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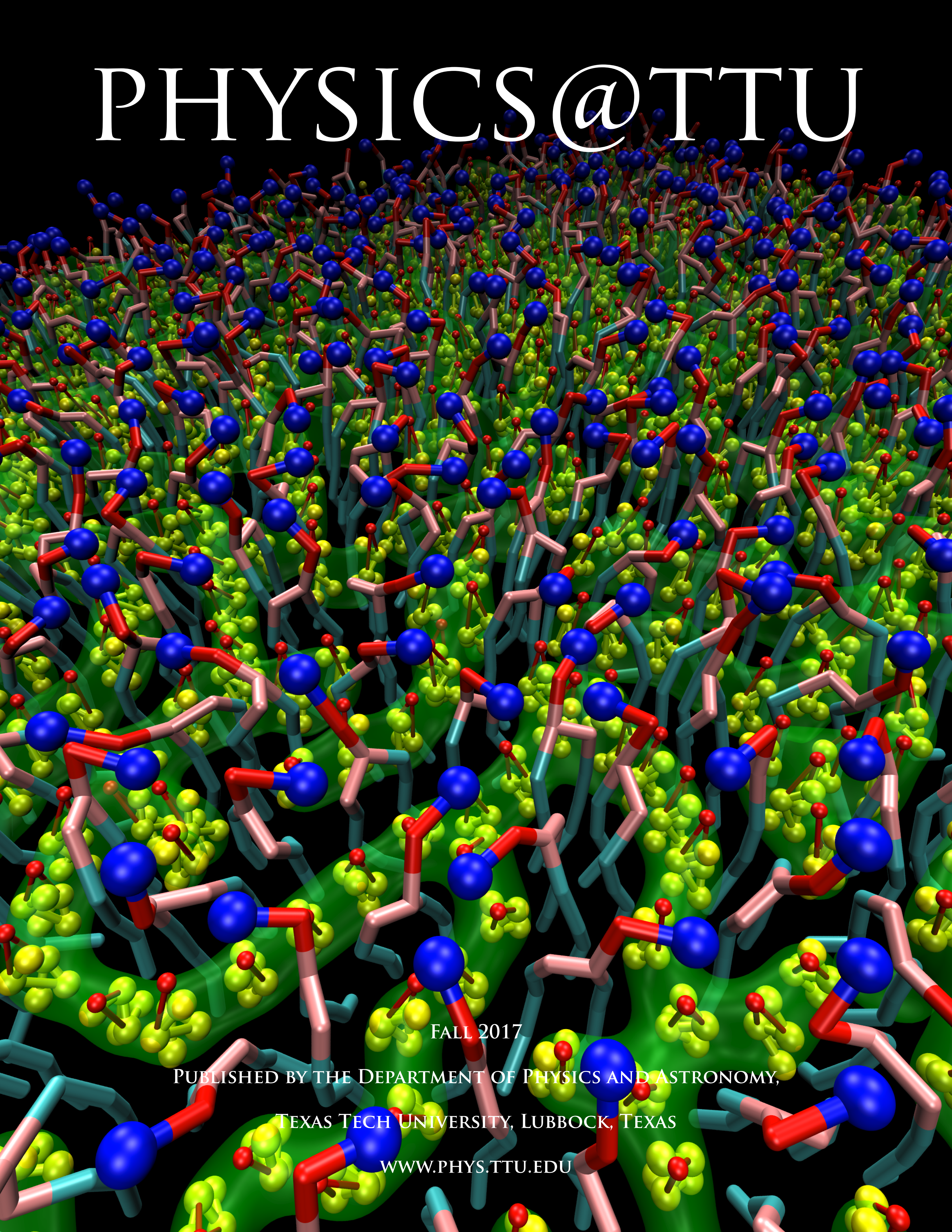

