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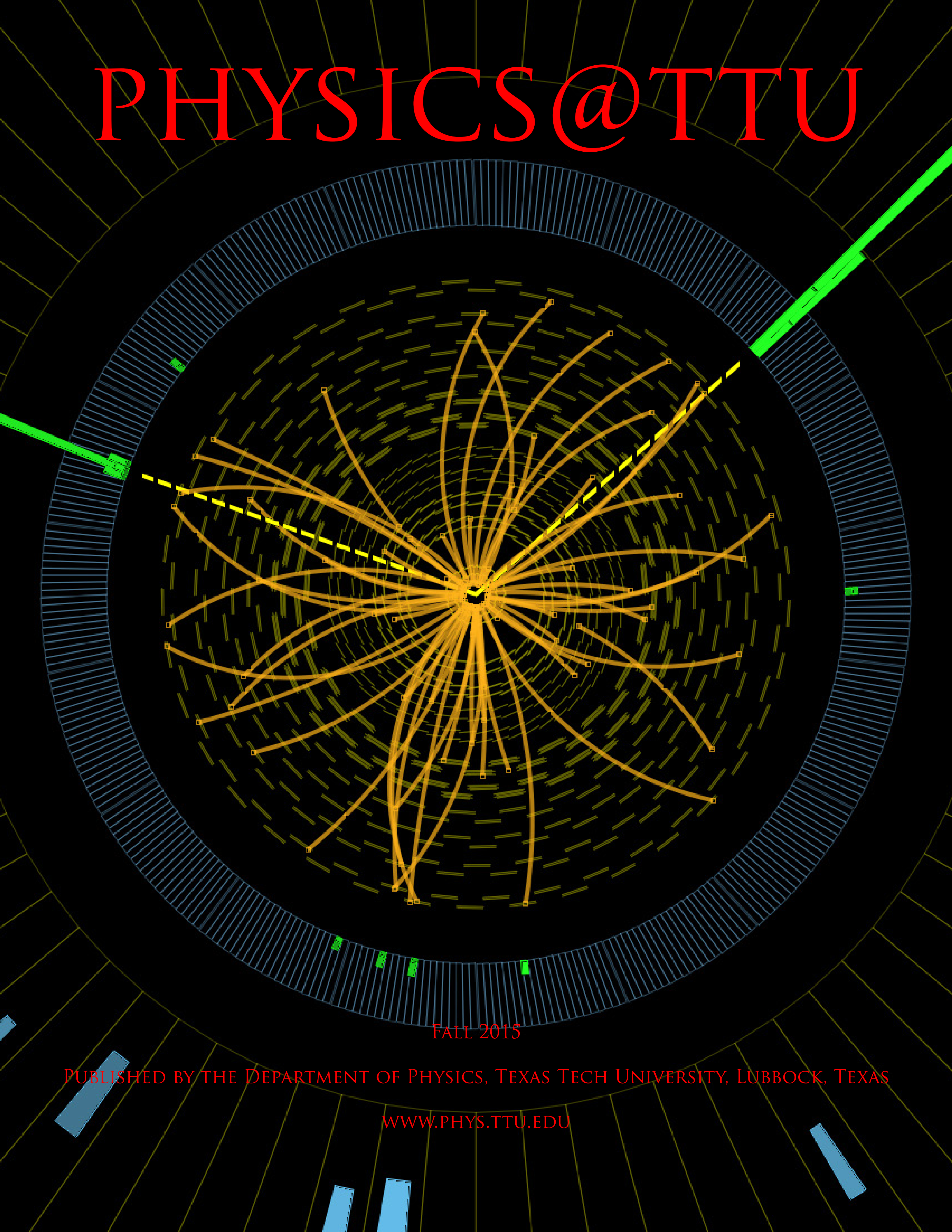

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In This Issue:

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Front Cover: Event recorded with the CMS detector in 2012 at a proton-proton center of mass energy of 8 TeV. The event shows characteristics expected from the decay of the SM Higgs boson to a pair of photons (dashed yellow lines and green towers). The event could also be due to known standard model background processes (Credit: CERN/CMS).

The View from the Chair

The holiday season is a good time to look back and reflect, and there are lots of things to think about as this issue of *physics@ttu* is being prepared. Let me share with you some of the latest news from our department.

Our department has been growing: undergraduate majors number over 130 while the graduate student count is 70 this semester. Five years ago, these numbers were approximately 50 and 40, respectively. Meanwhile, TTU enrollment has hit 36,000 this semester, an over 10% increase compared to five years ago. As a department, we are clearly growing at a much faster rate than the university and naturally new challenges emerge with this growth. While striving to enhance our research effort to an internationally recognized level, we are also modernizing and adapting more effective pedagogies in our classrooms. As we seek creative ways of using every square inch in our aging Science Building for classrooms and research labs, we recognize that this approach is not sustainable, especially as we plan to recruit additional faculty to diversify and strengthen our research mission in the next few years.

Our department now has several new faculty members, and you will find their short bios on pages 22-23. They either bring new expertise or complement an existing research area in astrophysics, gravitation, condensed matter, and particle physics. Three of them contributed articles to this issue of *physics@ttu*. Professor Corsi gives a snapshot of her work in bridging electromagnetic and gravitational waves on pages 5-7. Professor Sand discusses his current research interests on supernovae, small galaxies, and black holes on pages 8-11. Professor Kunori, who joined the high energy physics group in 2013, explains on pages 12-15 how we look for dark matter at the highest energy particle accelerator in the world, the Large Hadron Collider at CERN in Geneva, Switzerland.

Our high energy physics group was involved in the Higgs boson discovery at CERN, as announced on July 4, 2012. After a long and hard effort that, for some of our faculty, started in 1994, this discovery represented both a cherished reward and an honor. The 2013 Nobel Prize in Physics went to two theorists, François Englert and Peter Higgs, who independently predicted this symmetry breaking phenomenon in 1964. As the saying goes among particle physicists, "Yesterday's discovery is today's calibration and tomorrow's background." The Higgs boson is not yet our calibration signal, and much work needs to be done to understand all properties of the Higgs, but we are already moving onto higher energies in anticipation of new discoveries, perhaps involving dark matter.

As external research funding for physical sciences has been shrinking in the US, the competition for limited dollars has become fierce. Despite this tough funding climate, our research groups have garnered $1.4M in FY15, and there are good reasons to believe that FY16 will be a better year. Another indicator of healthy research activity is the number of postdoctoral researchers in our department. We had four only five years ago, and now we have thirteen (two in gravitation, seven in astrophysics, and four in high-energy physics).

The Society of Physics Students (SPS) has been very active. I remind everybody that it was awarded the Outstanding SPS Chapter in 2012-2013 by the American Physical Society and that they received the Marsh W. White Outreach Award twice, in 2010 and 2011. You can read Alexander Cardona's piece about their recent adventures on pages 18-19, as well as follow SPS on Facebook and Twitter.

In the last year, we awarded three BS, nine MS, and three PhD degrees. We are proud of our graduates and the three PhDs give a brief view of their work at TTU in this issue (pp 24-26). I wish Drs. Brittany Baker,

Daniel Dominguez, and Terence Libeiro the very best.

The history of graduate work in our department goes back to 1930, when the master's degree program was established. The first MS thesis was written by Charles E. Houston and titled *A Study of Certain Atmospheric Electric Phenomena Accompanying Sand Storms* under the direction of Professor W. A. Jackson. On page 27, a few images are reproduced from this thesis. The first PhD dissertation came from Gilbert L. Varnell, *Hindered Internal Rotation Fine Structure of the 3 Micron Vibration-rotation Spectra of* CH_3SH, under the direction of Professor Glen A. Mann in 1968. Professor Lichti unearthed some forgotten but intriguing history of theses written by our graduates and compiled a list that can be viewed on our web page. The list is long (126 PhDs and 169 MSs), and the wide variety of research topics provides for a fascinating perspective on the research trajectory of our faculty over the last 90 years.

Professor Lichti retired in August of this year. He was our chairperson for the last six years and a professor, colleague, friend, and mentor for many during his 36 years at TTU. Esther and Roger are currently preparing to move to Vermont, and we wish them the best. Professor Lodhi also retired earlier this year. He was one of the founding members of the physics doctoral program and was a valued member of our department for 52 years. Both Professor Lichti and his family and Professor Lodhi have established endowments to provide scholarships to our students in the coming years. I thank them for their generosity and continued commitment to our department!

I would like to continue working towards establishing a Physics Advisory Board (PAB) that will fulfill several critical functions in executing our strategic and long-term plans. I have had the pleasure of speaking with several enthusiastic alumni and friends about the function and make-up of this board, but I would also like to hear from our broader TTU physics family. I wish to see our department grow not only in numbers of faculty and students but also in scientific stature. In addition to building on our strengths, we must expand into new disciplines that hold the promise of discoveries and inventions that can address the most pressing problems of the day. Our physics department cannot be disconnected from daily concerns when the world is facing a serious energy crisis, for example. But neither can we afford to be bystanders to the puzzle of what makes up the universe as long as dark matter and dark energy remain enigmas. We will have to think hard about how to be effective participants in many types of journeys. One thing is clear, though: It will take sustained personal and institutional commitments to make major strides. I invite all of us to think ahead and do what we can for our department. I expect that the PAB will be in place in 2016 to help us consider some strategic initiatives.

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

Sincerely yours and Seasons Greetings,

Nural Akchurin

Nural Akchurin
Professor and Chair
(nural.akchurin@ttu.edu)

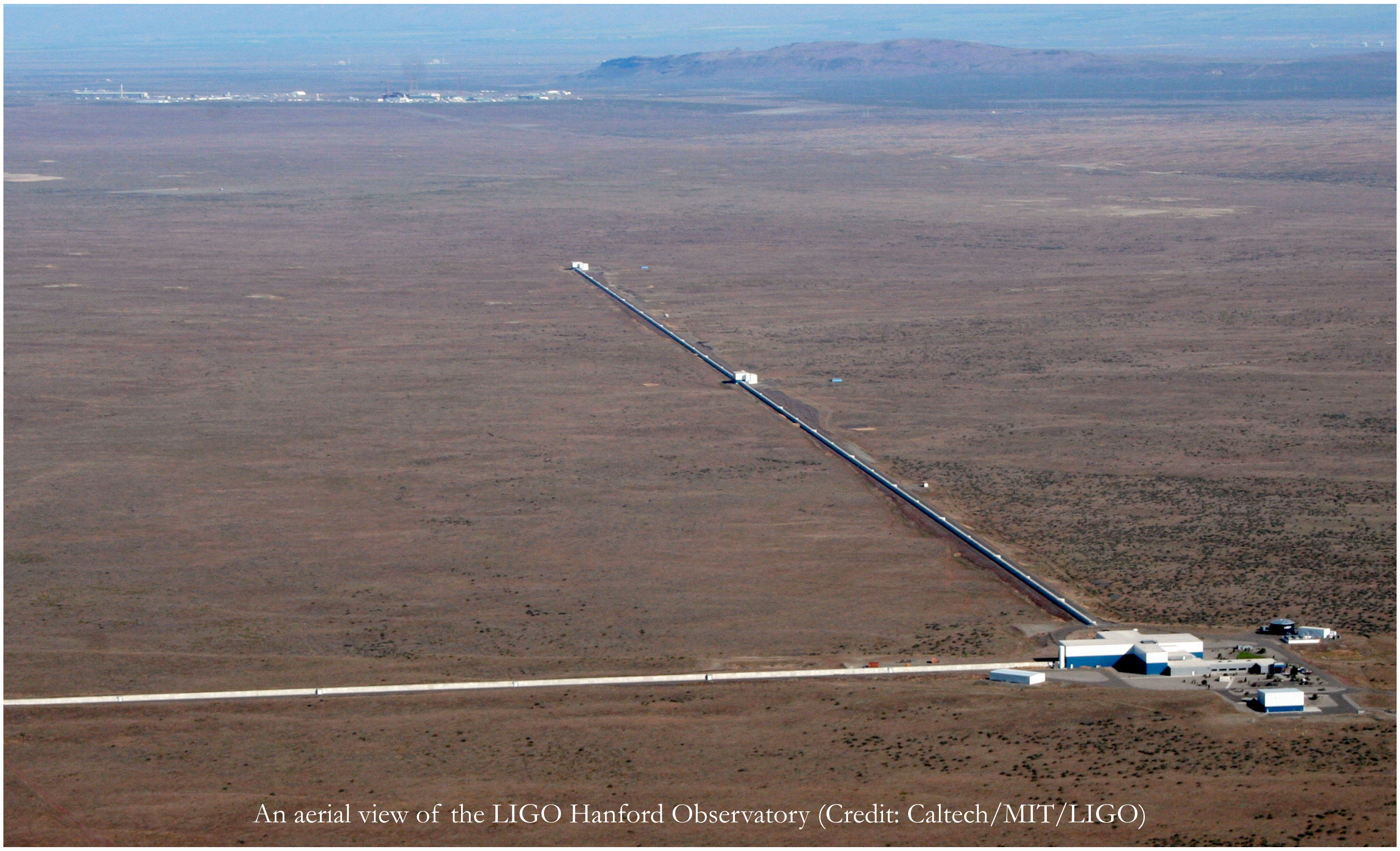
Bridging the Electromagnetic and Gravitational Wave Skies: A New Frontier in Astronomy

