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## In This Issue:




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Phone: 806-834-6355

Editing and Design:
Leslie Akchurin, Debra Boyce,
Tom Maccarone, Joyce Norton

Photos:
Nural Akchurin, Alexander Cardona,
Tom Gibson, Selen Gündüz

*Front Cover: The Cone Nebula NGC 2264. 50 minutes H-alpha, 50 minutes SII, 50 minutes OIII, 5" f/5 refractor at prime focus, taken by Dr. Maurice Clark at the department's Preston M. Gott Skyview Observatory.*

# The View from the Chair

I write this article with a particular sense of pride in our department. The first observation of gravitational waves from a black hole merger was announced by the LIGO scientific collaboration on February 11th this year, a monumental achievement many years in the making that will be remembered as a major milestone. Two of our faculty members, Alessandar Corsi and Benjamin Owen, are distinguished members of the LIGO collaboration and helped with this discovery. Professor Corsi's article in the last issue of *physics@ttu* had already signaled this new frontier and described her research in bridging the electromagnetic and gravitational wave skies. In this issue, Professor Owen explains the details of this discovery in a follow-up article on pp. 5-7. I am proud because this is the second historic discovery for our relatively small department in four years, as members of the high-energy particle physics team were among the discovers of the Higgs boson at CERN that many years ago.

We are also planning ahead by growing our faculty and staff strategically so that faculty members can play key roles in future discoveries. Of course, we are gratified to see that TTU was listed among the nation's top doctoral universities in the latest Carnegie Classification of Institutions of Higher Education. Of the 115 universities listed in the Highest Research Activity category this year, Texas Tech is one of 81 public institutions in the top tier. The Carnegie Classification of Institutions of Higher Education, announced every five years, is the foremost measure of a university's research, academic scholarship, and teaching. Among the three categories of research activity – highest, higher, and moderate – 335 universities were listed.

Our growth plan calls for increasing the current 19 faculty members to 30 in the next five years. As we expand the major research areas, we remain cognizant of our teaching mission to prepare our students for graduate school or the market place. The first major step of our plan calls for two additional faculty members in Physics Education Research (PER) by September 2017. It is important for us to remain current in our teaching techniques and to explore more effective pedagogies as we prepare our students for the future. This area is attracting nation-wide attention and federal funding as the need for a better prepared workforce becomes clear. Also, we will launch a major expansion in experimental condensed matter physics by adding two to three faculty members in 2018. It the same time frame, we plan to expand our high-energy particle physics group by an additional two junior faculty members.

Dr. Maurice Clark, who was the engine behind our observatory, retired and moved back home to Perth, Australia. He was an excellent colleague and teacher and is greatly missed. Dr. Robert Morehead arrived at TTU this fall to take the helm at the observatory. You can read about Robert's work in his contribution on pp. 8-10. Dr. Denija Crnojevic joins our department as a research professor. She is an astrophysicist who investigates the life and death of galaxies. Valerie Smith also joins the departmental front office as an assistant advisor. She assists undergraduate and graduate academic advisors and is building a more efficient archival and monitoring system.

You will notice that the name of our department has changed to "Department of Physics and Astronomy" from "Department of Physics" to better reflect the makeup of our faculty, current research, and future directions. We are one of few institutions in the state that offers an astrophysics concentration as part of a BS degree in physics. Further strengthening of the astronomy and astrophysics research teams is also part of our plan in the coming years.

As I reported a year ago, finding adequate teaching and lab space continues to be a challange. The renovation last year of one of the teaching labs (Room 104) resulted in a significant enrollment increase in introductory physics courses. This year, with funding from the College of Arts

and Sciences, we renovated ~1,500 sqf space by combining Rooms 106 and 108 for inquiry-based teaching/learning in algebra-based introductory physics courses. These initiatives are costly and require both major initial investment and continued upkeep. We have taken the first essential steps in renewing our pedagogies and will expand to other courses as resources are secured.

Dean Lindquist of the College of Arts & Sciences is spearheading a fund-raising campaign, "Unmasking Innovation," and he gives his thoughts in a letter on pg. 27.

We awarded six BS, five MS, and four PhD degrees this year (Dec 2015 to Aug 2016). We are proud of our graduates, and our PhDs give a brief view of their work (pp. 23-26). I wish Drs. Mehmet Bahadır Bebek, Gülten Karaoglan-Bebek, Thomas Halverson, and Sanchari Sen the very best.

GRASP (Graduate Association of Physicists) and the Society of Physics Students (SPS) have been very active this year. The newly formed GRASP will certainly address issues that concern graduate student life in our department (pp. 14-15).

We have improved our web page to better serve our students and faculty and also to effectively introduce our department to the entire world. You will find useful and detailed information by visiting *www.phys.ttu.edu*.

As we plan for growth in terms of faculty number, we also plan for state-of-the-art research space in the Experimental Sciences Building II (ESB-II), which will be completed by the end of 2018. ESB-II is central to our growth plan because it will offer new space for the major departmental research thrusts starting in late 2018. As some of the research labs are moved out of the Science Building into ESB-II, we plan to repurpose the space for teaching labs, classes, and offices. We have also finished planning for the Advanced Particle Detector Laboratory (APD Lab) to be constructed at Reese Technology Center for the high-energy particle group's upgrade project at CERN's Large Hadron Collider. This lab will house a large cleanroom facility for the development and construction of silicon detectors.

As always, I would like to hear from all our alumni and friends. Please share your ideas and news. And, if you are in the area, come over for a visit. Together, we can truly make TTU Physics and Astronomy the place to be.

Sincerely yours and wishing you happy holidays,

Nural Akchurin

Nural Akchurin
Professor and Chair

# *First Detection of Gravitational Waves*

Benjamin J. Owen

A hundred and one years ago, Einstein's general theory of relativity revolutionized our concepts of space and time, leading to all sorts of strange predictions. A hundred years ago, Einstein made one of the strangest of those predictions, the existence of gravitational waves. Then he flip-flopped on that prediction; other scientists kept arguing about the waves' reality after his death, and that reality wasn't widely accepted by physicists until fifty years ago. In February 2016, LIGO (the Laser Interferometer Gravitational-wave Observatory) announced the first direct detection of gravitational waves - an unmistakeable chirplike signal coming from two black holes merging into one, more than a billion light years away. That signal, and a similar one announced in June, verified Einstein's predictions about gravity and gave us some big surprises about astrophysics. The era of gravitational-wave astronomy has begun, and with LIGO running at increased sensitivity and being joined by a global network of gravitational wave detectors, we expect many more exciting discoveries in the years to come.

Gravitational waves shake spacetime itself and everything in it as they pass through, in a very specific pattern that makes distances between nearby points fluctuate by a fixed fractional amount or strain. They are produced by black holes and by the highest density matter in the present universe (neutron stars) or primordial universe (fluctuations from the Big Bang), subjects which themselves weren't understood until about fifty years ago. What has been understood from the beginning is that gravitational waves are very weak, shaking things on Earth with a strain of a part in $10^{21}$ on a really good day. Einstein thought that such weak waves would never be detected.

In 1974, Russell Hulse and Joe Taylor detected gravitational waves indirectly by tracking the shrinking orbit of a binary neutron star system, taking advantage of the fact that one of the stars is a pulsar - that is, it emits regular radio pulses that precisely time its orbit. As the binary emits gravitational waves, it loses energy, and the orbital period shrinks in precisely the way predicted by laborious calculations from the general theory of relativity. After four decades, agreement between the predicted and observed shrinking has only grown stronger as the error bars are reduced (they can't be read on plots anymore), and dozens more binary pulsars have been found. Even this indirect detection was enough to win Hulse and Taylor the 1993 Nobel Prize in Physics at just the time when I came to Caltech, the nerve center of LIGO, as a new grad student looking for a thesis project.

In early 1994, the National Science Foundation approved the construction of LIGO, its biggest project ever. Conceived decades earlier by Rai Weiss and Kip Thorne, and given a big leg up by Ron Drever, the idea behind LIGO was to use the most sensitive spatial measurement tools on an unprecedentedly grand scale. Laser interferometers, commonly tabletop instruments for precision optical machining, were built with 4-kilometer arm lengths, with the light reflecting in the cavities hundreds of times to increase the signal. Sophisticated seismic isolation techniques cut down on vibrations from traffic, earthquakes, and other things that could mask the shaking due to gravitational waves. LIGO set many records - for instance, the high-vacuum optical cavities to keep the laser light free of scintillation were the largest holes in the Earth's atmosphere. Throughout the 2000s, the Initial LIGO phase of the experiment increased its sensitivity until in 2015, at the beginning of Advanced LIGO, it became able to measure changes in the arm lengths of a thousandth the width of a proton.