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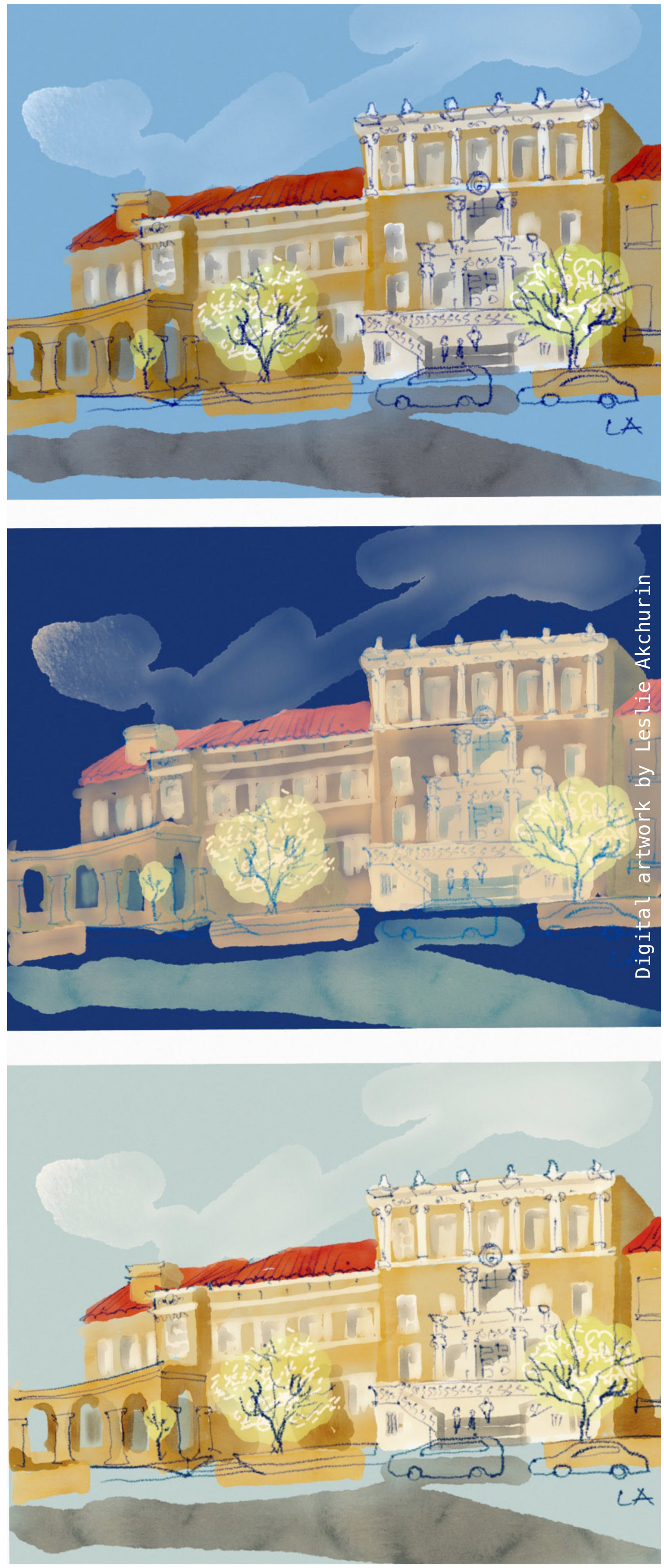

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Front Cover: Cholesterol molecules (yellow beads) are chained together to form a fascinating molecular scale "maze" in a lipid bilayer. The paths of the maze are filled by phospholipids (sticks) that act like umbrellas covering cholesterol from water. The "cholesterol maze" was recently visualized through molecular dynamics simulation by Prof. Juyang Huang's group, after it was predicted over a decade ago.

The View from the Chair

The observation of electromagnetic waves from a merger of two neutron stars, triggered by gravitational wave detection, takes the center stage this year, and our Professor Alessandra Corsi is one of the two discoverers of this electromagnetic signal in radio waves. She tells the story of this discovery in the first article in this issue (pp. 4-7). The announcement of this discovery was organized by the National Science Foundation on October 16 in Washington DC, and it was great to see Alessandra describe her discovery in a televised press conference. Professor Ben Owen gives details about this particular merger from the gravitational perspective in the next article (pp. 8-9). Professor Juyang Huang describes his passion for, as well as the physics of, cell membranes in his article on pages 10-12. Professor Igor Volobouev's informative article about oft misunderstood statistical concepts appears on pages 13-17.

