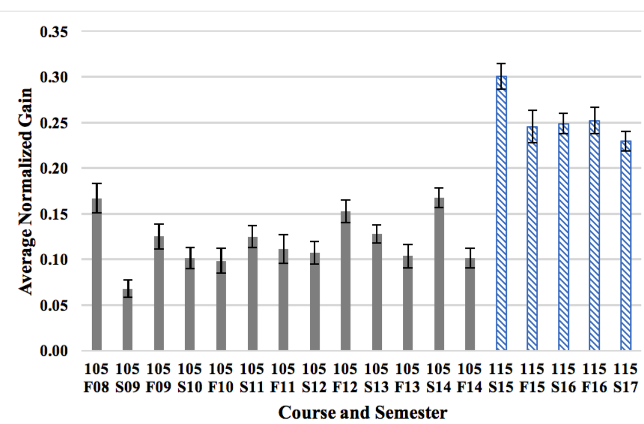
The content of all four of these introductory physics courses is also different than the previous versions. The Physics 114/115 sequence for life science majors now has a strong biological focus and includes topics such as diffusion and stress/strain. Physics 118/119 for the physical science majors includes special relativity in the first semester and quantum physics in the second semester course. These changes were made to better serve the students who are required to take these courses. Feedback from both students and instructors has been generally positive, and we plan to continue teaching these courses in their new structure for the foreseeable future.

figure 1:

Monday	Tuesday	Wednesday	Thursday	Friday
Lectures		Lectures		Q & A session (optional) or exams during Lecture time
	Studios		Studios	
Studios		Studios		

*Studios: 110 minutes each / Lectures: 50 minutes each

figure 2:



Normalized Gain for the Conceptual Survey of Electricity and Magnetism (CSEM). Physics 105 was the pre-transformed version of the course; Physics 115 is the transformed version. Gray bars are courses taught traditionally, blue bars are classes taught in Lecture/Studio mode. Error bars represent standard errors

STAFF MILESTONES

In the past six months, the department has recognized one staff member milestone:

10 YEARS OF STATE SERVICE

Beverly Loftin Department Manager (4/1/2017)

STAFF NOTES

In recent months, the department has welcomed two new staff members: Academic Affairs Coordinator Jhon Cimmino and Accounting Technician Gloria Kang.

Gloria Kang

Kang, who previously worked for the Alzheimer's Therapeutic Research Institute at the University of Southern California, has enjoyed the transition to UNC and North Carolina. Her accounting work is similar but she's working with a larger group, and the change of scenery was appealing – although she made the move in the middle of the summer heat. "It's very different here – a tad bit more humid than I'm used to," she said with a laugh. "But it's nice – very green."

Jhon Cimmino

Cimmino holds a master's degree in college student development from Appalachian State University – where he appreciated the winters, as a New York native. He spent the past year as a student success coach at High Point University. Prior to his academic advisory work, he was involved in student housing for four years. "I really like working with students, and I like this job because I stay on my feet all day," he said. "Every single day, I'm solving a different problem, and I like that flexibility. I would love to continue in higher education for my entire career."

STUDENT SPOTLIGHT

Bartram receives prize at TAUP 2017

Chelsea Bartram, a graduate student in the UNC Department of Physics and Astronomy, has received Third Prize for her poster presented at TAUP 2017 — the XV International Conference on Topics in Astroparticle and Underground Physics. The conference was held in Sudbury, ON, and awards were handed out by Nobel laureates Takaaki Kajita and Art McDonald. Chelsea's research involves searching for minuscule differences between the behavior of matter and anti-matter, specifically searching for CPT-violation in positronium decays. Her work is based at the Triangle Universities Nuclear Laboratory (TUNL) under the supervision of Prof. Reyco Henning.

Graduate Students as Teachers

Our graduate students get jobs in many different sectors, and nearly all of them benefit from their graduate teaching experience in some fashion. Before graduating, all of our PhD students are required to have at least the equivalent of a year of teaching experience, usually as a Teaching Assistant (TA) for one or more of our physics or astronomy courses. All new TAs in our department are required to take a one-credit seminar course on Teaching and Learning Physics (PHYS 510), which is taught by Dr. Alice Churukian. This course includes teaching theory and methods, along with opportunities for students to discuss and reflect on their own teaching experiences. The combination of teaching theory and practice, along with PhD coursework and research, has led to successful job offers at institutions of higher education. Here is a partial list of recent graduates and where they are teaching:

- Matthew Goodson – Hampden-Sydney College
- Josh Fuchs – Texas Lutheran University
- Brian Pohl – Wake Technical Community College
- Tommy Osborn – Emory University's Oxford College
- Ryan Tanner – Augusta University
- Courtney Hadsell – U.C. Berkeley Extension
- Haw Cheng – University of South Florida

IN THE LAB

By Prof. Tamara Branca

Temperature measurements in the body or in specific organs are not an easy task. Yet, some clinical applications, such as hyperthermia treatment of cancer, rely on accurate temperature measurements to effectively kill malignant cells. Current non-invasive tomographic imaging techniques such as nuclear magnetic resonance (NMR) can reveal changes in internal tissue temperature with an accuracy that reaches several degrees Celsius in organs and tissues outside of the brain.