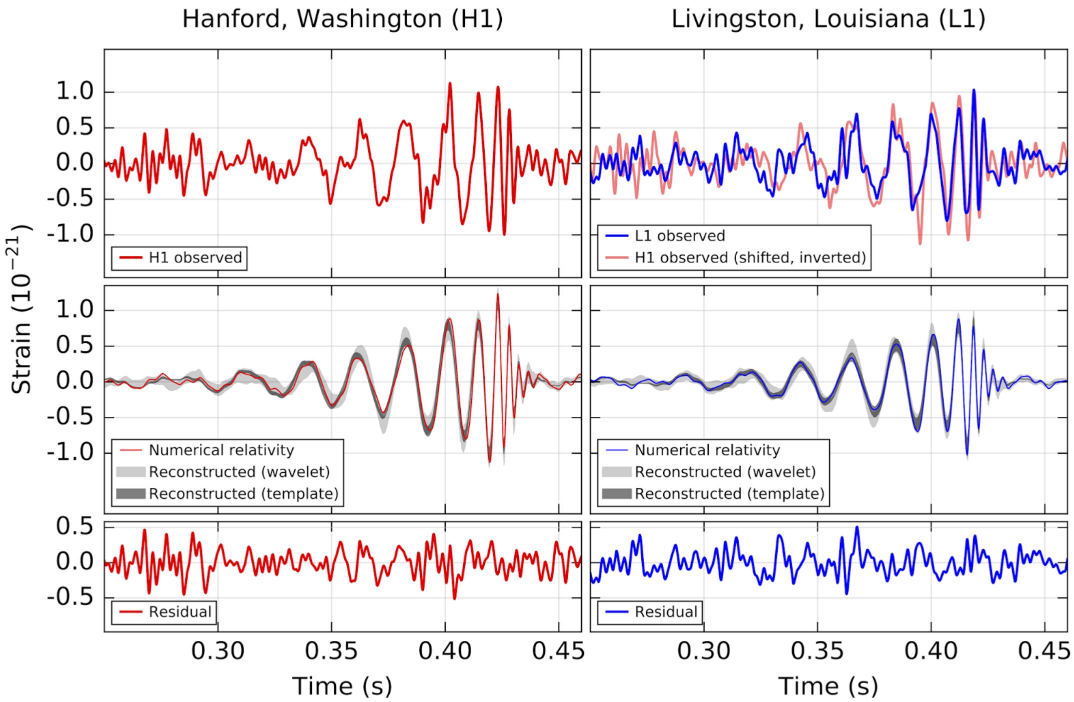
That works out to a strain on the arms of about one part in $10^{21}$, vastly smaller than any measured before but the number theorists had long proposed as possible if we were really lucky. A binary system of neutron stars, black holes, or one of each could produce such a signal if it were close enough to Earth - "close" meaning hundreds of times further from our galaxy than its nearest major neighbor.

*Aerial view of the LIGO Livingston Observatory in Louisiana. There is a twin site near Hanford, Washington. (Credit: LIGO Lab)*



Given astronomers' previous knowledge of binary star formation and the observed population of binary pulsars, we hoped that a double neutron star merger might happen close enough (and loud enough) to detect after a few years of running Advanced LIGO. And since nobody had seen the right kind of binary with a black hole, we figured they were pretty rare and would take even longer to detect.

We got a $10^{-21}$ amplitude signal from binary black holes a few days after the detectors were brought on-line. In the wee hours of the morning of September 14, 2015, automated search algorithms tripped an alarm that was spread through an ever widening circle of LIGO scientists and then partner telescopes to check for any x-ray or radio or light glow accompanying the event. Lots of people - like me - didn't believe the signal at first, since it was so loud and perfect. Someone might have fooled around with the system for injecting signals to test the data analysis pipelines. But the injection system hadn't been put together yet, and intense investigations discovered no human or instrumental problems. A month later we detected

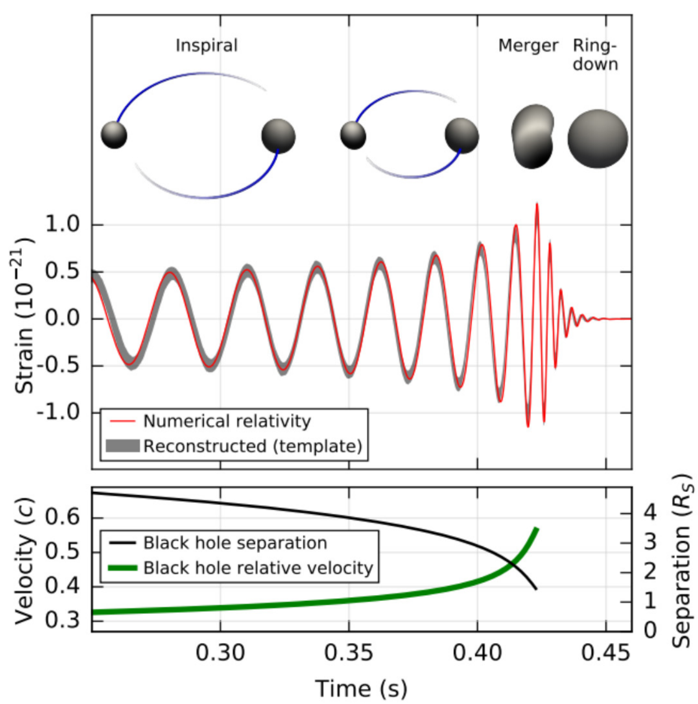



*Data (top row), inferred signal (middle row), and residuals (bottom row) for the LIGO Hanford (left column) and Livingston (right column) detectors for the first discovered signal are above, as reported in the discovery paper in Phys. Rev. Lett. 116, 061102 (2016) by the LIGO scientific collaboration.*

another, fainter and borderline believable signal; then just after Christmas came another loud and clear event.

The first thing the signals told us was that Einstein's theory of general relativity really is a good description of gravity. People have tried various alternative theories over the years, and the tight agreement of these signals with laborious and precise calculations from relativity put strict limits on the alterations consistent with the data. The signals also shored up existing evidence for black holes - the objects were much too massive (30 times the mass of the sun) and compact to be neutron stars, as was clearly shown by the frequencies and chirp rates. Astrophysically, we learned that black holes formed from stellar collapse could be more massive than most astronomers had anticipated (only 10 times the mass of the sun) and that their mergers were far more common, with possible implications for the history of star formation.

I started working on LIGO in 1994 by developing data analysis techniques for black hole binaries, and it has been incredibly exciting to see that work finally come to fruition. But we are already looking ahead to when LIGO starts detecting neutron stars, which can tell us about the properties of matter under the most extreme conditions in the modern universe. These days, my research group focuses on long-lived gravitational waves from young neutron stars like pulsars, and Alessandra Corsi's group focuses on intermediate-length signals and their possible connection to gamma-ray bursts and supernovae, which she also observes electromagnetically. From here, it's possible. We have been tremendously motivated by the recent discoveries and expect more great things to come.




*Sketch of the black holes (top), predicted and inferred signals (middle), and orbital separation and velocity (bottom) for the first detected signal. Credit: LIGO Scientific Collaboration, Phys. Rev. Lett. 116, 061102 (2016).*

# *TTU's Big Bang in Astronomy Education*

Robert Morehead

In the first few moments after the Big Bang, the universe underwent a period of rapid expansion, called Inflation, during which its scale increased by at least 26 orders of magnitude. The newly rechristened Department of Physics and Astronomy is experiencing its own inflationary period, rapidly increasing the scale of its astronomy program. In the last four years, we have hired several new astronomy faculty and a new observatory director, expanded our observatory, and started an astrophysics concentration within the physics major. And we have many new opportunities on the horizon.

One the biggest successes of our astronomy program is the rapid growth in the astrophysics concentration option for the physics major. Created in 2012, the astrophysics concentration currently comprises over half of our 170 majors. The concentration is designed to prepare students for graduate work in astronomy and astrophysics. A vital component to student success is active participation in research early in their academic careers. To give our students a jump-start, we have designed our Observational Astronomy class to be accessible at the early sophomore level. This builds a firm foundation for continued research. The course teaches students the fundamentals of astronomy research while giving them practical hands-on experience at the telescope as they complete a semester-long research project. In this course, students have imaged deep sky objects, tracked comets, measured the rotation period of asteroids, taken spectra of binary stars, estimated the age of star clusters, monitored the fluctuations of variable stars, and accomplished many other challenging projects. These experiences position our students to begin to work with faculty on cutting edge science and set them up to take advantage of external summer internships. Students will then go on to gain even more research experience near the end of their undergraduate studies by completing the new astrophysics capstone course, in which they will undertake an advanced research project under the supervision of a faculty member. This training and experience make our

*Still frame from the 2016 #IAmARedRaider Commercial time-lapse showing off the Preston Gott Skyview Observatory. This promo plays during all televised NCAA games Texas Tech plays in this year. See the full video at https://www.youtube.com/watch?v=9HIHpv-jUDE*

*A dumbbell nebula (M27) color image taken with a Skyview 12-inch telescope. Astrophotography and image processing by Kyle Artkop (BS'18).*