Our student organizations, Society of Physics Students, GRASP, and the physics honors society Sigma Pi Sigma, have never been as active as they have been this year. A vibrant student body at both undergraduate and graduate levels is essential for our future. They explain their activities and thoughts in this issue as well.

We awarded seventeen BS, eleven MS, and two PhD degrees this year, December 2015 to August 2016. We are proud of our graduates, and our PhDs give a brief view of their work (pp. 26-27). I wish Drs. James Faulkner and Darshan Desai the very best.

The year of 2017 was a good year for us. We have a record number of students graduating with their BS degrees, and we expect seven more graduates in December. Inquiry-based college algebra courses delivered in freshly renovated state-of-the-art classroom have been very successful. The third floor of the Science Building will be renovated to house offices and meeting space for our graduate students starting this month. The construction of the Advanced Particle Detector Laboratory (APD Lab) at Reese Technology Center for the high-energy particle group's upgrade project at CERN's Large Hadron Collider is nearly done and the 1,000 sqf cleanroom is being certified. Experimental Sciences Building II (ESB-II), which will be completed by Spring 2019, will also house some of our research labs. We have also been successful in garnering over \$1.3M in research funding from external federal agencies. This is a significant upswing compared to the previous year. We have not, however, been successful in making a faculty hire in the area of Physics Education Research (PER) as planned. Our faculty hiring plan calls for two junior faculty members in astrophysics and one junior faculty member in particle physics for Fall 2018 and I am looking forward to new young faculty joining our ranks soon.

I would like to thank friends of the department who generously established new (Hastings, Lodhi, Patillo, and Sundell) or continuing scholarship endowments for our students. These funds make an enormous difference in the lives of our students. I also thank those of you who make periodic contributions to our general education fund.

As always, I would like to hear from all our alumni and friends. Together, we can truly make TTU Physics and Astronomy the place to be. Wishing you happy holidays,

Nural Akchurin
Professor and Chair

Light from a Cosmic Smashup: The Story of a Weak Gamma-ray Flash, a Bright Optical Transient, and a Delayed Radio Glow

Alessandra Corsi

After the LIGO and Virgo detectors caught the first gravitational wave "chirp" from the collision of a pair of neutron stars (an event dubbed GW170817), a global network of telescopes spanning the entire electromagnetic spectrum was mobilized in the search for light from the cosmic smashup (Figure 1).

The time coincidence of the gravitational wave signal from GW170817 with a flash of gamma-rays detected by both the Fermi and Integral satellites (Figure 1, top left) confirmed the idea that the coalescence of two neutron stars can generate a so-called "short gamma-ray burst" (GRB) associated with a fast jet. The jet is shot out after the collision, in a direction that is orthogonal to the plane where the pair of neutron stars completed their last dance before merger. As the jet races through the interstellar medium (the gas and dust between stars) at almost the speed of light, it engulfs matter and decelerates, and its emission shifts to longer wavelengths, powering a broad-band "afterglow." Thus, after gamma-rays from GW170817 were discovered, the hunt for light at all other wavelengths was on!

While confirming the hypothesis of an association between neutron star mergers and short gamma-ray bursts, GW170817 also opened a new puzzle: the energy emitted in gamma-rays was about four orders of magnitude smaller than what we would have expected from a typical short GRB. Could this have been an intrinsically faint event, or could it be that we were observing the GRB jet off-axis as sketched in Figure 2? This last scenario was particularly appealing since astronomers had been searching for off-axis GRBs, unsuccessfully, for about two decades. Similar to a tilted flashlight, in an off-axis GRB we can see behind the main beam and learn how the fastest jets we know of in the universe interact with their surroundings. To confirm the off-axis GRB hypothesis in GW170817, observations at wavelengths other than gamma-rays were needed.