Alessandra Corsi

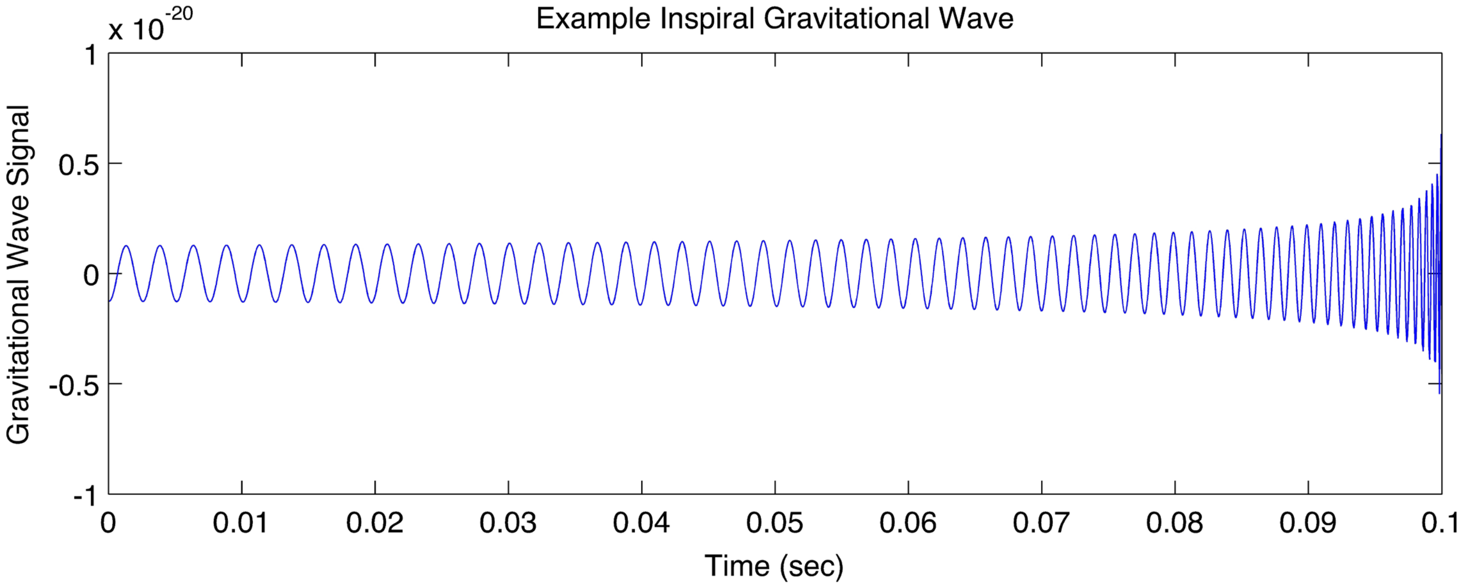
Throughout history, astronomers have relied on electromagnetic (EM) radiation ("light") to study the cosmos. Scientists have achieved exciting discoveries every time the development of new technology has enabled them to observe the cosmos using new parts (i.e. different wavelengths) of the EM spectrum (from gamma-rays to radio). But astronomy today is not only a multi-wavelength science; it is also a multi-messenger science. Indeed, phenomena that are "invisible" through EM radiation can be "observed" using other messengers, such as neutrinos and gravitational waves (GWs).

GWs, ripples in space-time predicted by Einstein's theory of General Relativity, provide complementary information to that provided by EM radiation and can be used to observe astrophysical systems that are "invisible" or almost impossible to detect by any other means, such as black hole (BH)-BH binaries. Although the Hulse–Taylor binary pulsar has given us indirect evidence of the existence of GWs, a direct detection of gravitational radiation has yet to be achieved. GWs interact with matter by compressing objects in one direction while stretching them in the direction perpendicular to it. But this effect is minuscule compared to that of EM waves on charged particles. In fact, the big challenge that scientists around the world are facing in the quest for a direct detection of GWs is the fact that GWs are exceedingly small.

LIGO, the Laser Interferometer Gravitational Wave Observatory, is a set of two GW interferometers (one located in Hanford, WA, shown in the image below, and one in Livingston, LA) with 4-km long arms. The LIGO detectors are L-shaped: GWs traveling through the plane of the detector should cause one arm to stretch



An aerial view of the LIGO Hanford Observatory (Credit: Caltech/MIT/LIGO)



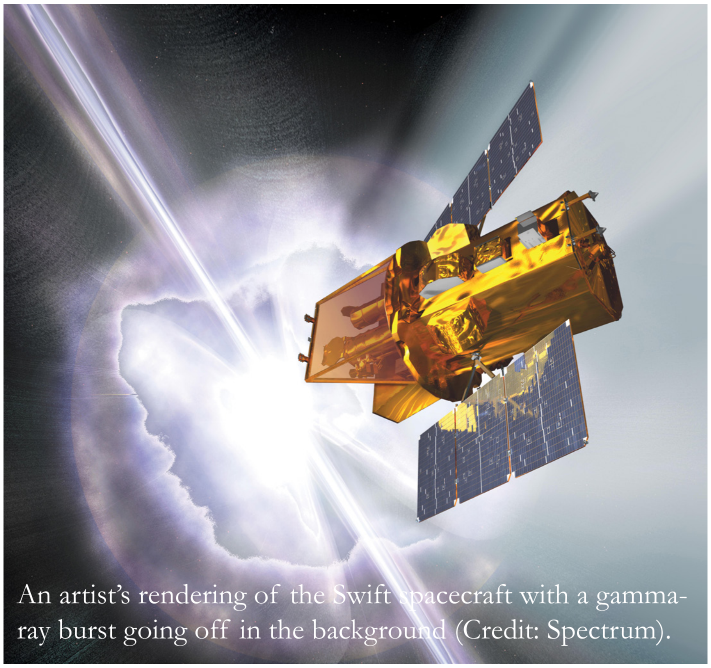
Simulated inspiral gravitational waveform (Credit: A. Stuver).

and the other one to compress. The relative difference in arm length cause by GWs is measured using interferometry, i.e. by looking at the interference patterns produced by light traveling along the two arms. From the most energetic astrophysical systems, GWs are expected to produce displacements of the order of 10^{-18} meters (1000 times smaller than the diameter of a proton!) over the 4 km-long arms of the L-shaped LIGO detectors. The so-called "chirp" signal that would be produced during the inspiral phase of a binary system of two compact objects (two neutron stars, two BHs, or a neutron star and a BH) that are about to coalesce is a good example of the type of GWs that LIGO is searching for.

The year 2015 marks, in my view, a true milestone in the field of GW physics and multi-messenger astronomy: Advanced LIGO is now online, collecting data during its first Science Run (September 2015 - January 2016). By 2019 Advanced LIGO is expected to reach a sensitivity 10 times better than Initial LIGO (whose last science run ended in 2010), thus enabling us to probe a volume of the universe 1000 times larger than before.

The first direct detection of GWs will by itself be a discovery worthy of a Nobel Prize. However, because the localization accuracy of ground-based GW detectors is rather coarse (a few tens to a few hundreds of square degrees), identifying the EM counterpart to a GW event could provide orders of magnitude better localization and enhance confidence in the detection. For this reason, the LIGO Scientific Collaboration is not only analyzing data collected during notable (and well-localized) astrophysical events discovered via EM observations but also working in direct collaboration with astronomers to enable the EM follow-up of coarsely localized GW candidate events. This multi-messenger strategy promises to yield a completely new view of the EM sky.

My group here at TTU is deeply involved in the LIGO electromagnetic follow-up program, with special focus on a particular class of multi-messenger sources: gamma-ray bursts (GRBs), the most relativistic cosmological "fireworks" we know of. GRBs are remarkable ex-



An artist's rendering of the Swift spacecraft with a gamma-ray burst going off in the background (Credit: Spectrum).

A cloudy twilight at the VLA: Clouds linger at twilight over the Karl G. Jansky Very Large Array in its most compact configuration. The National Radio Astronomy Observatory is a facility of the National Science Foundation operated under cooperative agreement by Associated Universities, Inc.

amples of astrophysical phenomena where radiation at all wavelengths, from radio to gamma-rays, have given us fundamental clues to the physics at play. In the so-called “fireball model,” GRBs are associated with relativistic blast waves generated by an impulsive energy release from collapsing massive stars or from the merger of double neutron star or BH-neutron star systems. Shocks (in which particles are strongly accelerated and magnetic fields are amplified) in the relativistic ejecta give rise to flashes of gamma-rays (GRBs), followed by a longer-lived, multi-wavelength (from radio to X-rays) “afterglow.”

Because the light we receive from GRBs is produced at distances greater than a light hour ($\approx 10^{14}$ cm!) from the central source, this “traditional cosmic messenger” can carry only very indirect information about the catastrophic stellar phenomena that yield to GRBs. Thus, in spite of the spectacular progress made in our understanding of GRBs in the last 20 years (since the discovery of their afterglows), key questions remain open: Can we probe directly the nature of GRB progenitors? What type of exotic object does the GRB leave behind, a BH or a neutron star? GWs are the only tool we have to directly probe the nature of GRB central engines and answer these key questions.