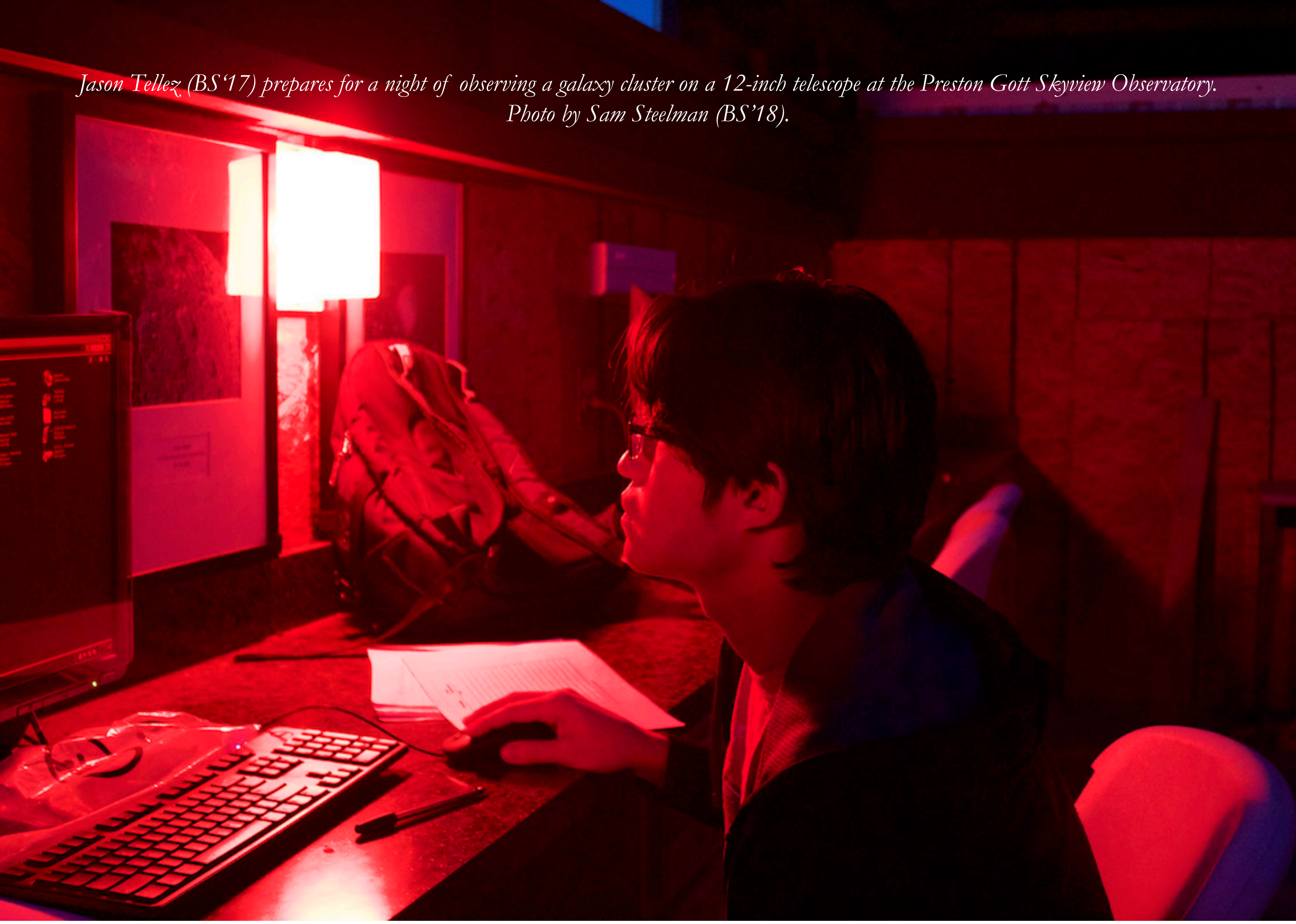
such as the construction and commissioning of robotic observatories.

General science education is an important part of our service to the university community. In many ways, astronomy is an ambassador science. We have lots of pretty pictures, after all, and that makes astronomy a popular choice for hundreds of students looking to fulfill their degree requirements each semester. Facilitated by the dark skies of the cotton fields north of Lubbock, Skyview gives many Texas Tech students their first experience of the night sky outside areas of urban light pollution. All of our introductory astronomy classes have several lab nights at the observatory, and on most nights during the semester, over 60 students find themselves making both naked-eye and telescopic observations of the Universe. For most of our students, this is the first time they see the Milky Way arching across the sky or glimpse the rings of Saturn through a telescope. Experiences like students very competitive when pursuing admission to graduate programs or finding positions in industry after graduation.

Central to astronomy education at Texas Tech is the Preston Gott Skyview Observatory which is an excellent facility for student research. In 2013, a second building, featuring a roll-off roof, was built that supports five computer-controlled 12-inch telescopes, each with its own CCD and RGB filter wheel. In addition, the main dome features a 20-inch Planewave telescope that includes multiple CCDs, photometric and imaging filters, and a small spectrograph. Students have the opportunity to engage with current and planned faculty research projects, such as looking for optical companions to LIGO gravitational wave detections with Dr. Corsi, rapid monitoring of supernova with Dr. Sand, following-up exoplanet candidates from ground and space-based surveys with Dr. Morehead, precision timing of compact objects in binaries with Dr. Maccarone, or commissioning a new Cherenkov telescope to detect cosmic ray interactions in the atmosphere with Dr. Akchurin.

To expand our research capabilities even more, we are actively seeking funding opportunities for a permanent, high-speed internet link back to campus, as well as a second 20-inch or larger telescope. These infrastructure improvements will increase our research efficiency by allowing us to automate some of our operations and will allow us to expand into new cross-disciplinary research,

*The Horsehead Nebula with the 20-inch Planewave at Skyview. Astrophotography and image processing by Sam Steelman (BS'18).*


*Jason Tellez (BS'17) prepares for a night of observing a galaxy cluster on a 12-inch telescope at the Preston Gott Skyview Observatory. Photo by Sam Steelman (BS'18).*

these have a profound impact and can foster a lifetime of appreciation for science.

Many students only take two science classes while at Tech, so it is vital that we build up our students' scientific and quantitative reasoning skills so they can be engaged and informed citizens in an increasingly technical world. To accomplish this, we focus on effective evidenced-based teaching in our introductory astronomy course lectures and labs. We are expanding our use of active learning methods, such as think-pair-share questions and peer instruction in our large lecture sections. These active learning techniques make a big impact on learning outcomes and student engagement and align well with our departmental focus on supporting physics education research. We are also in the process of revising and updating our introductory astronomy lab curriculum.

Expanding our public outreach activities is the next big frontier for astronomy education at Texas Tech. Currently, Dr. Maccarone coordinates a hub of the Pulsar Search Collaboratory, a national program that partners with local high school teachers to have their students search for radio pulsars and that funds undergraduates who work directly with the high school students. We are also actively working with community partners like the Museum of Texas Tech University and Moody Planetarium to create public outreach programs that target the local community. We are currently developing a permanent astronomy exhibit near the entrance of the planetarium that will focus on the history of astronomy in West Texas and feature past and current astronomy research done here in the department along with our national and international collaborators. With the aid of student and community volunteers, we are also planning monthly public observing nights at the planetarium during the First Friday Arts Trail in Lubbock. These consistent and reliable events will combine public science talks, planetarium shows, and telescope viewing to provide deep and meaningful astronomy experiences, not only for the Texas Tech community but for the general public as well.

# *Learning How Students Learn: Physics Education Research*

Beth Thacker

Physics Education Research (PER) is the field of physics devoted to the systematic study of students' conceptual understanding, problem solving skills and reasoning ability as applied to the learning and understanding of physics. The work is both experimental and theoretical, including observations and measurements designed to identify students' difficulties and track their learning gains, develop models of their learning processes and use those models to develop materials, curricula and instructional methods that will help increase students' understanding of physics concepts and their problem solving skills and reasoning abilities.

The recent emergence of PER as a sub-field of physics within physics departments can be traced to Lillian McDermott in the 1970s at the University of Washington. She was the first to systematically identify students' learning difficulties, although her predecessors, including physicists Arnold Arons and Bob Karplus, had laid the foundations in the 1950s and 60s. Soon others began the formal study of teaching and learning, including Dean Zollman (Kansas State), Bob Fuller (Nebraska), David Hestenes (Arizona State) and Fred Reif (Carnegie Mellon), and the field began to grow. Today, there are many PER groups in physics departments across the country, as can be found on the map at the PER Central website, http://www.compadre.org/per/. Some of the universities with larger PER groups are Maryland, Maine, Ohio State, North Carolina State, Kansas State, Illinois, Colorado and Florida International.

PER has become recognized as a sub-field of physics in many physics departments and by the American Physical Society (APS) because like other fields of physics, it attracts funding, has developed publication and dissemination mechanisms, contributes to the understanding of physics concepts and has trained PhD physics students in experimental and observational techniques and the development of theoretical models of physics learning. In addition, the outcomes of PER research can be used to improve teaching, learning and evaluation. Although there is still some misunderstanding by non-practitioners about what PER is and is not, it is a growing field that is finding its place in physics departments across the country, including TTU.

At TTU, PER researchers have made two major contributions to the field and to the institution. We have 1) developed an evidence-based, hands-on, laboratory-based physics course designed primarily for health science majors who take the algebra-based physics sequence and 2) run a large-scale assessment over a period of three years in all of the introductory physics courses, both calculus-based and algebra-based. Both of these projects have brought in significant funding and resulted in publications and dissemination of the materials across the country.

We are presently working on some other very significant projects: 1) The Letters Home Project, a project involving the assessment of students' laboratory and writing skills in the Modern Physics Labs, 2) assessment of students' thinking skills in the introductory physics courses, 3) research on students' understanding of quantum concepts in modern physics and 4) exploration of the role of rote memorization in learning 1-D kinematics. We briefly discuss some of these projects below.

Starting in 2000, we developed, implemented, assessed and disseminated an inquiry-based, algebra-based curriculum (INQ) for introductory physics courses. The work began with two National Science Foundation (NSF) grants in conjunction with collaborators in Michigan, Nebraska and New York, with the primary writing done at TTU. The curriculum was developed and disseminated through workshops and was made available on the web for use by others. Since then it has been taught every semester at TTU, adopted by others at both the high school and university levels and recently featured in the PER-Central, ComPADRE collections.

The INQ course is a laboratory-based, inquiry-based course that was developed primarily for health science majors, taking their needs, learning styles, backgrounds and motivations into account. It is taught without a text or a lecture in a workshop-physics/studio style environment and is an inquiry-based course in the manner of Physics by Inquiry, developed by the Physics Education Group at the University of Washington, but at the algebra-based level. The materials were developed by modifying and adapting parts of existing materials designed for other populations and integrating them with new units in our own format, creating a course aimed specifically at health science majors. In class, students work through the units in groups, learning to develop both quantitative and qualitative models based on their observations and inferences and then using the models to make predictions and solve problems. There are also homework sets, exams and quizzes, as in traditional classes. There is, however, a greater focus on observational, analytic and critical thinking skills.