Optical telescopes in the southern hemisphere were the first to reveal what came after the gravitational waves and gamma rays. About 10 hours after the merger, the One-Meter, Two-Hemisphere (1M2H) team discovered a bright optical transient consistent with the location of GW170817 using the 1-m Swope telescope at Las Campanas Observatory in Chile (Coulter *et al.* 2017, Science, in press, DOI:10.1126/science.aap9811). The transient was located in NGC 4993, an early-type galaxy at 40 Mpc (or about 130 million light years) from Earth. The bright optical counterpart to GW170817 was also independently detected by several other teams and telescopes (Figure 1, bottom left panels marked in green).

The optical discovery opened yet another puzzle: the visible light from GW170817 was much brighter than expected from the afterglow of an intrinsically weak or off-axis GRB! This, together with further observations in the UV and infrared, revealed that the bright optical/UV/IR counterpart was not coming from the fast jet that produced the gamma-rays but from a so-called "kilonova" (*e.g.*, Evans *et al.* 2017, Science, in press, 10.1126/science.aap9580 and Valenti *et al.* 2017, ApJ Letters, 848, L24). This is an optical/IR transient associated with the radioactive decay of heavy nuclei that is produced and ejected fairly isotropically (see Figure 2, left panel) during the merger of two neutron stars. Kilonovae are thought to be responsible for the creation of a large fraction of heavy elements in the universe, such as gold and platinum (Figure 3).

Although the discovery of the kilonova emission was incredibly exciting, we were still missing the opportunity to probe the very first off-axis GRB jet. Given that the UV/optical/IR emission was dominated by the kilonova, radio and X-rays were the only remaining messengers that could possibly be used to probe this jet.

After 16 long days following the neutron star merger, our TTU team was one of two teams who independently discovered the faint radio glow from GW170817 in images taken with the Karl G. Jansky Very Large Array, one of the most sensitive radio telescopes on Earth. After show-