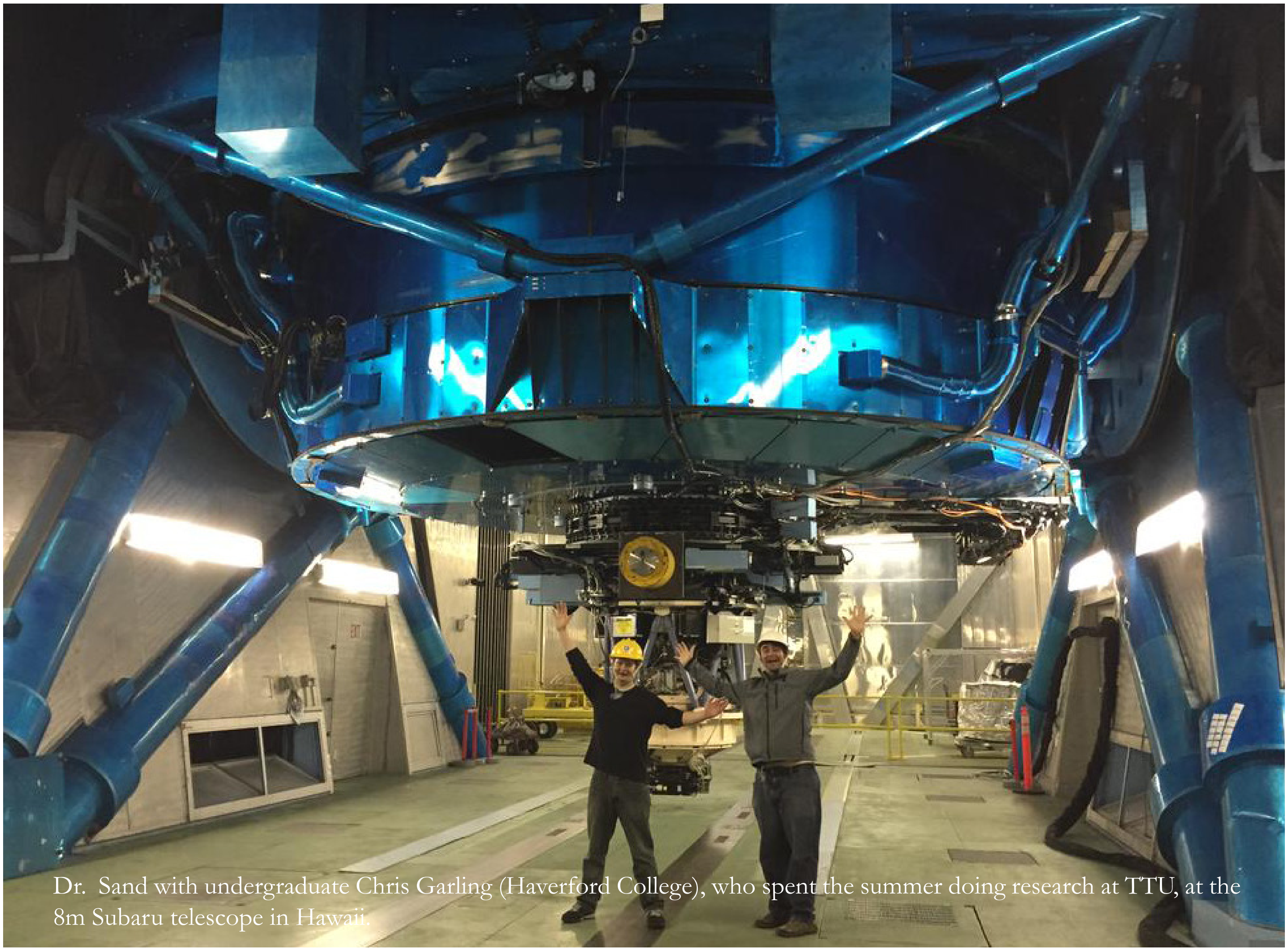
Here at TTU/Physics, we are combining LIGO data with data from ground- and space-based telescopes, such as the Very Large Array (radio), the Palomar Transient Factory (optical), and the Swift X-ray Telescope, to help LIGO achieve the first direct detection of GWs and to carry out a multi-messenger study of GRBs and other cosmic transients. We are also developing new data analysis techniques aimed at searching for GWs from “long-lived” highly magnetized neutron stars possibly surviving the GRB explosion that have not been searched for in Initial LIGO data. With Advanced LIGO now online, we are going through a very exciting time and looking forward to important discoveries. All this would not be possible without the support of the National Science Foundation (NSF), National Aeronautics and Space Administration (NASA), and TTU students and post-docs who have chosen to join me in this endeavor.

The Youngest Supernovae, the Tiniest Galaxies, and the Biggest Black Holes

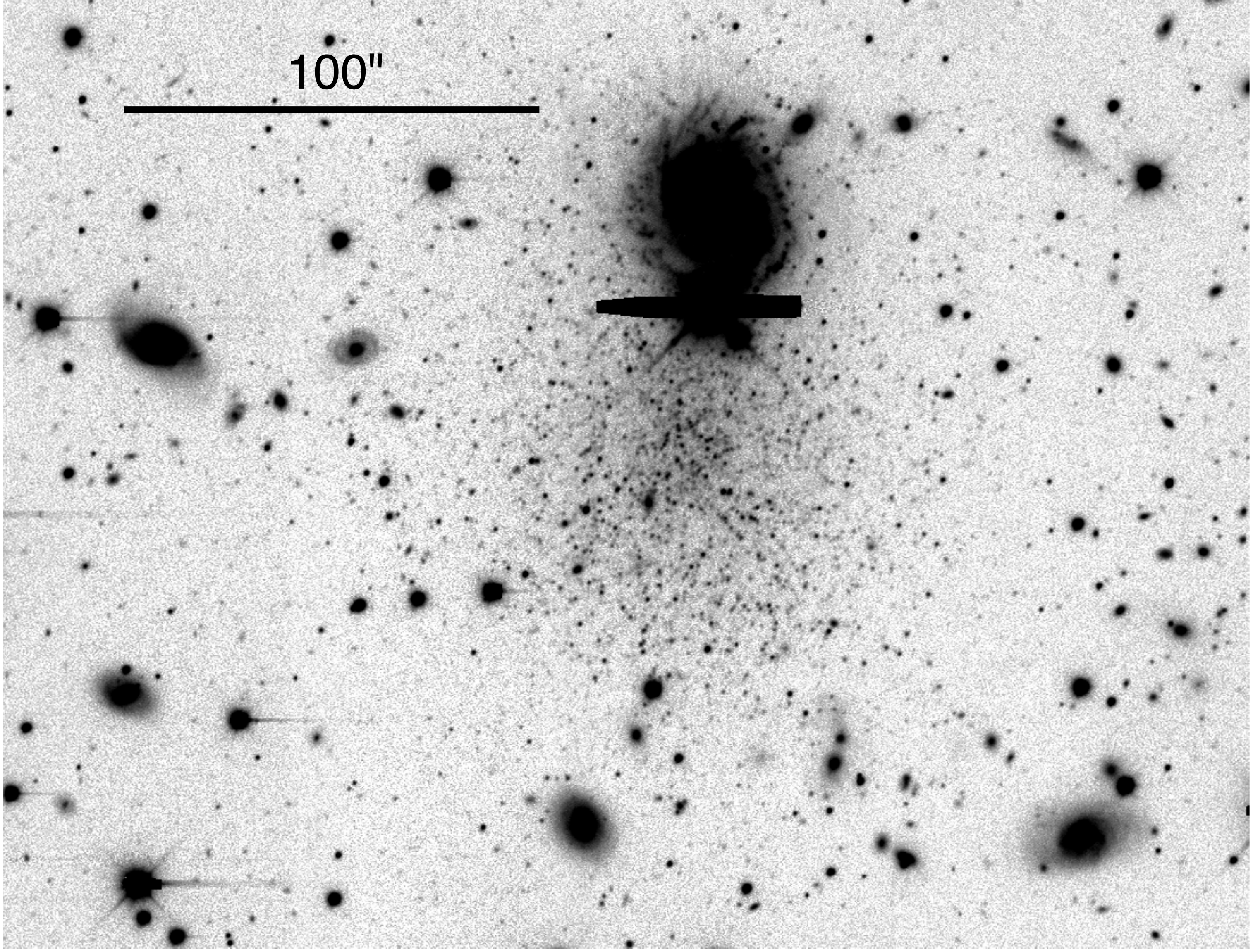
David Sand

One of the main goals of our research group is to find the faintest and smallest galaxies in the Universe. Why do we care about these "ultra-faint", barely detectable objects? Well, they are among the most dark matter dominated objects that we know and they are a relatively simple laboratory for understanding how stars form within dark matter halos in general. Additionally, so-called dwarf galaxies are the basic building blocks for larger galaxies -- galaxies like our own Milky Way gobble up smaller galaxies to gain gas and mass to become what they are today. Disturbingly, the number of faint dwarf galaxies around our own Milky Way seems to be a factor of 100 less than what we expect from our current models of galaxy formation. Traditionally, most effort has been spent on looking for faint dwarf galaxies around our own Milky Way, but there are reasons to look further afield. First, the Milky Way itself gets in the way, making it difficult to get an accurate census locally. Second, it is important to gain perspective by surveying the faint dwarf galaxies around a variety of larger host galaxies in order to make comparisons.

Our group is leading the charge in exploring the faintest members of the nearby Universe. Funded by an NSF grant, we travel to large telescopes in Chile and Hawaii (with the best conditions for observing) to peer deeply



Dr. Sand with undergraduate Chris Garling (Haverford College), who spent the summer doing research at TTU, at the 8m Subaru telescope in Hawaii.

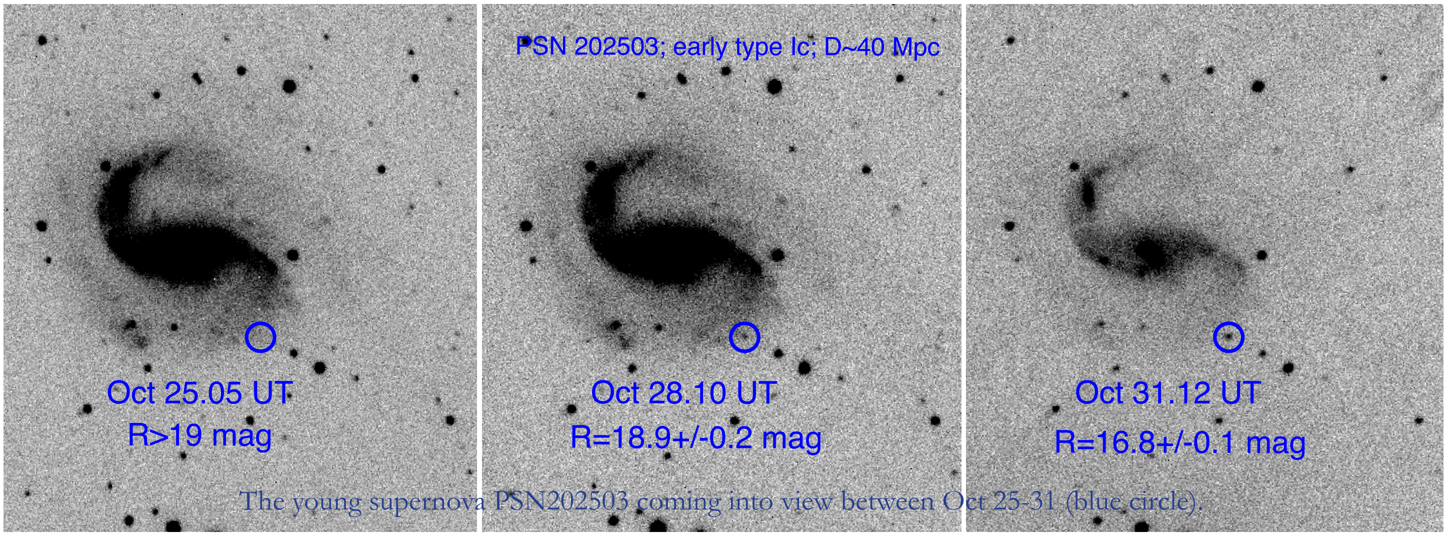


into the outskirts of these nearby galaxies. This is great fun, as you can see from the photo on the previous page that shows Haverford undergraduate Chris Garling (who spent the summer of 2015 doing research at TTU) and me at the Subaru telescope on the top of Mauna Kea, Hawaii. This 8-m telescope has a new camera, called Hyper Suprimecam, whose field of view is several times that of the full moon. We spent two nights at the summit surveying several nearby galaxies to look for faint companions. We then followed up our dwarf galaxy finds by using the Hubble Space Telescope – we have successfully applied for time the past two years in a row. And postdoctoral researchers Denija Crnojevic and Elisa Toloba have each submitted ground-breaking papers in the last year that detail new tidal streams and dwarf galaxies in orbit around some of our nearest galaxy neighbors – NGC 253 and Centaurus A. The figure above shows one of these new dwarf galaxies – named Antlia B – which is in our backyard at only ~4 million light years away. In the image, the new galaxy is the over-density of stars clumped in the middle; this nearby galaxy was likely hidden before because of the bright, saturated foreground star and background spiral galaxy just above it in the image. The scale bar shows 100 arcseconds, which is about 100 times the width of a hair projected onto the sky. Our group has discovered dozens of similar galaxies in our neighborhood and we are learning about their dark matter properties and role in galaxy formation.