Most recently, we have remodeled two labs into a large studio-format room to accommodate 60 students in a hands-on, laboratory environment. The course will be "scaled-up" to be taught in this larger learning environment starting in Spring 2017. The teaching and learning assistants (TAs and LAs) and faculty interested in teaching the course will receive significant pedagogical training in the instructional techniques necessary to teach this way.

In 2009, researchers at TTU were awarded a large National Institutes of Health (NIH) Challenge grant to assess evidence-based changes made to the labs and recitations in the traditionally taught algebra-based and calculus-based



introductory physics courses. Data were collected in all of the sections of both the large algebra- and calculus-based introductory courses for a number of years, employing commonly used conceptual inventories, locally written free-response (FR) problems, scientific attitude and scientific reasoning surveys and teaching assistant (TA) evaluation surveys. We also collected and reported results from the INQ course. The research results suggest that when PER-informed materials are introduced in the labs and recitations only, independent of the lecture style, there is an increase in students' gains in terms of both conceptual inventories and FR problems, there is an even more significant increase when PER-informed instruction is used in the lecture. The highest gains in both conceptual inventories and FR assessment were achieved by a combination of PER-informed lectures and laboratories in large class settings and by teaching the INQ course in a small class setting. In FR testing, the students in the INQ course performed at least as well as and usually better than all of the other students in both the calculus-based and algebra-based classes.

The Modern Physics course is a lecture and lab that covers many of the previous century's ground-breaking discoveries, such as special relativity and quantum mechanics, while serving as an introduction to the upper-level core physics courses. The lab has become a bridge from the introductory- to the advanced-lab experience, and in it, students expand their conceptual understanding while learning experimental and observational skills. Our research in this course focuses on a project called Letters Home (LH) in which students practice scientific writing skills, first in the form of letters "home" to a non-physicist then at different levels of scientific audience. LH is an informal means of reporting knowledge to various kinds of audience while engaging the writer in gathering, critically analyzing and reporting data. In Fall 2015, we conducted four sets of LH with 28 students. Currently, we are analyzing the data from the previous semesters to report our results. We are also using a survey, the Colorado Learning about Science Survey for Experimental Physics (E-CLASS), to assess students' attitudes about physics, communication and experimentation. We are continuing this research to increase our understanding of students' learning and attitudes. The primary work on this project is being done by graduate student Charles Ramey.

We are re-analyzing the data from the large-scale assessment for critical thinking skills used by students in answering questions using a rubric based on Bloom's

taxonomy (Bloom, B.S. (Ed.) Taxonomy of Educational Objectives, Handbook I: The Cognitive Domain, (1956) David McKay Co Inc.). Preliminary data indicate that students taught traditionally and assessed primarily by multiple-choice questions on quizzes, exams and online homework rarely demonstrate even lower-level thinking skills in solving free-response physics problems (problems that require them to explain their reasoning). This raises significant questions about our instructional methods and points to a need to promote critical thinking skills both in class and in homework and problem solving. This work has led to collaboration with the math, engineering and philosophy departments in an attempt to develop curricula and assessment methods that address critical thinking skills as the thread that joins together the three disciplines. Our curriculum development is presently in the grant proposal stage. Analysis of the large-scale assessment data is being conducted by graduate students Zhuang Zhuang and Aliaa Alrashidi.

We are collaborating with colleagues at Bahir Dar University in Ethiopia and the University of Colorado to study both students' understanding of concepts in quantum mechanics and issues involved with the teaching and learning of quantum mechanics. We will also be attending a Quantum Learning Goals working group meeting at the University of Colorado in March 2017.

In addition to its regular group meeting, the PER group hosts a seminar each week that draws researchers from many other fields, including math, engineering, biology, psychology and education. The physics department is leading a multi-disciplinary approach to discipline-based research. We also work closely with the Teaching, Learning and Professional Development Center (TLPDC); the Science, Technology, Engineering and Mathematics - Center for Outreach, Research and Education (STEM-CORE); the STEM Teaching Engagement and Pedagogy Program (STEP); and, more recently, the Center for Integration of Science Education (CISER). We also regularly present at statewide and national meetings of the American Association of Physics Teachers (AAPT) and the Physics Education Research Conference (PERC). In addition, I am a member of the APS Committee on Education (COE) and head the COE graduate sub-committee.

# GRASP

Ceren Uzun, Allie Hughes, and Charles Ramey II

The physics graduate students are proud to announce the formation of the GRaduate ASsociation of Physicists (GRASP), the department's first official graduate student organization in decades. With over 80 domestic and international graduate students, the Department of Physics & Astronomy is one of the largest and most diverse graduate communities at Texas Tech University. Because GRASP is affiliated with such a diverse department, we seek to achieve an inclusive environment in which all physics and astronomy graduate students can find support, share cultural differences, improve the graduate experience, and pursue leadership and philanthropic opportunities. Individuals who are employed as teaching or research assistants in the department are strongly encouraged to join.

The goals of GRASP are the following:

- To seek to improve the graduate student experience in the Department of Physics & Astronomy by providing necessary support for graduate students.
- To serve as a representative body for physics graduate students at Texas Tech University and in the Department of Physics & Astronomy.
- To promote physics education.
- To host events and other activities that promote friendship and increase cultural, scientific, and social awareness throughout the university, the physics community, and the public.
- To promote discussion and understanding of science on campus and elsewhere.

To accomplish our mission and incorporate as many graduate student voices as possible, our organization has established multiple committees that focus on specific tasks:

- The Networking Committee (headed by Michael Holcomb) works to strengthen the relationship between industry and academia for recent and soon-to-be graduates.
- The Outreach/Social Committee (headed by Mahsa Servati) organizes social and cultural events as well as volunteer and outreach opportunities.
- The Academic Committee (headed by Ceren Uzun and Leo Diaz) coordinates academic resources to prepare students for their courses and the PhD Preliminary Exam.
- The Student Advocacy Committee (headed by Paul Bennet) provides a safe space where students can anonymously give feedback about the department and our organization.
- The Fellowship Committee (headed by Sueli Skinner) coordinates funding opportunities for graduate students, including fellowships, scholarships, and grants.
- The Technology Committee (headed by Sam Wyatt) supports the organization's tech-related issues and maintains its online presence.

We have also elected our first Executive Board to oversee the more general aspects of the organization. Our Executive Board Members are Allie Hughes (President), Charles Ramey II (Vice-President), Jigesh Patel (Treasurer), Leo Diaz (Secretary), Ceren Uzun (SORC/Department Representative), Dr. Mahdi Sanati (Faculty Advisor), and Dr. Denija Crnojevic (GRASP Mentor).

Within the first two months of its inception, GRASP conducted three meetings during which the constitution and bylaws were written, elections were held, and committees were formed. We have also sponsored social events, including a BBQ to welcome incoming graduate students, a bike excursion, and a football tailgate with the Chemistry Graduate Student Organization. Our committees are currently working on a budget, long-term goals, and membership participation. Obtaining a MS or PhD can be both challenging and stressful; in an effort to ameliorate this process, GRASP offers a multitude of opportunities for members to be involved, ranging from leadership positions to supporting roles in our events.

Although we have laid the groundwork for our governance, this is only the beginning. We strive to establish an inclusive and supportive graduate student community that will be a crucial building block within our department for generations to come. To continue the values of our institution and department, we intend to create a culture of solidarity and diversity among bright scholars who are conscientious and self-aware, as well as among researchers who are knowledgeable and skilled critical-thinkers. GRASP members are excited about our new organization and are fully committed to the success of all physics and astronomy graduate students. If anyone is interested in assisting us with our endeavors, please feel free to contact anyone who is mentioned in this article.

May the $d\mathbf{p}/dt$ be with you!

*LIGO Discovery Celebration*

# *New Faces*

Dr. Crnojevic is an observational astronomer who researches the life and death of galaxies. By analyzing the stellar content of the closest galaxies with state-of-the-art telescopes, she investigates their properties -such as luminosity, distance, chemical content, host environment, and mutual interactions-, with the goal of understanding their evolution throughout the Universe's life. Dr. Crnojevic received her PhD in Astronomy from the University of Heidelberg, Germany in 2010. Before joining TTU, she was a postdoctoral fellow at the University of Edinburgh, UK, and she was subsequently a postdoctoral research associate at TTU.

Dr. Robert Morehead joined us in August of 2016 as an instructor and the Director of the Preston Gott Observatory. He received his BS from Columbia University in 2009, his MS from the University of Florida in 2011, and his PhD from Pennsylvania State University in 2016. While at Penn State and UF, he was National Science Foundation Graduate Research Fellow and worked on understanding the statistical properties of exoplanet populations uncovered by NASA's Kepler Mission. He is transitioning back to observational astronomy and is developing a program to follow-up future exoplanet missions from Tech's observatory.

Valerie Smith joined the department as an Advisor in August 2016. Smith comes to the department via the university's Department of Operations where she served in the office of the utilities department. Here, she is working with undergraduate students in the established advising program and also with graduate students, for whom she is setting up a new advising and tracking system. She is responsible for the department's course scheduling and the scholarship program as well. She has a long history in student services as a Lubbock-Cooper ISD Band Booster President for six years and as a youth staff member at a local church for five years. She also played a substantial role as Secretary of the Board and Steering Committee President for Cman's One DROP. When not at work or volunteering, Smith enjoys cooking, reading, and spending all the time she can with her five children and grandchild.