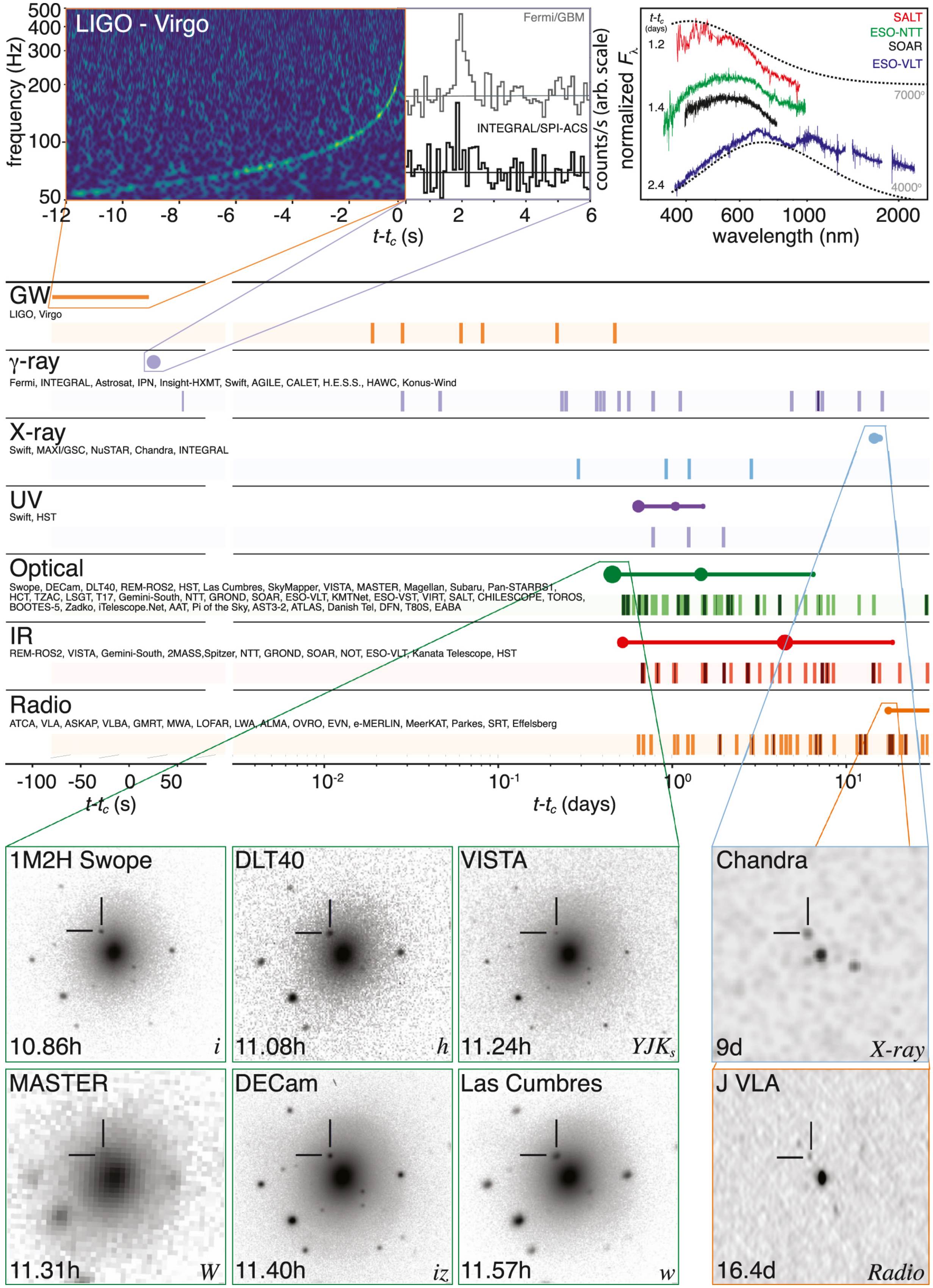


Figure 1: Timeline of the discovery of GW170817 and of the follow-up observations shown by messenger and wavelength relative to the time t_c of the gravitational-wave event. Two types of information are shown for each band/messenger. First, the shaded dashes represent the times when information was reported in a Circular. The names of the relevant instruments, facilities, or observing teams are collected at the beginning of the row. Second, representative observations in each band are shown as solid circles with their areas approximately scaled by brightness; the solid lines indicate when the source was detectable by at least one telescope. Magnification insets give a picture of the first detections in the gravitational-wave, gamma-ray, optical, X-ray, and radio bands. Abbott et al. 2017, The Astrophysical Journal Letters, Volume 848, Number 2.