Understanding which Stars Explode as Supernovae

During the hours to days after a supernova explodes, the fireball gives off clues as to how it exploded and what type of star it came from. By studying the very early rise in the supernova light curve, as well as by measuring its chemical and velocity signatures, one can actually map back to the type of star that exploded and even understand what the ignition mechanism was. The problem is that almost no supernova searches are tuned to finding supernova so young, and so progress in the field has had to rely on luck.

This year, I received an NSF award to do exactly that – find supernovae within a day of explosion. After renting



The young supernova PSN202503 coming into view between Oct 25-31 (blue circle).

a small 0.5m telescope down in Chile (see photo below), we are observing 500 galaxies per night – night after night after night – in hopes of finding the very youngest supernovae. Based on known supernova rates, we should find 10 per year, more than enough to keep us extremely busy. The telescope itself is not particularly special – in fact, it is just a high end amateur telescope – but it is completely robotic and situated at an excellent site in Chile, allowing us to observe the requisite 500 galaxies per night, every night, that should yield the number of supernovae that we expect.

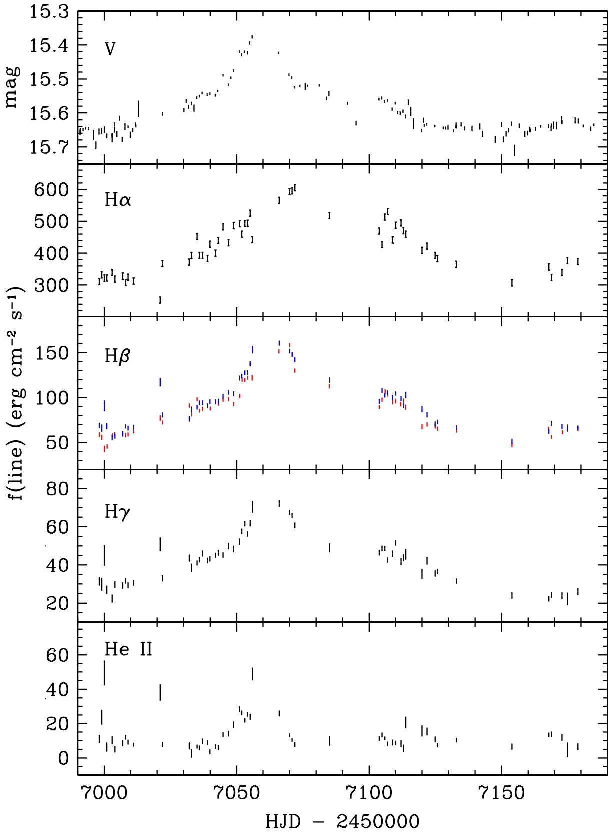
I am currently advertising to hire a postdoctoral researcher to run this program, but pilot data clearly demonstrate that we can accomplish what we wish. The image above displays some proof of concept data, showing the young supernova PSN202503 coming into view between Oct 25th and 31st. In each panel, the position of the supernova and its brightness (in R-band magnitudes, a red filter) have been labeled, along with the date as it pops into view, on Oct 28th in this case. The final panel shows that the supernova continues to brighten, even though the objects in the image as a whole have dimmed somewhat due to clouds. The NSF award will also fund two TTU undergraduates each summer for the next three years so that they can make their own supernova light curves with Gott Observatory telescopes.

Measuring the Masses of Supermassive Black Holes with Robotic Telescopes

Despite their name, black holes are not necessarily black. If they are actively accreting, the inspiraling material itself heats up due to friction and other processes and can be very bright – a dead giveaway that they are massive. We now believe that most normal galaxies house so-called supermassive black holes in their centers that are millions and even billions of times more massive than our own Sun. A fraction of them are actively gobbling up material in this way, and their centers are unusually bright. The figure on the top of the next page shows a NASA artist's conception of what these "active" black holes may look like. Here the black hole itself is obscured by a "donut" of material that is being accreted, and a jet can also be seen streaming away from the central black hole. The size scale of the donut is light-days – or roughly equivalent to the size of the solar system at its largest extent – and housed within this region is the same amount of mass as millions to billions of Suns.

One challenge is to measure the mass of these behemoth black holes. In a few cases, like at the center of our own Milky Way galaxy, we can observe the orbits of stars around the central black hole and thus derive its mass. But most of the time we cannot resolve the region of interest under the influence of the supermassive black hole; we must take an indirect route. Our group uses a technique called "reverberation mapping" or "echo mapping." By watching the light from around the black hole, which naturally goes up and down as it gobbles up gas, we can see it ionize and reemit after "bouncing" off nearby high-speed gas clouds. There is a lag time from when light is emitted from very near the black hole to when it "echoes" off these gas clouds, a lag that provides us a distance (given the speed of light travel time). That, combined with the velocity of the gas (measured from its Doppler shift), allows us to infer the mass of the black hole to within a factor of a few.

This technique for measuring black hole masses works very well but is very human intensive. It can take months of telescope time to acquire the necessary data, and until now, someone had to operate the controls. However, using a spectrograph that I built on a totally robotic telescope, we have measured the mass of a supermassive black hole, without human involvement, for the first time. In the figure below, one can see the light curve from this galaxy, Arp 151, in several different wavelengths. By comparing the light curve in the top panel to those below it, one can see a clear lag time of eight or more days, indicating that the gas clouds we are probing are eight light-days from the central black hole! These exciting results were recently accepted by the Astrophysical Journal Letters and featured as one of their research highlights, as can be seen at http://aasnova.org/2015/11/11/measuring-a-black-holes-mass-with-robotic-telescopes/. In the future, we hope to study nearby and very distant black holes so that we can learn how they grow across cosmic time. Texas Tech graduate student Leopoldo Diaz will work on this project for his thesis.