*SPS Spring 2016 Banquet*

# *President's and Dean's List Scholarships & Awards*

**President's List**

Aashish Gupta, Alejandro Ibarra, Hector Ruiz, Andrew P. Smith,
Rachel Smith, Jean Joseph Rene Theodule

**Dean's List**

Kyle Artkop, Juan Dominguez, Justeen Gamboa, Jose Garcia, Thomas (Blake) Head, Brandon Matthews,
Gregory Skillman, Anthony Sosa, Anvar Szulczyk, Clayton Tuller,
Montana Williams, Max Zhelyeznyakov

The Scholarship Committee, chaired by Professor Glab, reviewed many strong undergraduate and graduate applications for departmental awards. The 2017 winners are listed below. The award ceremony was held on April 22, 2016 as part of the Physics & SPS Spring Banquet. Congratulations to all! We are grateful to alumni and friends who generously established the funds that make these scholarships possible.

- Bucy Undergraduate Award to Beth Eckert, Roberto Espinoza, Jose Garcia, Eric Goodheer, Greg Skillman, Rachel Smith, & Max Zhelyeznyakov ($1,000 ea.)
- JW Day Award to Alex Cardona ($300)
- Gangopadhyay Undergraduate Award to Adalia Schenk ($500)
- Gott Gold Tooth Award to Anthony Sosa ($500)
- Glen A. Mann Award to Adalia Schenk ($500)
- Roland E. Menzel Award to Kyle Artkop, Ganesh Chaulagain, & Dominic Elizondo ($1,000 ea.)
- CC & Alma K. Schmidt Award to Kacie Almond, Michael Keeler, Jake Noltensmeyer, Clay Tuller, Aashish Gupta, & Chase Whitworth ($1,000 ea.)
- Kenneth Sterne Award to Gwen Armstrong, Juan Dominguez, Hamza Farhat, & Alejandro Ibarra ($200 ea.)
- Henry C. Thomas Award to Alex Cardona ($500)
- Sidney Sundell in Astrophysics Award to Blake Head ($2,000)
- Peter Seibt Award to Ceren Duygu ($800)
- David Howe Award to Premitha Pansalawatte ($1,000)
- Bucy Applied Physics Graduate Award to Michael Holcomb, Christopher Stanley, Sonaina Undleeb, Darshan Desai ($2,500 ea.), & Premitha Pansalawatte ($3,000)
- Professor of the Year went to Dr. Rick Mengyan
- Outstanding PhD student went to James Faulkner
- Outstanding MS student went to Victor Siller
- Outstanding TA went to Ceren Duygu
- Outstanding Graduating Seniors were Hamin Choi, Raymond Taylor, & John Hefele

# *Society of Physics Students*

Alexander Cardona

Texas Tech's chapter of the Society of Physics Students (SPS) continues to strive to present opportunities for professional growth and scholarship and to maintain a place for new colleagues to meet. Not only has there been a surge in new members within the organization, but SPS has been working diligently to lay the foundation over the past year for the most growth we have experienced. Members, officers, and faculty alike look forward to the new faces of SPS.

During the Spring 2016, we were extremely fortunate in taking a tour at the Pantex facility located in Amarillo, TX. This would not have been possible if not for one our alumni members, **Keelan Walsh** (BS'16). After security clearances were received for all of the members who attended the trip (a lengthy process), we were able to take a peek at some of the extraordinary technologies that are being researched and developed at the plant. Although none of the members can talk about the trip in detail, we can say that quite a lot was learned at the information session and that the experience overall was a significant one.

SPS returned to the NRAO Very Large Array for one of our weekend-long trips. Many thanks are given to Dr. Amy Mioduszewski for helping our group receive an in-depth tour of the facilities. This trip, held in April, was a special one for the fellow members. In the previous year, SPS toured the operation facilities and had interesting conversations with some employees. This time around, more SPS members were able to experience this and also to scale one of the 25-meter radio telescopes (see below). After learning a great deal that was beneficial to our members in terms of possible careers, SPS took a break and stopped at the UFO Museum in Roswell, NM. We dove deep into the mysteries behind the incident that occured in Roswell almost 70 years ago. After gathering important and dark intel, we ended our trip on a lighter note with some great souvenirs.

During the 2015-2016 academic year, SPS kept up with its usual social events that are designed to help current members unwind during the stresses of the school year and to create a strong network within the organization. We understand that exams, studying, or even work can cause strain for students, and we aim to alleviate some of this with fun and relaxing events. These include Bowling Nights, Game Night, Movie Night, and various other activities, some of which are hosted by SPS members independently. One of these events is playing basketball with some of the faculty on the weekends. Creating professional networks among the members is another aspect of the social events hosted by either SPS or members, whether with peers to discuss ideas and learn or with faculty and staff to make connections for future careers.

Another great year for the Department of Physics and Astronomy ended with the annual Departmental Spring Banquet, this year hosted by SPS. Thanks to the Bucy Foundation in conjunction with SPS, the expenses of all attendees and their guests were able to be covered. Recently, new mathematical physics courses have been created in collaboration with the Mathematics and Statistics Department. For this reason, we invited Dr. Kevin Long to present a small lecture for the attendees of the banquet. The second presentation was given by two of our own grad students about the physics of sound, which turned out to be a crowd favorite. In the upcoming year, we intend to invite each of our new faculty members so as to learn what he or she brings to the department and our members in terms of research and engagement.

Plans are being arranged to keep our SPS Star Party an ongoing outreach event for members of the local community. Currently, our idea is to expand the parties to schools within the local districts, in which we will collaborate with the South Plains Astronomy Club (SPAC) and Dr. Robert Morehead, the newest addition to our department (see his article on pp. 8-10). Additionally, SPS has begun to participate in the Research Carnival hosted by CISER, a professional organization that assists undergraduate research. Undergraduates are able to present their research to the general public, allowing high school students to see the possibilities available to them in college. This has also enabled student organizations such as ourselves to showcase what we are up to and how we can be beneficial to new students once they commence their college careers.

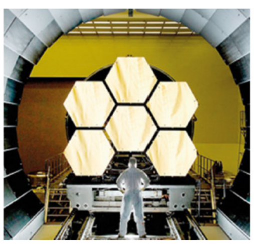
In addition to renovating itself, SPS continues to renovate the room in which it is situated. New rolling task chairs have replaced the fixed and antiquated ones. Updated furniture is on its way, and textbooks have been added for check-out by members. New paint and more whiteboards are also to be added. Pictures of the events and activities mentioned in this article can be accessed on our new website, *ttusps.com*. We look forward to another year of physics.

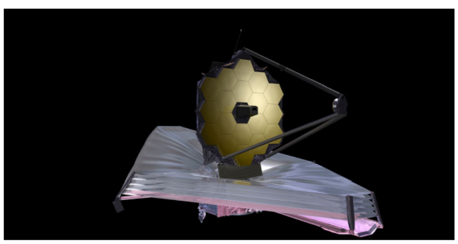
# *We Hear that...*

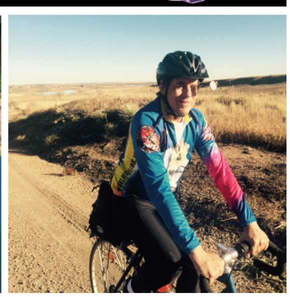
Dr. Robert Morehead (see page 16) was accepted as an Ambassador of Astronomy by the American Astonomical Society.

Alessandra Corsi, assistant professor in Physics and Astronomy, was welcomed to her honorary position as adjunct assistant professor in the Mathematics & Statistics Department.

**Scott Acton** (PhD'90) gave a public lecture on October 14 about his bicycling tour around the world to teach others about the James Webb Space Telescope. He can be followed at http://www.jwstwbt.com/

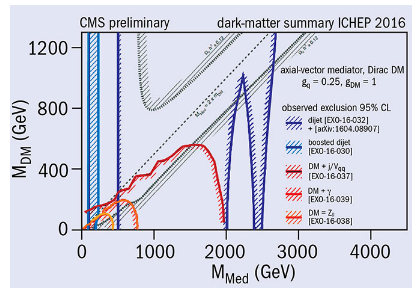






**Ginger Kerrick** (BS'91, MS'93) was inducted into the Texas Women's Hall of Fame. She serves as division chief of the Flight Operations Directorate Integration Division at NASA's Johnson Space Center in Houston. Ginger also received TTU's College of Arts & Sciences Distinguished Alumni award earlier this year.

Chris Britt, Denija Crnojevic, Tom Maccarone, and David Sand are scheduled for telescope time this year at National Optical Astronomy Observatory-coordinated facilities, which include Kitt Peak National Observatory, Cerro Tololo Inter-American Observatory, and Gemini Observatory.




The CERN Courier included a result from Zhixing (Tyler) Wang, a graduate student in the high-energy particle physics group, in its September 2016 issue in an update on Dark Matter searches (see http://cerncourier.com/cws/article/cern/66165).

Faculty members in astrophysics, Denija Crnojevic, David Sand, and TomMaccarone, were awarded observing time at the Hubble Space Telescope for research on "An Extremely Asymmetric Dwarf Satellite Distribution around M101," "Two New Local Volume Dwarfs Associated with Compact High Velocity Clouds," and "Finding AM CVn Stars in 47 Tuc."

The HELADO (High Energy Llano Estecado Detector) group, an undergraduate research team led by Nural Akchurin investigates Cherenkov radiation from high-energy gamma ray sources, was recognized at the 56th Annual Homecoming Dinner on October 14. The Texas Tech Alumni Association awarded a $10K Excellence Grant for this research.

The Society of Physics Students (SPS) organized a Welcome Back Picnic on September 1 to welcome new graduate and undergraduate students.