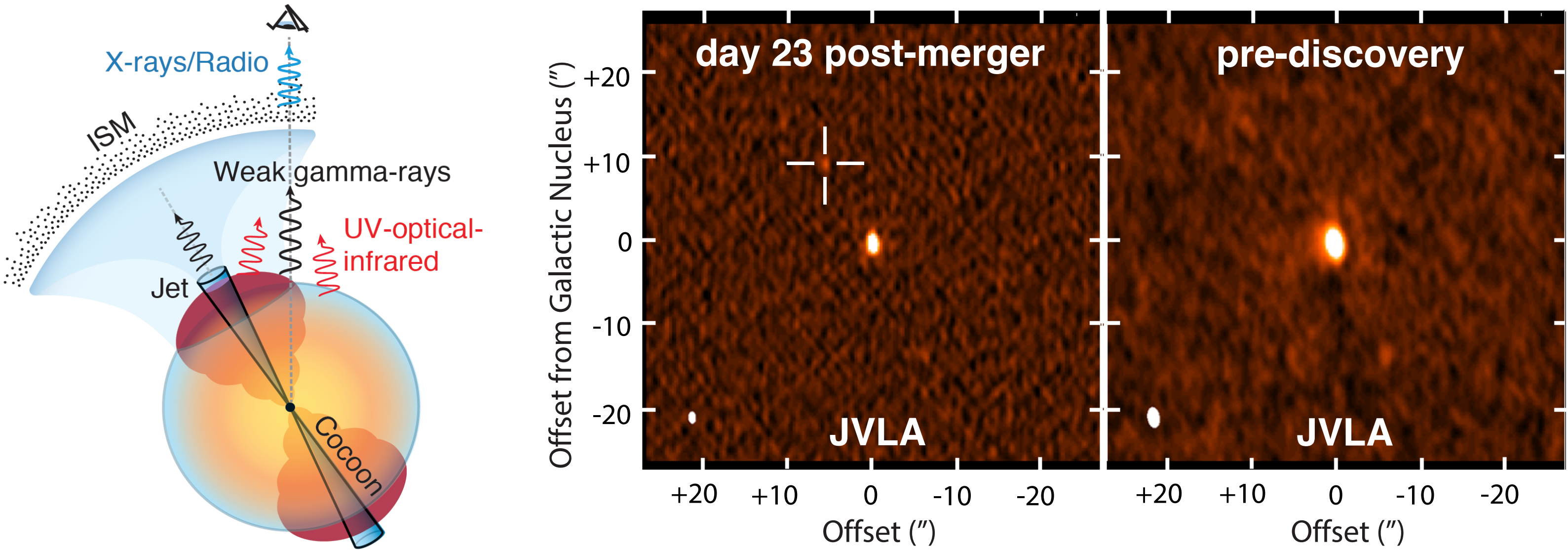


Figure 2: The left panel shows a schematic representation of the relativistic jet, cocoon, and more isotropic neutron-rich debris formed in the binary neutron star collision. The eyeball marks our point of view from Earth. The central panel shows the radio counterpart to the binary neutron star merger GW170817 marked by the crosshairs. The brighter radio source visible in this panel, and in the pre-discovery image in the right panel, is the far away galaxy that hosted the merger. The images shown in the central and right panels are from the Karl G. Jansky Very Large Array (NRAO/NSF), one of the most sensitive radio telescopes on Earth. This figure is adapted from Hallinan, Corsi, et al. 2017, Science, in press, DOI:10.1126/science.aap9855 and Kasliwal et al. 2017, Science, in press, DOI: 10.1126/science.aap9455.