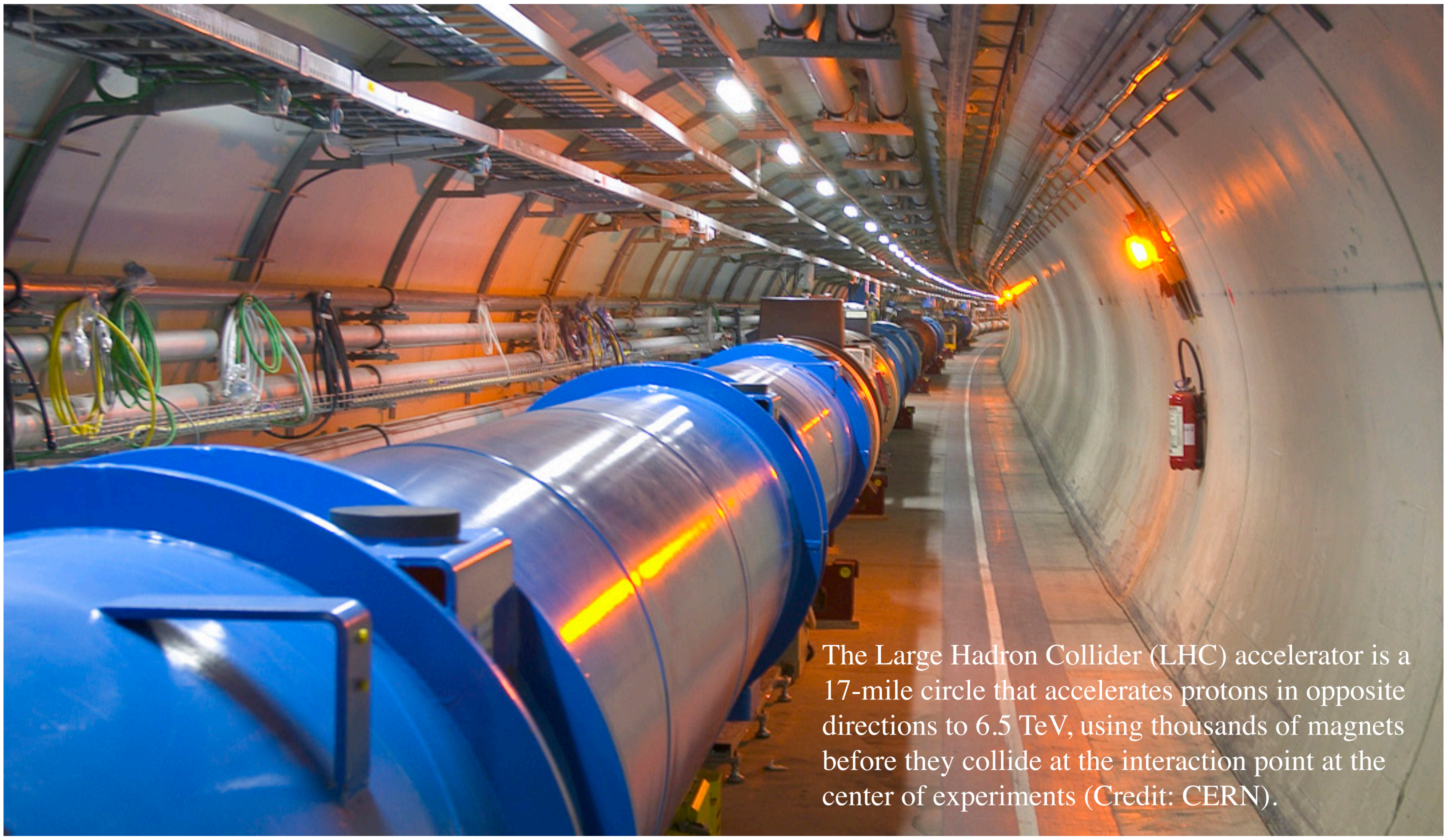
Search for Dark Matter at the LHC

Shuichi Kunori

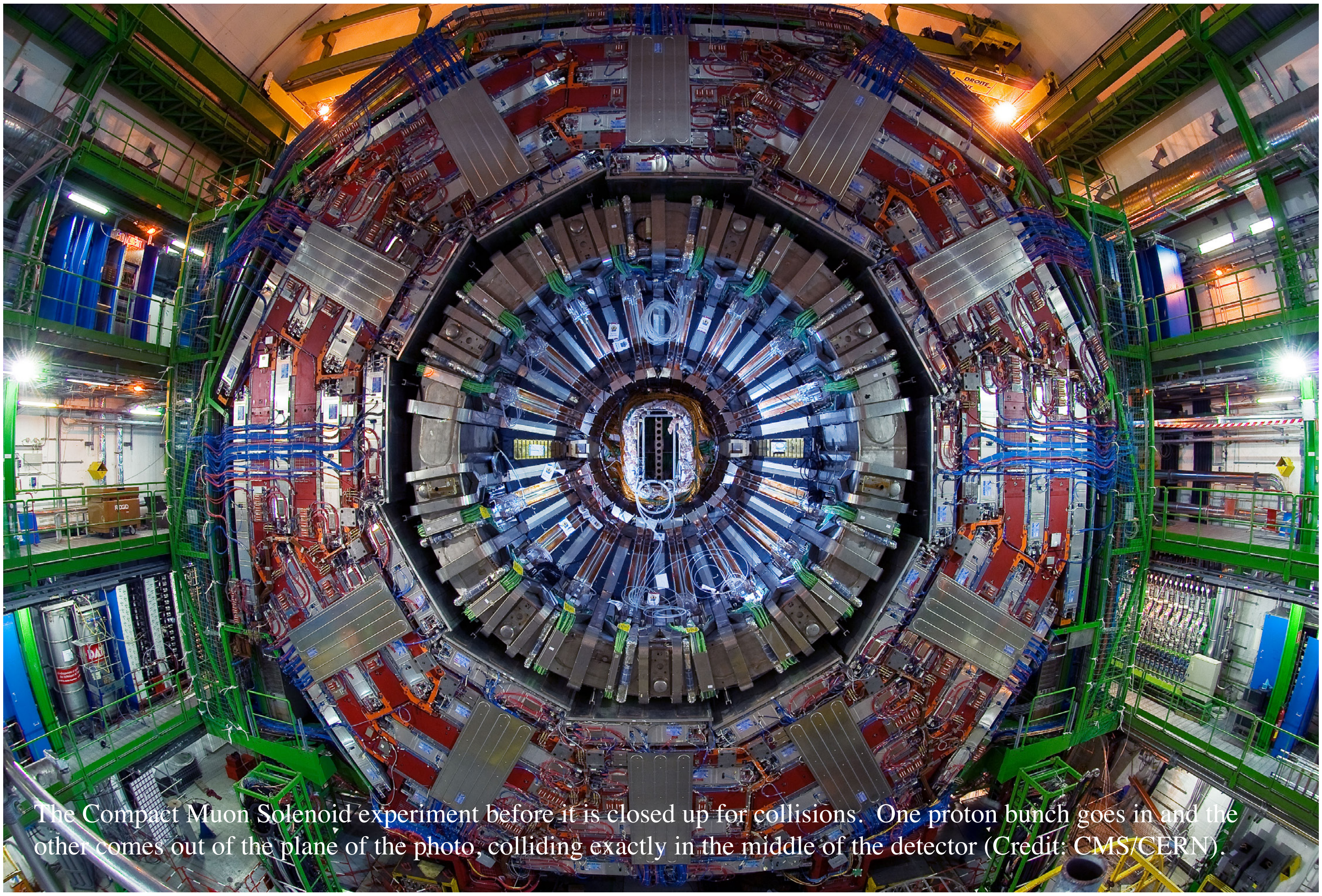
There is strong evidence from astronomical and cosmological observations that our universe is abundantly filled with dark matter. The rotation speed of outer regions of galaxies seems much higher than what is expected from the known visible matter making up these galaxies. Light rays from very distant stars are curved when they pass near a massive galaxy due to the gravitational force of the galaxy. This effect is called gravitational lensing. This curvature is also found to be much larger than that expected from the visible matter in the galaxies. Some cluster of galaxies are violently colliding with each other and emitting large amounts of light. Astrophysicists have analyzed the distribution of the matter in these collisions using X-rays which trace the baryons and gravitational lensing which trances total gravitational mass and have found that most of the matter apparently exists far from the X-ray bright region. These observations strongly suggest the existence of invisible matter – dark matter – in the universe.

According to the Standard Model of Cosmology, dark matter particles were produced in a soup of matter – quarks, leptons, and gauge bosons– after the Big Bang. The production and annihilation of dark matter continued in this hot soup. As the universe expanded, the soup cooled down, the production-annihilation processes of dark matter stopped, and dark matter remained in the universe. Because of the quantum effects at their production time, the distribution of dark and normal matter is not uniform in the universe and is imprinted in the cosmic microwave background. According to the recent Planck satellite measurement of cosmic microwave background, ordinary matter accounts for 5% of the mass-energy content in the universe, dark matter for 26%, and dark energy for 69%.

There are several theoretical explanations for the existence of dark matter. For example, primordial black holes, axions, and sterile neutrinos might be just forms of



The Large Hadron Collider (LHC) accelerator is a 17-mile circle that accelerates protons in opposite directions to 6.5 TeV, using thousands of magnets before they collide at the interaction point at the center of experiments (Credit: CERN).



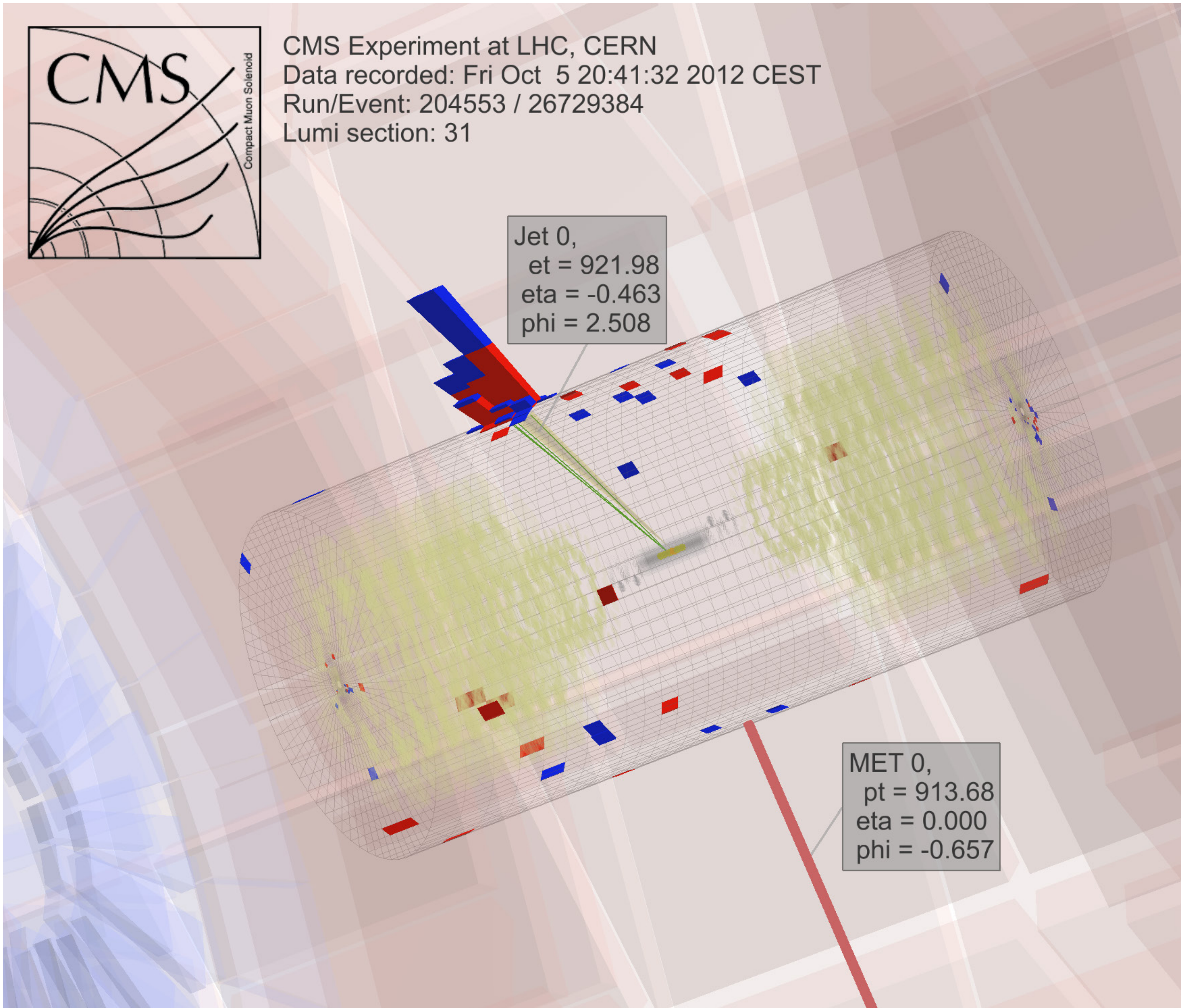
The Compact Muon Solenoid experiment before it is closed up for collisions. One proton bunch goes in and the other comes out of the plane of the photo, colliding exactly in the middle of the detector (Credit: CMS/CERN).

dark matter. One leading dark matter particle candidate is called the WIMP, or "weakly interacting massive particle." In the Standard Model of Particle Physics, neutrinos have the characteristics closest to those required for WIMPs as they are electrically neutral and stable particles with mass that interact with ordinary matter weakly via electroweak forces. But the problem is that the neutrino mass is very small, too small to explain the total amount of dark matter in the universe today.

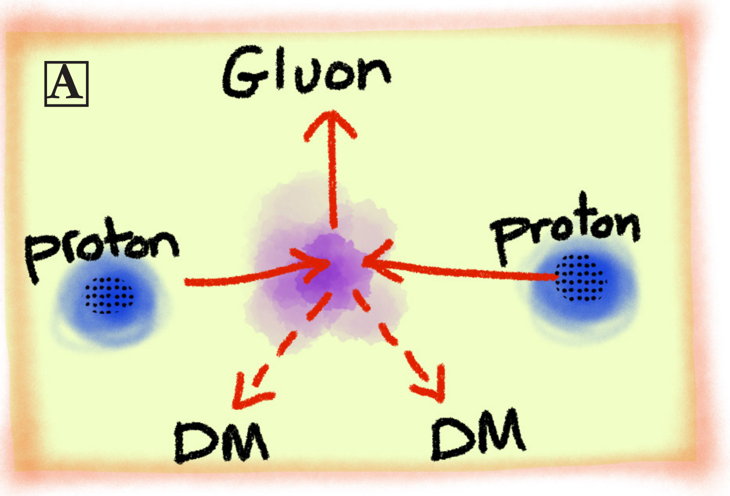
Three kinds of approaches are employed in hunting for WIMPs: The first approach among direct detection experiments assumes that dark matter particles were produced in the early universe and are still around in our universe, forming the "WIMP wind." These experiments are designed to detect the recoiling nucleons from dark matter-nucleon scattering in the detectors.

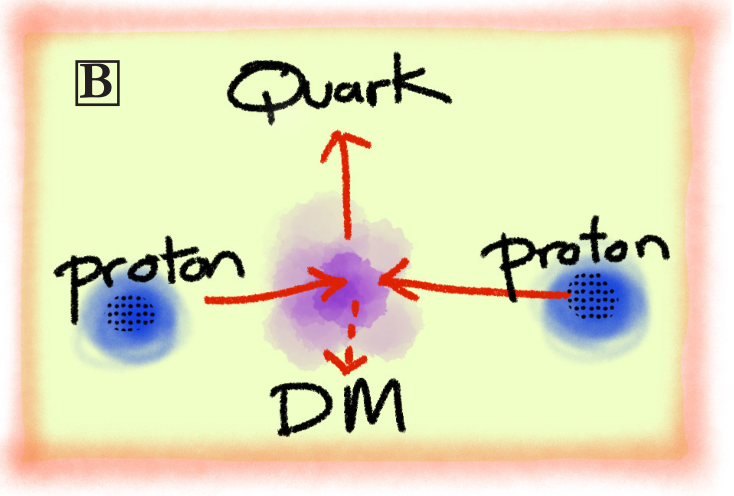
The second approach assumes dark matter particles may be concentrated in the centers of the sun, stars, and galaxies. The high-density dark matter particles may annihilate and produce a pair of ordinary neutrinos, electron-positron pairs, or photons. Indirect detection experiments search for those particles from the annihilation processes by using large underground detectors or detectors in space.