In 2010-2012, our department was among the top physics departments in the US in terms of granting degrees to women: 43% of our graduates were women.

**Tom Jones** (BS'85, MS'91) says that since his graduation from Tech he has been working in the area of nuclear safety, both at the Pantex plant and Los Alamos National Laboratory.

**Jennifer Doak** (BS'02) says in a Christmas card to the department that she works from home in New Hampshire for the USPTO, examining patents, and also enjoys kayaking and singing.

The Bucy Distinguished Lecture was delivered by Shrinivas R. Kulkarni, McArthur Professor of Astronomy and Professor of Planetary Sciences, at the California Institute of Technology on April 26 at the McKenzie-Merket Alumni Center. His public lecture was titled "Cosmic Fireworks (The Dynamic Universe)."

**Thomas Hayes IV** (BS'16) and **Zachary Brown** (BS'17) made an oral presentation, "Measuring the Beam Current of a Van de Graaff Electron Accelerator," at TTU's Undergraduate Research Conference held on March 29-31. Daniel Ballinger, Casey Mills, Logan Smith, and Max Zhelyeznyakov, all physics majors, had posters at the same conference.

Debra Boyce, Academic Analyst in our department, was nominated again for the "Distinguished Staff Award," and the "Chancellor's Award of Excellence," and, for a second time, the "President's Excellence in Academic Advising Award."

The National Physics Honor Society, Sigma Pi Sigma, held a reception and induction ceremony on May 11 for its new members in the department: Maged Alotaibi, Omar Alsalmi, Kavitha Arur, Paul Bennet, Juan Dominguez, Roberto Espinoza, Mark A. Marsalis, Brandon M. Matthews, and Millind Pattanayak. This is a lifetime honor that recognizes dedication to the field of physics.

Jordan Damgov, a postdoctoral fellow in the high-energy physics group, is awarded the 2017 Distinguished Researcher Award by the Large Hadron Collider Physics Center at Fermilab.

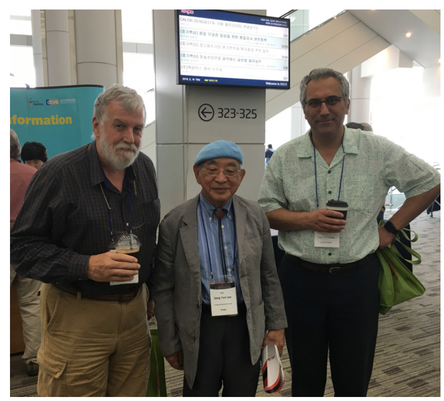
Elizabeth Eckert (BS'18), a sophomore physics major, was a student volunteer at SC16, The International Conference for High Performance Computing, Networking, Storage, and Analysis, in Salt Lake City in November.

**George Laity** (BS'08, PhD'12) is employed as an experimental physicist at the "Z" Accelerator at Sandia National Laboratory where he focuses on multiple aspects of high energy density physics. He is a principle investigator in both inertial confinement fusion and bright X-ray radiation source programs.

Tom Maccarone contributed to the discovery by NASA of a binary star system containing a low-mass star and a black hole, the first ever found without a bright X-ray outburst. See http://today.ttu.edu/posts/2016/06/black-hole.

Allison Hughes, a graduate student in astrophysics, received a Texas Space Grant Fellowship. Congrats Allie!

At the XVIIth International Conference on Calorimetry in Particle Physics (CALOR2016) in Daegu, South Korea in May 15-20, Nural Akchurin and Richard Wigmans met with Sang-Yun Lee, father of our own faculty member Sung-Won Lee, who is an emeritus professor of physics at Kyungpook National University.




Nural Akchurin spoke about quarks and the cosmos at the screening of Stephen Hawking's "Genius," a documentary shown by KTTZ Public TV, at the Science Spectrum on May 31.

Max Zhelyeznyakov (BS'17) was nominated for the Goldwater Scholarship and received an Honorable Mention. He is a physics major who plans to earn a doctorate in applied physics and to pursue research

in optics while teaching at a university.

Frank Chlebana, senior research scientist from Fermi National Accelerator Laboratory near Chicago, was “Faculty in Residence in Global Scholar Academy,” sponsored by the Honors College, College of Arts & Sciences, and high-energy particle physics group.

The “Special Breakthrough Prize in Fundamental Physics” was awarded for the detection of gravitational waves. The $3M prize will be shared among LIGO founders Ronald W. P. Drever, Kip S. Thorne, and Rainer Weiss and also with 1,012 contributors to the discovery, including our own Benjamin Owen, Alessandra Corsi, Santiago Caride, Robert Coyne, Ra Inta, and Nipuni Palliyaguru.

Richard Wigmans received the “Volta Medal” from the University of Pavia (Italy). The medal is awarded annually to a physicist who has made substantial contributions to the development of experimental techniques for physics research. The recipient is also asked to deliver the annual “Volta Lecture.” On January 28, following the award ceremony, Professor Wigmans delivered a lecture titled “Some Practical Applications of Calorimetry.”

David Sand received funding from NASA for his proposal, “Explosion Physics and Progenitors from a One Day Cadence Supernovae Search,” for participation in the Swift Cycle 12 Guest Investigator Program.

An image from TTU postdoc Paul Sell’s research has been included in TIME Magazine’s list of the Best Space Photos of 2015. This image (see below) focused on the large ring features created by scattered X-rays from Circinus X-1 and was made from observations with very different telescopes that help tell a more complete story. It shows all three main features he helped discover. Paul took a new post in Europe during the summer.

The next-next generation space telescope will be the Wide-Field Near Infrared Space Telescope (WFIRST), which will utilize a gifted 2.4 m mirror from the National Reconnaissance Office to conduct an array of infrared studies of dark energy, exoplanets, and general astrophysics. Dr. Sand is on the WFIRST Nearby Galaxies (WINGS) Science Investigation Team, which is tasked with simulating observations of nearby galaxies with a putative WFIRST telescope to provide feedback to NASA about the basic parameters of the mission (cryo temperature, field of view, filter set, pixel scale, etc). David Sand is the lead of the dwarf galaxy sub-team and is busy preparing to discover ultrafaint dwarf galaxy satellites around some of our nearest neighbors in about 10 years.

The high-energy particle physics group hosted a national workshop at TTU on the next generation endcap calorimeter for the Compact Muon Solenoid detector at the High Luminosity Large Hadron Collider. Over 20 physicists presented their work in this two-day event in October that also included a field trip to ELJEN and ADIT in Sweetwater, TX, where they manufacture high quality plastic scintillators and photomultier tubes.

Charles Ramey, a graduate student in physics education research, presented his work “A Pedagogical Method for Advanced Laboratory Writing: Letters Home Project” at the AAPT Summer Meeting in July 2016. He was also awarded a Scholar-in-Residence Grant by AAPT PER Topical Group (PERTG) for the same work.

Beth Thacker presented an invited talk titled, “Large-scale Assessment Yields Evidence of Minimal Use of Reasoning Skills in Traditionally Taught Classes” at the Joint Meeting of the Four Corners and Texas Sections of the American Physical Society in Las Cruces, NM in October 2016.

The County of Lubbock paved the road to the Preston M. Gott Observatory, making access much easier and safer after rainfall. Special thanks go to Commissioner Jones.

The National Science Foundation awarded a grant of $25K to support the “USA-Pakistan International Conference on Renewable Energy” under the direction of M.A.K. Lodhi. After his retirement, Professor Lodhi continues to hold a research professorship in the department and focuses on energy problems.

# Recent PhDs

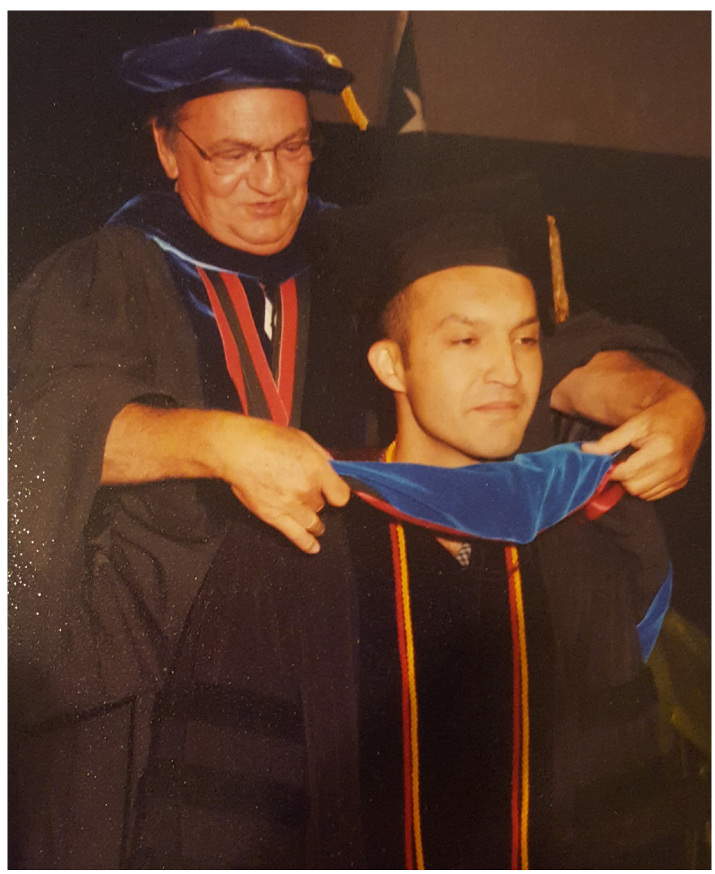
**Mehmet Bahadır Bebek** received his PhD in May 2016 under Dr. Stefan Estreicher's guidence. He is now at Intel and he describes the significant results that are the basis of his dissertation:

"My learning experience as a PhD student was very satisfying. The professors had an open-door policy and always welcome questions and discussions, even outside of class. The staff was also very helpful. What I appreciated the most is the research culture and collaboration opportunities that helped us excel in our studies. Today, as a process development engineer in the 'etch group' at Intel, I am able to implement many of the useful skills I gained during my years at TTU.