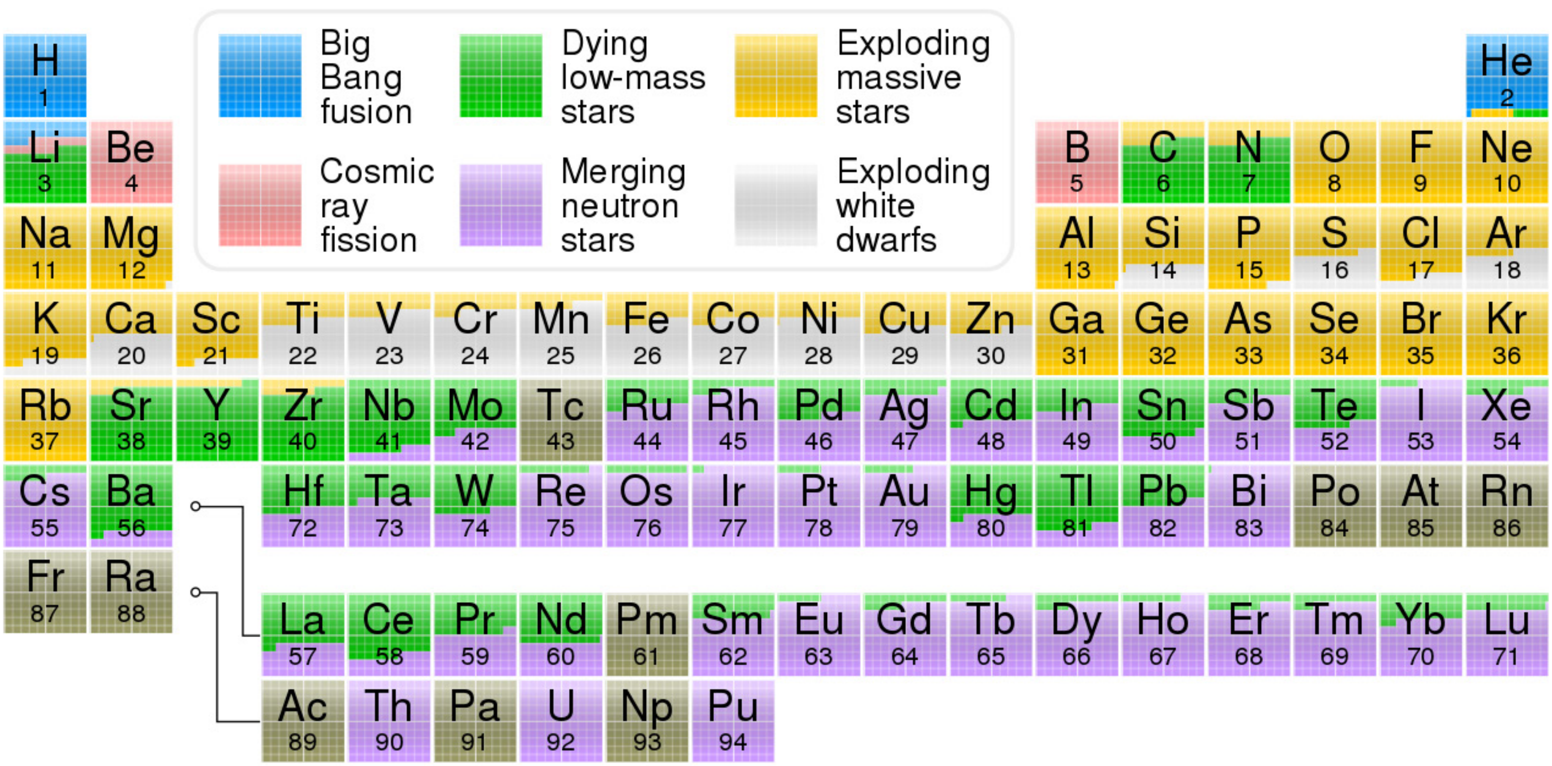


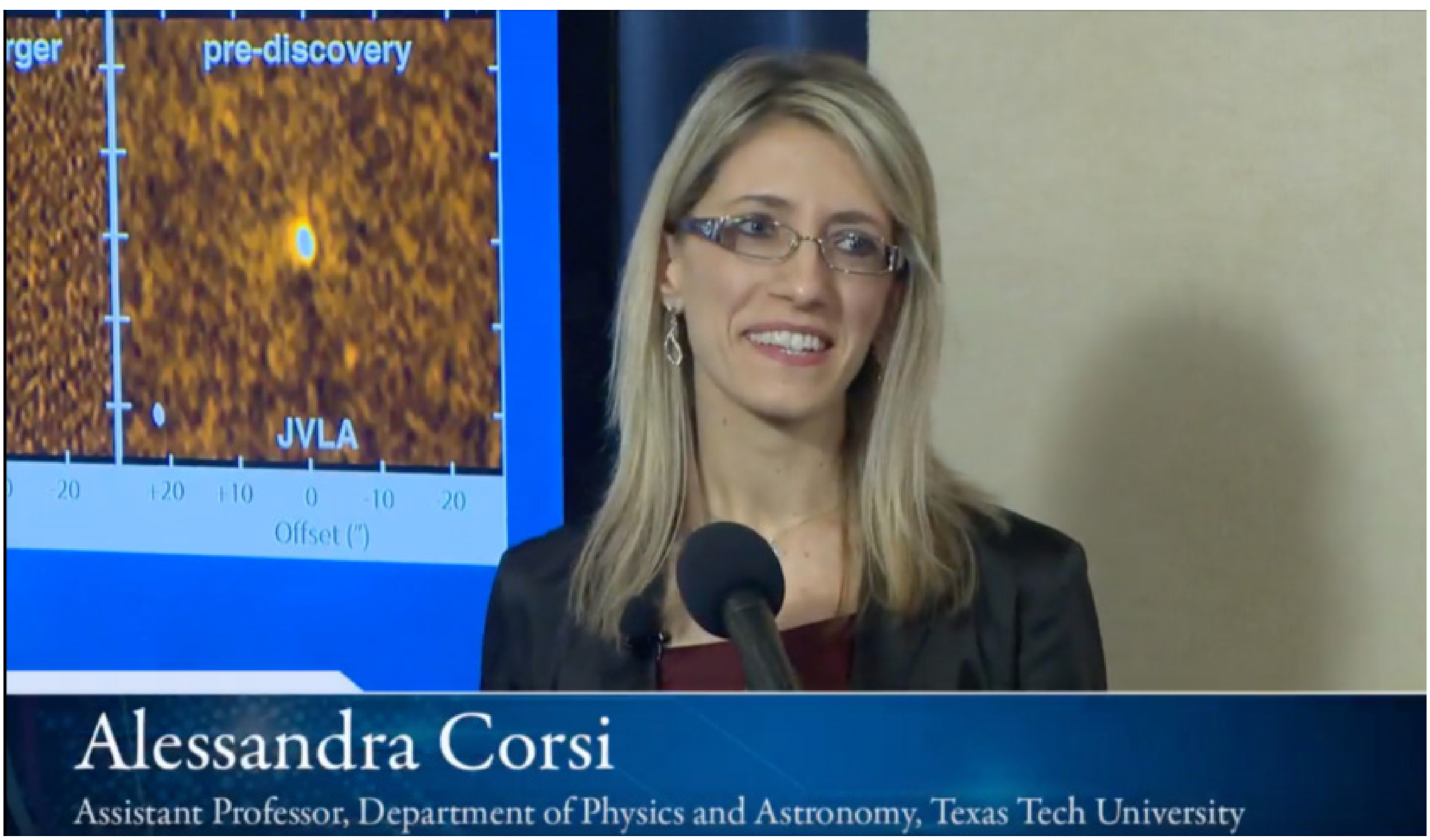
Figure 3: Periodic table showing origin of elements in the Solar System, based on data by Jennifer Johnson at Ohio State University. The percentages of each element's origin are represented by squares (out of a hundred) to make it easier to estimate proportions. Elements above Plutonium are not included.