A team led by Dr. Tamara Branca, an Assistant Professor in the UNC Department of Physics and Astronomy, has been using the noble gas xenon as an NMR temperature sensor to measure absolute temperature in vivo with accuracy better than a few tenths of a degree Celsius. The team combined frequency measurements of the temperature-sensitive xenon nucleus—made visible by a physical mechanism previously developed at Princeton University by Prof. William Happer, a former UNC physics undergraduate—with frequency measurements of hydrogen nuclei in lipid molecules, to extracted absolute temperature measurements.

This technique is now being used in humans to monitor the metabolism of brown fat, a fat tissue present in newborn babies and adult humans now being considered as a pharmacological target for the treatment of diabetes, thanks to its ability to regulate blood glucose level without insulin.

BLACK VANITY MIRROR MADE OF GRAPHENE

By Prof. Dmitri Khveshchenko

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

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

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

While neither supersymmetric gauge theories nor black holes are readily available in an average physics lab, some mathematically related spin-offs of the same idea have been applied to far more accessible physical systems, such as heavy-ion collisions, ultra-cold atomic gases, and even the various novel electronic materials. At the UNC Department of Physics and Astronomy, theoretical research on some of these topics is being pursued by Dr. Dmitri Khveshchenko and his students. In such work, the latter 2D and 3D systems would be viewed as 'holograms' of some relatively simple Einstein-like 'bulk' models of classical gravity in one higher dimension. Unlike the esoteric strings and back holes, though, such materials can—and have already been—systematically studied by condensed matter physicists.

At this moment, it is still too early to tell whether the intriguing holographic predictions can be verified in such desktop experiments. However, the quest is on—and a pitch-black 'tell-all' mirror made of graphene (a monolayer of carbon atoms first synthesized in 2004—where much of the tantalizing evidence consistent with the holographic theory has been gathered so far) may indeed be just around the corner.

Note: This project is not supported by any governmental or private funding sources, though.

CoSMS NEWS – SPECIAL VISITORS, COLLOQUIA, AND WORKSHOPS

CoSMS was honored to host Daniel Kleppner, recipient of the 2017 APS Medal for Exceptional Achievement in Research, who gave a talk on "The Three Seeds in the Flowering of Quantum Science" in April. Over the summer, the Institute hosted the 20th Capra Meeting on Radiation Reaction in General Relativity, an annual international meeting that brings together the leading experts on theoretical modeling of extreme mass ratio in spirals and binary black holes for a week of talks and collaboration. This year's meeting was particularly exciting, coinciding with the recent gravitational wave discoveries. The Institute also hosted a one-day symposium of nuclear physics luminaries honoring the career of Professor Tom Clegg, who spearheaded many of UNC Physics' and the Triangle University Nuclear Laboratory's growth and scientific achievements over a span of 50 years. CoSMS also contributed to this year's Southeastern Strings Meeting and is planning a joint event with the Morehead Planetarium later this year.

Check our webpage at cosms.unc.edu for upcoming events, or email cosms@unc.edu to request being added to our listserv.

UNC PHYSICS & ASTRONOMY
Facts

In 2016-2017, UNC Physics and Astronomy awarded **67 bachelor's and 12 doctorate degrees.**

Two new faculty members have joined UNC Physics and Astronomy this year: **Assistant Professor Amy Nicholson and Lecturer Dan Young.**

Phillips Hall has a new **Community Room**, where students, faculty, and staff can enjoy a break in their day, socialize, or collaborate. We also now host our **weekly pre-colloquium** gathering in the space.

Professor Chuck Evans was elected a 2017 Fellow of the American Physical Society.

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GREETINGS FROM CHAPEL HILL!

My name is Halie Sue Clifton, and I am delighted to have the opportunity to work directly with the department of Physics and Astronomy on behalf of the College of Arts and Sciences Foundation. My mission is to help Physics and Astronomy accomplish its goals by working with alumni and friends like you to raise private support for the Chair, Christian Iliadis, to make strategic investments in the department. Private philanthropy plays a critical role in the department's ability to maintain its stature of excellence. For gift options, including multi-year pledges, stock donations, or planned gifts, please do not hesitate to contact me. I hope to meet many of you in the year ahead.

Halie Sue Clifton

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The Department of Physics and Astronomy Excellence Fund helps enhance our world-class programs in research and education by supporting visiting speakers, providing seed funds for new instrumentation, and expanding research experiences for our students.

Gifts of any size will greatly increase our ability to support outstanding faculty and students.

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

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Thank you!