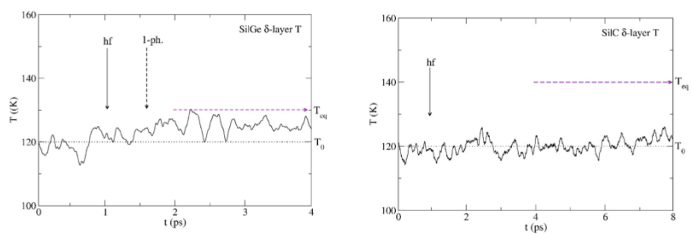
My dissertation focused on the impact of an interface on heat flow, calculated at the atomic level. Defects are known to reduce thermal conductivities. This is traditionally attributed to "phonon scattering" processes that assume static defects and the dynamic properties of the interface are ignored. Heat waves interact with defects like a water wave splashing against a rock in its path. This approach cannot explain issues such as the temperature dependence of the transmission and reflection of heat at an interface. Atomic-level calculations of the interaction between thermal phonons and an interface require the use of *ab-initio* molecular dynamics (MD) simulations. Such calculations contain no parameter fitted to an experimental database.

The host material I designed comprised silicon (Si) nanowires containing a thin layer of substitutional germanium (Ge) or carbon (C) atoms. The defect is the interface, which is defined as the thin layer of atoms that form Si-Ge or Si-C bonds. This interface – just like all other defects – introduces normal vibrational modes that are localized: Only a small number of atoms in the vicinity of the interface are involved in the oscillations. Such modes are called Spatially-Localized Modes (SLMs). C, Si, and Ge all have the diamond lattice, but the mass of C is smaller than that of Si, which itself is smaller than that of Ge. Since vibrational frequencies vary as the inverse of the square-root of the mass, my nanowire with a C layer involves modes with very high frequencies (associated with C-C bonds), intermediate frequencies (C-Si bonds at the interface), and low frequencies (Si-Si bonds). When the Ge layer is present, the lowest-frequency modes are of course associated with Ge-Ge bonds within the layer. Thus, I was able to analyze the interactions between thermal phonons and defects that have either higher- or lower-frequency modes.

The most consequential difference between bulk modes and SLMs is their vibrational lifetime, which is the characteristic time needed for a defect-related vibrational excitation to decay into lower-frequency bulk modes. My calculations show that the vibrational lifetimes of SLMs are much longer than those of bulk modes, even if they have very similar frequencies: localized oscillators do not



couple easily with delocalized ones. Thus, when exposed to a temperature gradient, defects capture small amounts of vibrational energy in SLMs, a phenomenon we call 'phonon trapping'. This certainly must compete with the universally-accepted 'phonon scattering' processes. My MD simulations – now published in Nature Scientific Reports 6, 32150 (2016) – show that the interactions between a heat front and the interface depend on the presence of SLMs with frequencies within the temperature range of interest. Here is one example: I begin with the Si nanowire at $T_0$=120 K and set the system away from equilibrium with a Si slice heated so that the heat front arrives at the interface at some higher temperature $T_{hf}$. In the case of the SiGe interface, there are low-frequency SLMs within this temperature window. These SLMs are resonantly




excited by the heat front (1-phonon process) within a few tenths of a picosecond (ps), and then the temperature of the Ge layer (left figure) increases promptly because Ge has many low-frequency modes. This is, of course, precisely what one would expect from phonon scattering as well. The figure on the right shows this substantial delay. Phonon scattering cannot explain these data.

These results show that knowledge of the vibrational properties of defects suffices to predict how a heat front will interact with defects in various temperature windows. And if such processes can be theoretically predicted, they can also be controlled experimentally. This ability to control heat flow with defects suggests the possibility of designing 'thermal circuits' – analogous to electrical circuits – an exciting prospect that could revolutionize the industry. Much more research is needed in this area, and I leave this to my successors in Stefan Estreicher's group."

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**Gülten Karaoglan-Bebek** graduated in May 2016 with her PhD degree. She completed her thesis work with Dr. Ayrton Bernussi at the NanoTech Center. She currently works at Intel, and she says the following:

"Terahertz (THz) waves have many applications in areas such as security screening, material characterization, biomedical imaging, and communications. However, at this frequency range there is a lack of optical components

such as optical switches, filters and modulators. Among many materials used in THz device applications, vanadium dioxide ($VO_2$) is of particular importance. $VO_2$ experiences a fast reversible insulator-to-metal phase transition at ~68 °C. This material property is accompanied by significant changes in $VO_2$ electrical and optical properties, especially in the THz and infrared (IR) regions of the electromagnetic spectrum. In my dissertation, I studied the optical properties of doped and undoped $VO_2$ thin films in the THz and IR range for a variety of applications. Terahertz Time-Domain Spectroscopy (THz-TDS) was used to investigate the THz transmission properties of $VO_2$. We explored effects of doping with tungsten and hydrogen on electrical and optical properties of $VO_2$ thin films in the THz range. By doping with tungsten, we were able to obtain a gradual phase transition window for future analog based device applications in the THz range. Similarly, by hydrogen-doping, we were able to get THz antireflection applications at room temperature.

I am very grateful for the opportunities available to me through the physics department and the facilities and resources of the Nanotech Center. I attended several American Physical Society and Material Research Society meetings to present my research thanks to funds from the department and Graduate School. Without this financial support, it would not have been possible for me to carry out and present my research. I am also very thankful for the scholarships I received from Bucy and Seibt families."

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**Thomas Halverson** graduated in May 2016 with his PhD for his work with Dr. Bill Poirier in the Department of Chemistry and Biochemistry. He said the following about his time here:

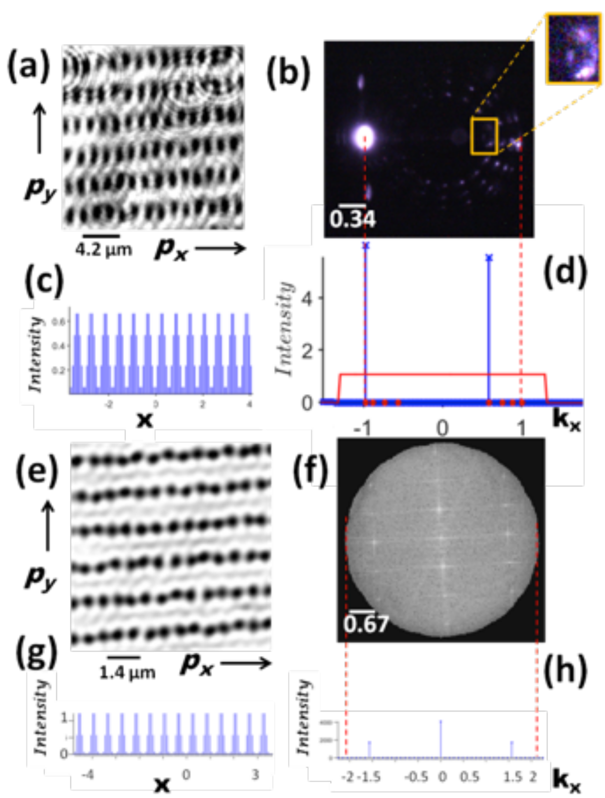
"Very few students at Texas Tech know that the physics and chemistry departments have joint faculty. However, this fact should not come as a shock since chemistry and physics, at the fundamental level, are inextricably linked. It is in the marriage between these two subjects that the focus of my research could be found. The ultimate goal of my dissertation work was to explore what is known as the exponential scaling problem, which is ubiquitous throughout computer science. This issue has been the bane of quantum chemistry since, essentially, the advent of computers. In short, the exponential scaling problem states that the size of the matrix needed to compute a fixed number of numerically converged eigenvalues grows exponentially with the dimensionality of the system. This is, of course, compounded by the cubic relationship between matrix size and time needed for direct diagonalization. The combination of these two poorly scaling methodologies creates a bottleneck as to the size of molecules that can be directly studied using quantum mechanics and, in turn, stunts the degree of our understanding of how quantum effects play a role in large-scale processes.

Throughout the course of my research, the main tool I used to confront the issue of exponential scaling was phase space—i.e., the mathematical space where each state of a given system is denoted by a unique coordinate. The use of phase space is quite straightforward and prevalent in classical mechanics, but its use is not obvious in the realm of quantum mechanical. However, there does exists a mathematical formalism, developed by Wigner and Weyl, that allows for direct transformation from the Hilbert space, and quantum mechanical operators, to phase space, and quasi-probability distributions. By utilizing this formalism to better understand basis set representation, I was able to explore how phase space localized basis functions (known as wavelets) combined with phase-space based basis truncation can be used to create very efficient basis sets for bound state molecular calculations. In fact, basis sets of this type are able to directly defeat the exponential scaling problem, at least in the infinite basis set limit. Moreover, I systematically explored the use of phase space ideas to increase the efficiency of another, more traditional basis set, the harmonic oscillator basis. Through this analysis I was able to develop new truncation methods that dramatically increase the efficiency of the harmonic oscillator basis set. In the end, we were able to establish that combining multiple truncation schemes with multiple basis sets allows for the best overall picture of the energy spectrum.