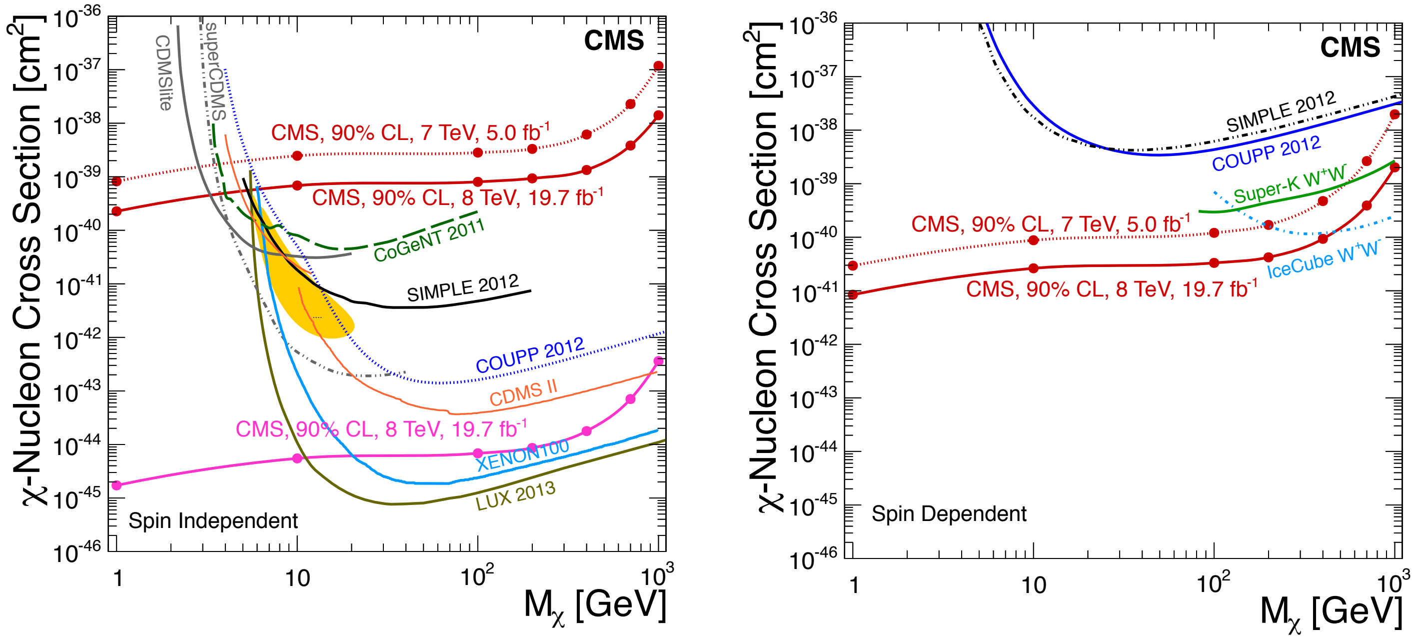
Dark matter particles may also be produced in proton-proton collisions at the LHC at the European Laboratory for Particle Physics (CERN), in Switzerland. This is the third approach. The temperature of the collisions there may be as high as during the early universe when the dark matter was originally produced. The simplest process to produce dark matter at the LHC is pair production of dark matter particles via a quark-antiquark annihilation (diagram A). Since dark matter interacts with ordinary matter very weakly, a pair of dark matter particles produced in collision simply escapes from the detector without leaving any signature. A trick to detect the escaping dark matter particle is to demand that an additional photon or gluon be radiated from the colliding quark or antiquark. The signature we are looking for is a high energy photon or gluon recoiling against a pair of escaping dark matter particles. In the case of gluon radiation, gluon materializes as mesons and baryons, forming a "jet" of these particles along the direction of the "parent" gluon. The tell-tale signature is a photon or a jet appearing in one hemisphere while there is nothing in the other hemi-



Two types of dark matter production mechanisms are shown below. The process on the right produces dark matter and a quark that leads to baryon asymmetry in the universe. The mono-jet event shown above is a candidate dark matter event, although our statistical analysis concluded that it is most likely a background event from a Standard Model physics process.







The plots show the dark matter-nucleon cross section against dark matter mass, M_χ, where the upper-right regions of curves are excluded by experiments. Our results (in red as CMS) predominantly exclude the lower mass region. Other curves come from various direct detection experiments.

sphere of the experiment. We call these "mono-photon" or "mono-jet" events, which look like violations of the law of conservation of momentum.

There is another hypothetical process that provides a solution for two mysteries in the universe –dark matter and baryon production. At the LHC, we routinely produce equal numbers of particles and antiparticles in proton-proton collisions. In our universe, however, ordinary matter comprises mostly particles (baryons) not antiparticles (anti-baryons). This asymmetry is very unnatural to particle physicists and we call it the "baryon asymmetry problem."

The amounts of dark matter and visible baryons in the universe are remarkably similar. Recently, particle physicists started developing theoretical models that explain the productions of dark matter and baryons from a common origin. In one such model, a pair of anti-quarks transforms to a dark matter particle and a quark (diagram B). The produced quark is "extra" in the universe and leads to the baryon asymmetry. The numbers of dark matter particles and protons in this case are the same. If the mass of dark matter is similar to the mass of a proton (~1 GeV), the energy densities of dark matter and baryons also become similar, which is consistent with the estimated dark matter and baryon contents in the universe. We may be able to reproduce this process in proton-proton collisions at the LHC: dark matter will escape from detection because dark matter interacts very weakly with the ordinary matter of our detectors and the quark will form a quark-jet, similar to the gluon jet in the previous case. The signature is again a "mono-jet" with an extra feature.

The LHC started operation in 2009 and produced more than one quadrillion ($\sim 10^{15}$) collisions at the center of our Compact Muon Solenoid (CMS) detector from 2009 to 2012. We had been hunting for the Higgs boson for decades and finally succeeded in finding the needle in the haystack in 2012. Now that Higgs hunting has become relatively routine, the TTU high energy group has turned its attention to dark matter searches.

Results from the running experiments are summarized in the figure above. Our results (CMS curves) are effectively covering the small mass region, including an interesting mass region for dark matter-baryon production process, around the proton mass of 1 GeV.

The LHC was shut down in 2013-2014 so that the machine energy could be upgraded from 8 TeV to 13 TeV. This year, we took the first data at 13 TeV, which we are busy analyzing. We are also working to develop a new detector for future higher intensity collisions. With a very high intensity beam, the detector will receive large radiation doses and the development of new types of radiation-hard detector is in progress.

Scholarships & Awards

The Scholarship Committee, chaired by Professor Glab, reviewed many strong undergraduate and graduate applications for departmental awards. The 2016 winners are listed below. The award ceremony was held on April 24, 2015 as part of the Physics & SPS Spring Banquet. Congratulations to all! We are also grateful to alumni and friends who generously established the funds that make these scholarships possible.

- Bucy Undergraduate Award to Kyle Artkop & Ben Rodriguez ($1000 ea.), Eric Garcia, & Alejandro Ibarra ($500 ea.)
- Ron & Nancy Miller Award to Raymond Taylor ($800)
- JW Day Award to Onome Akene ($300)
- Gangopadhyay Undergraduate Award to Jared Gonzales, Celicio Perez, & Collin Brown ($500 ea.)
- Gott Gold Tooth Award to Ramiro Torres ($500)
- Glen A. Mann Award to Aaron Smith, Joslin Andretti, & Sean O'Connell ($500 ea.)
- Roland E. Menzel Award to Eric Goodheer, Miguel Vega, Alex Cardona, & Ramiro Torres ($1000 ea.)
- CC & Alma K. Schmidt Award to Elizabeth Eckert, Ashley Taylor, Emily Flicker, Patrick Wigger, Seth Larson, David Winski, Rachel Smith, Max Zhelyeznyakov, Clayton Tuller, & Gregory Skillman ($1000 ea.) and Collin Brown ($500)
- Kenneth Sterne Award to Deven Bhakta & Mafuz Krueng ($400 ea.)
- Henry C. Thomas Award to John Hefele & Anthony Sosa ($500 ea.)
- Sidney Sundell in Astrophysics Award to Max Zhelyeznyakov ($1000), Brandon Matthews, & Blake Head ($500 ea.)
- Peter Seibt Award to Gülten Karaoglan ($800)
- David Howe Award to Zhuang Zhuang ($1000)
- Bucy Applied Physics Graduate Award to Mehmet Bebek, Michael Holcomb, Gülten Karaoglan, & Yu Mao ($4000 ea.) and James Faulkner & Christopher Stanley ($2000 ea.)
- Professor of the Year went to Professor Thomas Gibson
- Outstanding PhD student went to Mehmet Bebek
- Outstanding MS student went to Keller Andrews
- Outstanding TA went to Darshan Desai
- Outstanding Graduating Seniors were Justin Way & John Hefele

Society of Physics Students

Alexander Cardona

Over the past year and a half, the SPS chapter has been revamped as a student organization and has become more active. In addition to holding several successful annual activities, the student members have become a solidified group by working with each other to create organized events and trips, upgrade the SPS room, and help each other understand physics.

In Spring of 2014, SPS went on a weekend trip to the Very Large Array and also to the Trinity Site. The visit to the Very Large Array was particularly helpful to students in the new and thriving TTU astrophysics concentration group, who were able to observe the day-to-day operations in several careers that may interest them. At the Trinity Site, students learned about the history of nuclear physics.

During the 2014 - 2015 school year, SPS held various social events to ease the stress that students tend to face as they settle into the school year or prepare for exams. These included Bowling Night, Game Night, Movie Night, SPS lunch/dinner, and various other activities. Related to this, motivated SPS members independently organized a hugely successful Super Smah Bros. Tournament that was open to the public. At the start of the Spring 2015 semester, SPS held the annual Departmental Scholarship Award Banquet. This was the first year that the SPS chapter was able to pay for all attendees. As a twist to the tradition of inviting a speaker, SPS asked new and current faculty, as well as students and other members of the department, to give small presentations of their own. This allowed undergraduate and graduate students alike to learn about all the kinds of research that engage members of the physics department.

SPS has also encouraged many of its members to consider undergraduate research projects. To date, well over three-quarters of the upperclassmen are involved in some sort of research group in areas ranging from nanotechnology and semiconductors to solid state and astrophysics, astronomy, and more. SPS is proud that so many undergraduates are developing their skills outside of the classroom.

In past years, SPS held an annual night-time event at the Gott Observatory at which all who were interested could observe multiple astronomical objects alongside professors. This appropriately named "Star Party" is now being hosted by SPS every semester, in conjunction with the South Plains Astronomy Club (SPAC) and Dr. Maurice Clark. Participants are able to use not only the telescopes provided by SPAC but also those used for observational astronomy labs to observe the night sky and learn about the equipment.

Recently, the TTU SPS chapter was able to take a weekend trip to Sandia National Labs. After all attendees passed background checks, the group was able to get an inside look at various projects being conducted at the Labs and to acquire priceless information and advice regarding graduate school, careers, and internships there. **Rayburn Thomas** (BS2002, MS2004), who arranged our visit to Sandia, is now a program manager in accelerator operations. SPS was able to get a closer look at Hermes III (bottom), the Saturn Project, and related projects. Capping the exciting weekend, SPS attended both the Albuquerque Balloon Festival and the Nuclear Science Museum. Currently, SPS is working on a trip to the Pantex Plant for the upcoming spring semester.

Renovation was key when it came to the SPS Lounge. The single, old, and lonely computer was recently replaced with three new ones so that SPS members could better utilize the lounge for research and studying. Older posters were removed to make room for more whiteboards. A surplus printer was found and placed

in the lounge to provide free printing for members. An archaic microwave and mini-fridge have been upgraded and a coffee maker added to help with late night sessions. Pictures of the aforementioned events and activities can be found at www.phys.ttu.edu/sps/. SPS plans to update its homepage soon to create a more streamlined and professional appearence.

We Hear that...

Tony Kaye was one of the few winners of the 2015 competition for the Presidential Collaborative Research Grants Program and will receive full funding of $50K.

* * *

In May 2015, the Space Telescope Science Institute, AURA awarded Dave Sand $26K in support of his HST project, "A New Dwarf Galaxy Associated with an Ultra-Compact High Velocity Cloud."

* * *

Tom Maccarone's project "Deep Observations of NGC 4472: A Special ULX, Point Sources, and Diffuse Emission" has been funded at the level of $68K by NASA.

* * *

Charles Ramey II, a Physics Education Research (PER) graduate student working with Beth Thacker, contributed "Redesigning the Structure and Pedagogy of a Modern Physics Laboratory" to the American Association of Physics Teachers (AAPT) conference in July. Charles was also awarded a Physics Education Research Topical Group (PERTG) scholarship-in-residence grant from the PER Leadership Organizing Council (PERLOC) for continued work and collaboration on researching, developing and assessing upper level laboratories. Hani Dulli, a visiting assistant professor in our department, discussed "How Educated Is Educated Guess, Anyway? Cueing Effects in Physics Concept Inventories" at the same conference.

* * *

The NSF awarded Dave Sand a grant of $538K for support of his project entitled, "Unveiling the Physics and Progenitors of Cosmic Explosions with a One-Day Cadence Supernova Search." This award starts in 2015 and ends in 2018.

* * *

Kazim Gümüs (PhD 2008) was promoted to associate professor in October 2015. He is with Erciyes University in Turkey.

Alessandra Corsi won an NSF CAREER grant for $720K for the next five years for her project, "Radio and Gravitational-Wave Emission from the Largest Explosions Since the Big Bang."

* * *

James Faulkner and Zhixing "Tyler" Wang, graduate students in the high energy physics group, were awarded Guest Visitor Fellowships for 2 months each at Fermilab.

* * *

The high energy physics group, Nural Akchurin, Shuichi Kunori, Sung-Won Lee and Igor Volobouev, was awarded $250K in supplementary funds by the Department of Energy for their work at the LHC this year.

* * *

Phil Dudero, a high energy physics postdoc, was awarded the LPC Distinguished Researcher Fellowship in 2015 for his analysis work on dibosons in CMS. The award carries $58K for stipend and research travel.

* * *

The high energy physics group has won funding for "SPRACE-UNESP and TTU Collaboration in High-energy Physics in the Compact Muon Solenoid Experiment at the Large Hadron Collider" from the state of Sao Paulo FAPESP (Brazil) and TTU for joint projects for two years.

* * *

Stefan K. Estreicher talked about heat flow in nanostructures and about the history of wine at Zhejiang University in Hangzhou (China). He also learned to say nihao and xiexie – two expressions you actually should use in public. Stefan also gave talks at the Universities of Bologna (June) and Oslo (July). He then chaired the International Advisory Committee meeting for the ICDS conference series (International Conference on Defects in Semiconductors) in Helsinki. This was his last time chairing this committee: after six years with the gavel, it was high time to rotate out of the position.

Next on his agenda are invited talks at two conferences: “Gettering And Defect Engineering in Semiconductor Technology” in Southern Germany (September) and then “Probing Potential Energy Surfaces” in Switzerland (April). The latter conference is held at the base camp of the Matterhorn in Zermatt, a region almost as flat as Lubbock (with emphasis on ‘almost’).

Sung-Won Lee and Shuichi Kunori were featured, along with other U.S. physicists, in the Jan. 30, 2015, issue of Fermilab Today. Their research contributions were described as crucial to the search for resonances and quantum black holes using dijet mass spectra in proton-proton collisions at CERN’s Large Hadron Collider.

Sung-Won Lee received a service award from the AKPA (Association of Korean Physicists in America) for his outstanding service as Membership Director. The award was granted during the American Physical Society March meeting in San Antonio, TX.

Ben Owen received a $60K grant from NSF to study “Gravitational Waves from Compact Objects” last summer, and he wrote a book review for Physics Today of “Gravity” by Eric Poisson and Clifford Will.

James Faulkner was awarded TTU’s Doctoral Dissertation Completion Fellowship earlier this year. James is working with Dr. S.-W. Lee in the high energy physics group.

The department hosted a lecture on “The Discovery of Pulsars,” by Dame Jocelyn Bell Burnell, who was the discoverer of pulsars. She spoke to an audience of about 200 people from both physics and the general Lubbock community about her discoveries and her experiences as a pioneer for women in science in March.

New Faculty

Dr. Alessandra Corsi joined the Texas Tech Department of Physics as an assistant professor in August 2014. She received her PhD in astronomy in 2007 from the University of Rome Sapienza (Italy). Before arriving at TTU, Dr. Corsi carried out post-doctoral studies at several universities in the US, including at the Penn State and Caltech. In 2008, Dr. Corsi received a l'Oreal-UNESCO National (Italy) award for Women in Science. In 2014, the University of Rome Sapienza recognized Dr. Corsi as one of the outstanding PhD scholars of the 30-year Sapienza PhD program. In 2015, she was selected as a scholar of the Research Corporation – Scialog, and received a CAREER award from the NSF. Dr. Corsi is a member of the LIGO Scientific Collaboration and of the Palomar Transient Factory, and her research activity bridges traditional astronomy and gravitational physics, making use of data from some of the most advanced telescopes and observatories on Earth and in space, including the Very Large Array, the Palomar Transient Factory, the LIGO gravitational wave observatory, and the Swift satellite.

Dr. Robert V. "Rob" Duncan joined TTU as the Vice President for Research in January, 2014. Prior to accepting this position, he served as the Vice Chancellor for Research at the University of Missouri. He received his bachelor's degree in physics from MIT in 1982 and his doctorate in physics from the University of California-Santa Barbara in 1988. He has served as a professor of physics and astronomy, and as a joint associate professor of electrical and computer engineering at the University of New Mexico, as a visiting associate on the physics faculty at Caltech, and as the associate dean for research in the College of Arts and Sciences at UNM. He is a Fellow and a life member of the American Physical Society and a Fellow of the National Academy of Inventors.

Dr. Anthony B. "Tony" Kaye joined our department in January 2013 as an associate professor and as our only native Texan. Prior to his arrival at Texas Tech, Dr. Kaye served as the Chief Scientist for Exelis' Strategic Systems; in his nine years at Exelis (formerly ITT), he won, managed, and performed on a wide range of contracts totaling over $500M in value, primarily supporting various components of the United States military. These efforts (among others) earned Dr. Kaye a number of awards, including several letters of appreciation from the Department of Homeland Security and from the United States Air Force. Prior to working in industry, Dr. Kaye served at the Los Alamos National Laboratory in the Applied Physics (X) Division, where he earned the highly prestigious Distinguished Performance Award. Dr. Kaye's PhD was awarded from Georgia State University in 1998 for the discovery of the first new variable star class since the late 1970s. Dr. Kaye's research group is working on the production, characterization, and fundamental understanding of ultrafast transition metal oxide thin films.

Dr. Shuichi Kunori joined the TTU Department of Physics as an associate professor in 2013. He earned his PhD degree from Tohoku University in Japan in 1981 before taking a postdoc appointment at the University of Maryland. He moved to Fermilab as a physicist and played key roles in the E545, E665, and DZero experiments there. Before joining the Compact Muon Solenoid (CMS) experiment at CERN in 1995, he served as the group leader of the software and simulation group at the Superconducting Super Collider Lab. As a member of our high energy physics group, he is now hunting for dark matter using the CMS detector. He is in charge of the hadronic calorimeter performance group and busy preparing the detectors for the next run (Run II) at CERN.

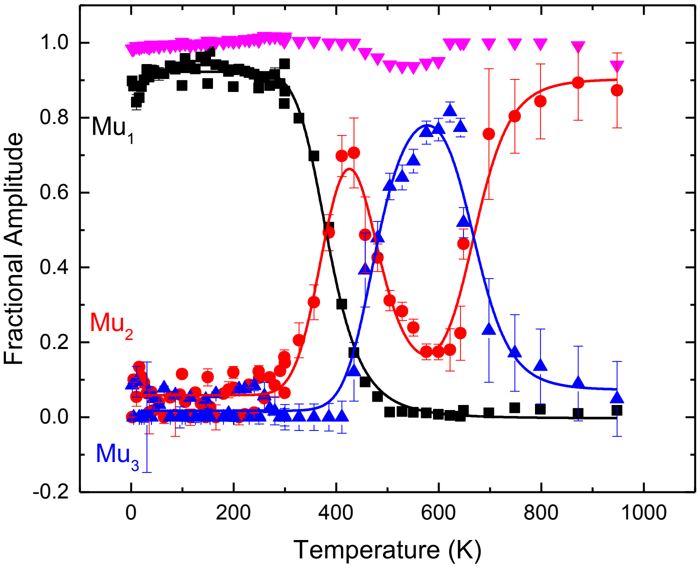
Dr. Tom Maccarone joined the department in January of 2013 as an associate professor. He earned his bachelor's degree from the California Institute of Technology in 1996 and his PhD from Yale University in 2001. He then held postdoctoral positions at the International School for Advanced Studies in Trieste, Italy, and the University of Amsterdam. In 2005, he began a faculty position at the University of Southampton, in England. Since arriving at Texas Tech, he has taught Physics I, Physics III, computational physics, and stellar evolution. His research focuses on binary star systems where one member of the binary is either a black hole or a neutron star, as well as on globular clusters.

Dr. Benjamin Owen joined Texas Tech as a professor of physics in January 2015, after serving one eighth of a century on the faculty at Penn State. He completed his PhD on gravitational waves from black holes and neutron stars under renowned film producer Kip Thorne at Caltech in 1998 and did postdoctoral work in Milwaukee, Wisconsin, and Potsdam, Germany. While his wormhole graphics did not make it into the films Contact or Interstellar, the rest of his graduate work won Caltech's Clauser Prize for thesis of the year, and he was later elected Fellow of the American Physical Society for continuing that work. He continues to moonlight as a theorist while searching Advanced LIGO data for gravitational waves from spinning neutron stars.

Dr. David Sand joined the TTU Department of Physics as an assistant professor in January 2013. He received his PhD in physics in 2006 from the California Institute of Technology. Dr. Sand was a Chandra Postoctoral Fellow at the University of Arizona from 2006-2008 and then held a dual postdoctoral position at Las Cumbres Observatory Global Telescope network and the Harvard Center for Astrophysics from 2008-2012. He was selected as a Scialog scholar of the Research Corporation in 2015. Dr. Sand is a general observational astrophysicist, having worked on dark matter halos in galaxy clusters, gravitational lensing, early supernova detection, astronomical instrumentation, dwarf galaxies, and active galactic nuclei.

Recent PhDs

Brittany Baker received her PhD in August 2015 under Dr. Roger Lichti's guidence. She is on temporary assignment to our department to teach introductory physics. She describes the main results of her research below:



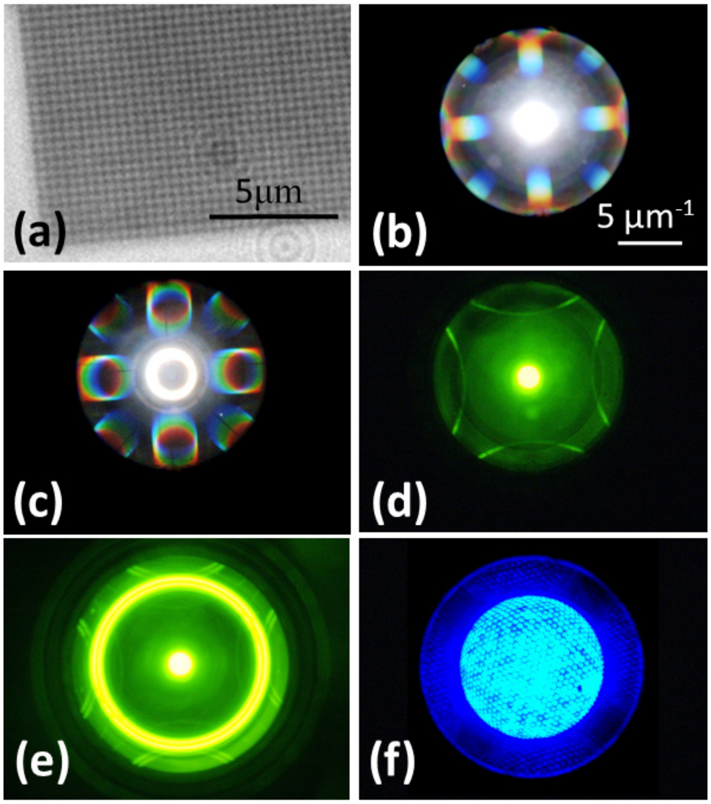
"I studied indium oxide powder (In_2O_3) using Muon Spin Relaxation (MuSR) experiments to determine the characteristics of the muonium (Mu=μ^+ e^-) defect. Muonium is essentially a short lived light hydrogen isotope. I tested In_2O_3 from 2 K to 950 K under no external magnetic field. Over the temperature range, I observed three positive Mu states and one neutral Mu state. The neutral defect is ionized by 50 K, as expected given the small ionization energy of H in In_2O_3. The occupancy of the three Mu^+ states was proportional to signal amplitude and varied with temperature. I was able to determine transition energies from the variation in signal amplitude of the states: The Mu_1 state, the main state at low temperatures, and transitions to Mu_2 over a barrier energy of 0.39 eV. The Mu_2 begins hopping between equivalent sites and soon traps at a high density trap. The diffusion barrier energy for the Mu_2 state before trapping is 0.75 eV. The transition barrier from Mu_2 into Mu_3 is 0.62 eV. The escape energy out of Mu_3 back to Mu_2 is roughly 1.10 eV. The figure above shows the fractional amplitudes of the muonium signal as a function of temperature. From the MuSR data, we concluded that the Mu_2 state is the Mu^+ defect in the lowest energy oxygen antibonding site and that the Mu_3 state is likely at one of the metastable oxygen antibonding sites or undergoing local motion between multiple of the metastable oxygen antibonding sites about a single oxygen."