All of the aforementioned ideas were used to create a stand-alone software package (SwitchBLADE) that can compute the vibrational energy levels for any molecule whose vibrational potential energy can be expressed as a normal mode expansion. At first glance this seems to be somewhat limited; however, this actually constitutes a large number of applicable systems. The key is that code is "dimensionally independent" in that the total number of degrees of freedom is an input parameter. Using SwitchBLADE, I was able to compute a very large number of accurate vibrational states for many different systems—phosphorus dioxide, methyleneimine, acetonitrile, and benzene. Moreover, SwitchBLADE was written to take advantage of state-of-the-art high performance computing platforms and was shown to scale up to thousands of cores. This culminated in the direct diagonalization of matrices close to one million squared in size, constituting some of the largest calculations ever done beyond those of simple benchmark tests."

**Sanchari Sen** received her PhD degree for her research with Dr. Luis Grave de Peralta. She too is now employed by Intel and sent the following about the main results from her dissertation:

"My dissertation focused on Electronically Controlled hemi-spherical Condensers (ECC) with the capability to individually control each light emitting diode (LED). Microscope condensers enhance the resolution of an image by illuminating the sample with a cone of light. Traditional microscope condensers consist of a combination of bulky lenses (or mirrors) and diaphragms designed to illuminate the sample with a cone of inclined light. Digital condensers illuminate the sample from multiple directions with inclined light produced by an array of LEDs. Such an electronically controlled condenser permits a smooth switch from bright field to dark field microscopy without having to mechanically change the microscope condenser attached to the microscope or to introduce a spatial filter into the back focal plane of the objective lens. Moreover, electronically controlled microscope condensers permit the implementation of novel microscopy techniques that provide resolution values well below the Rayleigh resolution limit of diffraction-limited imaging instruments.
Such condensers will find multiple applications in digital pathology, hematology, immunohistochemistry, and neuroanatomy. Several techniques – namely, Fourier Plane Imaging Microscopy (FPIM: by Dr. Peralta's lab 2013), Fourier Ptychography Microscopy (FPM: by Caltech 2012), and Dual Space Microscopy (DSM: by Dr. Peralta's lab 2016) – were implemented using ECC for the first time. Photonic crystals were imaged using the FPM technique, and it was discovered that the technique cannot surpass the resolution limit for this particular kind of sample with single periodicity in one direction. FPM was implemented in 1D, and a case similar to the experimental result was simulated to verify this fact (see figure). Also, my research implemented FPM outside of visible light range for the first time. DSM was introduced to surpass the resolution limit for photonic crystals. I also discussed the fundamental flaw of small field of view for using LEDs as well as future prospects for implementing FPM/DSM using IR laser.




The figure displays some significant observations from my dissertation research: (a-b) Experimental NIR images, (c-d) simulated, (a, c) low resolution RP, and (b, d) FP images with $NA_o$ =1.3 obtained with an individual LED with $NA_c$ = 0.96 corresponding to (a-b) the 2D sample, (c, d) 1D simulated object with a period px = 0.6 µm. The inset in (b) shows the first-order diffraction spot contained in the yellow rectangle. The red window in(d) signals the region of the FP accessible to the microscope. (e, g) High-resolution RP, and (f, h) corresponding synthetic FP images obtained using the FPM algorithm using (e-f) experimental 2D, (g-h) simulated 1D low resolution RP images. Intensity, x, and kx are plotted in arbitrary units, µm, and NA units, respectively.

I am currently working at Intel, at the LABS division on a metal oxide semi-conductor detector for gases. My work is research-based and is exciting. I am analyzing the data for better, cheaper, and quicker detection of gases as opposed to optical spectroscopy. I was enthused by the philanthropic interest of Intel to provide free samples of these detectors to developing countries, along with other contemporary clients."

# Unmasking Innovation

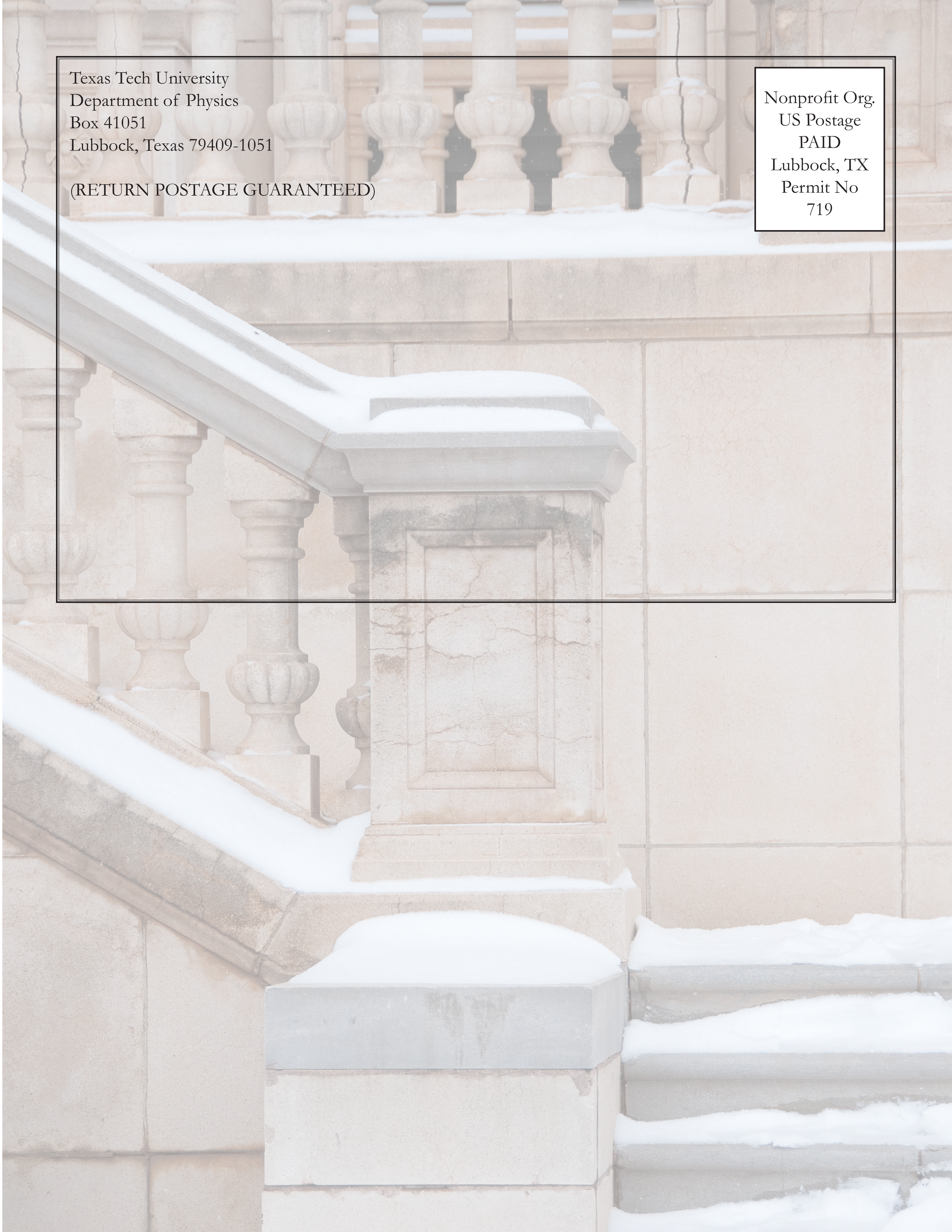
THE CAMPAIGN FOR ARTS & SCIENCES

The College of Arts & Sciences has long played a vital role in the success and growth of Texas Tech University. As one of the university's original four colleges, Arts & Sciences has sustained and enhanced the unique humanities, social sciences, physical and life science programs that are the hallmarks of the Texas Tech education experience. My biggest challenge as dean is finding ways to support our students and faculty as Texas Tech moves forward to become a nationally known research university. What distinguishes the College of Arts & Sciences is its scholarship and research. Faculty who are innovators in their areas of expertise and students who develop into innovators in their respective careers: innovative astrophysicists such as Alessandra Corsi and Benjamin Owen, who are part of the national team that detected gravitational waves, an event that leads to the prospect of an entirely new form of astronomical observation; and innovative high energy physicists such as Nural Akchurin, Shuichi Kunori, Sung-Won Lee and Igor Volobouev, who are members of the international CMS team that discovered the Higgs particle, the particle that gives all matter mass and is the last missing piece for understanding of the fundamental nature of the universe. Other results of university-led research include future understanding of and protection against the Zika virus; grasping the cultural differences leading to conflict in the Middle East; and developing cheaper, more efficient energy production; the fact that there is more computational power in your mobile phone than was available on the computers that took man to the moon, profoundly affects our lives. We take for granted the tremendous results produced by modern research universities and normalize amazing advances in our lives. Unmasking Innovation: The Campaign For Arts & Sciences is the first campaign dedicated exclusively to the College and will provide much needed support for our students and faculty. The campaign focuses on five critical areas that are outlined in *www.depts.ttu.edu/artsandsciences/Campaign*. I would encourage you to read through these areas of focus and learn how you can contribute to the success of future generations of Red Raiders. All gifts, large or small, have an enormous impact on our ability to provide an environment of learning, discovery and innovation where our students can excel and grow.

Thank you for your support of the College and Go Tech!

W. Brent Lindquist
Dean of the College of Arts & Sciences

• Campaign Contact • Amy Crumley • (806) 834-3847 • amy.m.crumley@ttu.edu •



Texas Tech University
Department of Physics
Box 41051
Lubbock, Texas 79409-1051

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