* * *

Daniel Dominguez, after earning his PhD in December 2014 under Dr. Luis Grave de Peralta, is now working at Intel and contributed the following about his thesis research and his time at TTU:

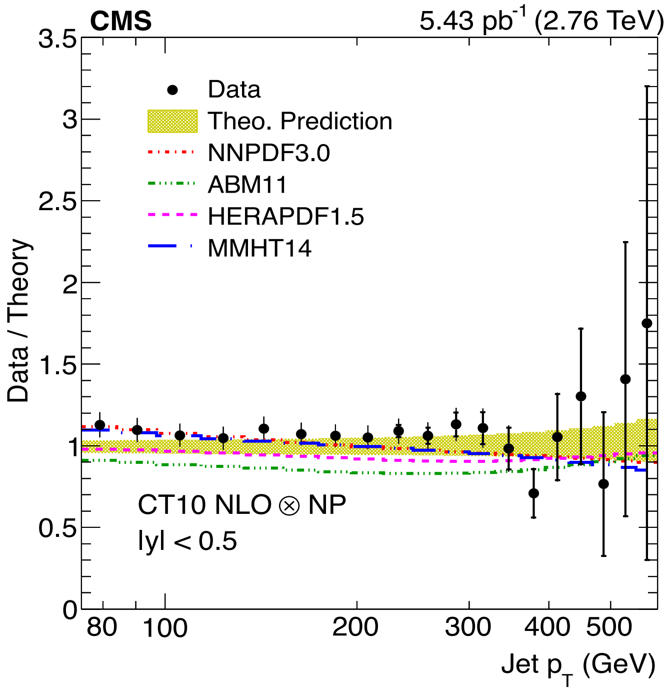
"The development of traditional optical condensers revolutionized optical microscopy by providing a mechanism that can easily double a traditional microscope's resolution. The optical condensers comprise a combination of bulky lenses (or mirrors) and diaphragms designed to illuminate a sample with a cone of inclined light. My PhD research project consisted of the development and characterization of new types of optical condensers based on our understanding of the information available at the back focal plane, or Fourier Plane (FP), and its relation to what is imaged in the Real Plane (RP). When imaging periodic structures, similar to the one shown in the figure below in panel (a), the RP image can only be resolved when at least two diffraction orders, as seen in panel (b), are captured within the Numerical Aperture (NA) in the FP. As the period of a structure becomes smaller, the diffraction spots grow apart; when the diffraction features grow beyond the NA, the image will no longer be resolved in the RP. By manipulating the shape of the diffraction feature using a condenser, like an aperture condenser in panel (c), it is possible to obtain enhanced resolution. The increase in resolution comes from the fact that only a portion of two diffraction orders is needed to resolve an image. As such, a condenser producing large features (like rings in my experiments) that can still be captured within the NA for small periods - defined by $p_{min} \sim \lambda/(NA_o + NA_c)$ where λ is the illuminating wavelength, NA_o is the numerical aperture of the objective lens, and NA_c is the numerical aperture of the condenser - will increase resolution. For cases when $NA_c > NA_o$, a computational technique we developed called Fourier Plane Imaging Microscopy can be used to reconstruct an image of the structure in the real plane. The condensers studied consist of evanescent wave-based condensers like the one producing the rings in the FP shown in panel (d), a liquid-drop condenser like the one shown in panel (e), and an LED-based hemispherical digital condenser in panel (f). These new condensers prove to be more cost-effective, easier to make, and orders of magnitude smaller than their traditional counterparts and have successfully demonstrated resolution enhancements comparable to the traditional bulky condensers. In addition, the condensers developed provide direct, non-scanning, far-field images that do not require computer post-processing and have immediate imaging applications in biological and semiconductor fields.

During my academic career at TTU, I was also involved in other projects, including work with surface plasmon polaritons in the search for an optical superlens and quantum plasmonics. In addition, I had the privilege of collaborating with various departments, in particular the TTU Nano Tech Center, where I fabricated the samples used in my research with e-beam lithography and deposition systems. Beyond research and academics, I was able to participate in the local chapter of the Society of Physics Students, become a part of the National Sigma Pi Sigma Physics Honor Society, and attend several American Physical Society meetings. Without a doubt, my success as a physicist, researcher, and now a professional at Intel would not have been possible without the opportunities available to me through the physics department."



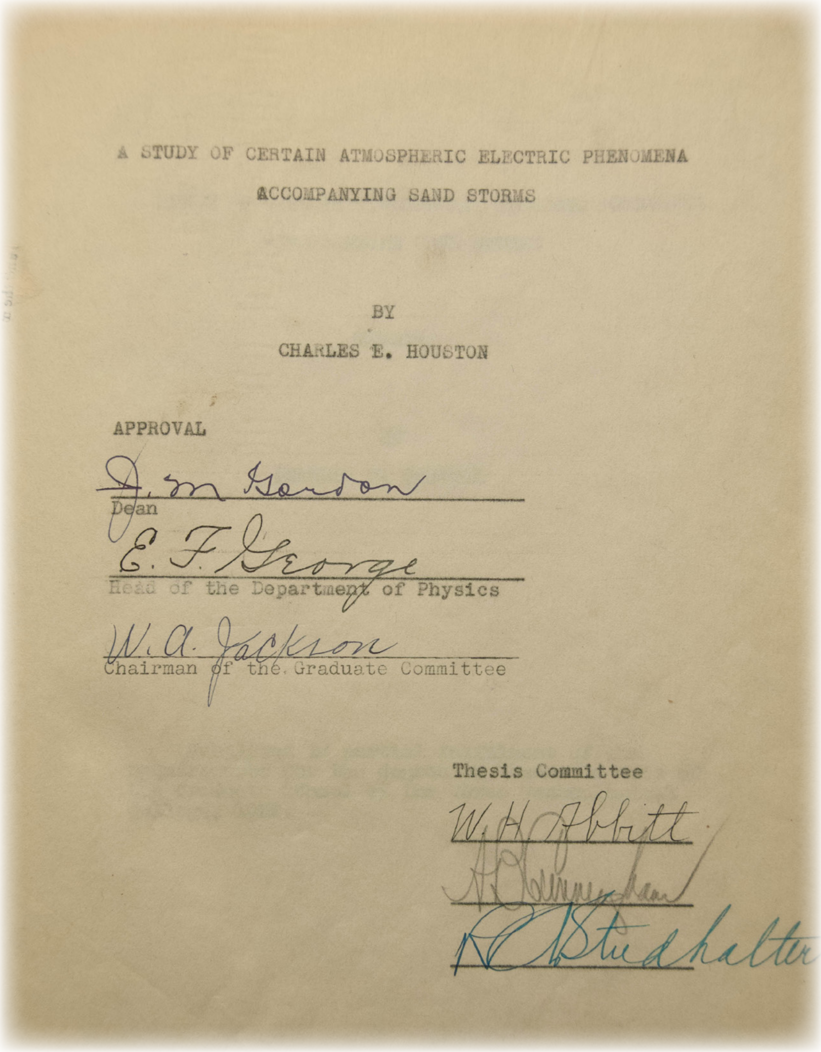
Terence Libeiro received his PhD in May 2015 under Dr. Igor Volobouev. His research was in experimental high energy physics and in particular concerned the inclusive jet production at the center-of-mass energy of 2.76 TeV in the Compact Muon Solenoid (CMS) experiment at CERN. He currently holds a visiting fellowship at Fermilab where he is finishing up the publication of his thesis results. He describes the highlight of his research below:

"The interaction of partons in high-energy proton collisions produces a collimated spray of particles as a final-state product. The specific energy signature resulting from such an interaction in the experimental detector is called a 'jet.' The production of jets is one of the most basic predictions of the quantum chromodynamics (QCD) theory and is rigorously tested at various energy scales at the Large Hadron Collider (LHC). A seven-fold increase in the collision energy at the LHC relative to the previous colliders provides useful means to investigate QCD predictions in greater detail than ever before. Two critical parameters of QCD, namely the parton distribution functions that describe the structure of a proton and the strong coupling constant that determines the interactions of the proton constituents, are calculated exclusively through experiments. The measurement of jet production rates, in terms of the inclusive jet cross section, is used to infer the values of these parameters and is crucial to setting stringent limits on their possible values. My thesis work includes the measurement of the inclusive jet cross section performed using data from the CMS experiment at CERN, collected at the collision (or center-of-mass) energy of 2.76 TeV. The data represent a transition from similar measurements made at a lower center-of-mass energy at the Tevatron collider at Fermilab to the ones at the LHC. The ratio of inclusive jet cross sections measured at 2.76 and 8 TeV is also calculated. The systematic biases between the two measurements are correlated and used together to reduce the experimental uncertainty on the ratio, allowing for a more precise test of the theory. We find that both the inclusive jet cross section and the cross section ratio are described well by the theoretical predictions. The ratio calculated with jets in a certain geometric region of the detector in comparison to one of its theoretical prediction, is illustrated in the figure below.



The other predictions are also shown in colored, dash-dotted lines. The improved precision of the ratio reveals that data have some preference for two of the theoretical predictions compared here. These two predictions are derived using calculations that include data at the same center-of-mass energy as our measurement, while these are not included in the other predictions. This approach demonstrates that theoretical predictions are improved by introducing relevant experimental data into the calculations. This analysis confirms the theory in an previously unexplored kinematic region and presents an experimental measurement for future QCD studies."

Moments in Time



A STUDY OF CERTAIN ATMOSPHERIC ELECTRIC PHENOMENA
ACCOMPANYING SAND STORMS

BY

CHARLES E. HOUSTON

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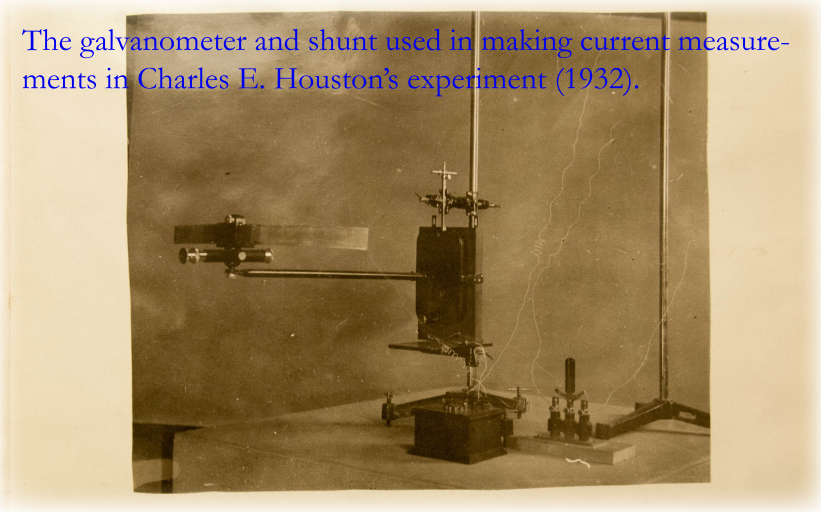

The galvanometer and shunt used in making current measurements in Charles E. Houston's experiment (1932).

Roger L. Lichti

Professors Lichti and Lodhi, who retired this year, as they appear in a departmental brochure from the early 1980s.

M.A.K. Lodhi

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