ing up on day 16, the radio counterpart to GW170817 grew brighter. The crosshairs in the central panel of Figure 2 show the radio transient at day 23 after the merger. The radio emission of the far away galaxy that hosted the merger is also clearly detected in this image, and in the pre-discovery one (right panel of Figure 2). The delayed turn-on in the radio, together with a similarly delayed turn-on in X-rays (Troja *et al.* 2017, *Nature*, in press, DOI:10.1038/nature24290), confirmed the hypothesis of an off-axis jet. After 20 years of searching, we had finally formed our very first view of a relativistic jet observed from the side!

The results of the radio follow-up campaign have been published in *Science* in an article for which the two discovery teams (Caltech and TTU) share first authorship (Hallinan, Corsi, *et al.* 2017, Science, in press, DOI:10.1126/science.aap9855).

The radio, in particular, reveals the presence of mildly relativistic and pressurized material, a cocoon, formed in the interaction of the jet with the neutron rich debris (Figure 2, left panel). Theorists such as Davide Lazzati from Oregon State University (who will be visiting our TTU Physics and Astronomy Department in Spring 2018) had predicted that cocoon emission could be observed in radio from binary neutron star mergers (Lazzati *et al.* 2017, Mon. Not. Roy, Astron. Soc., 471, 1652), but we did not have data to prove such prediction until LIGO and Virgo unveiled GW170817.

In summary, GW170817 was not "just" the first binary neutron star merger ever observed in gravitational waves, but it was also a fantastic opportunity that nature gave us to probe many "firsts": the first gamma-ray flash observed off-axis (thus the weak gamma-ray signal), the first direct observation of a kilonova (thus the unexpectedly bright optical transient), and the first view of the cocoon formed by a relativistic jet seen from the side (thus the delayed turn-on in radio). This story of a faint GRB, a bright optical transient, and a delayed radio glow marks the start of a new way of doing astronomy. From now on, astronomers and physicists will routinely work together to explore the cosmos in a completely new way. As this article is being written, the follow-up in radio waves continues, and the future of this field looks incredibly bright!



Professor Alessandra Corsi at the NSF press conference announcing the detection of the radio waves from a neutron star merger, GW170817, on October 16, 2017 in Washington, D.C.

Gravitational Wave Event of the Century

Benjamin J. Owen

On August 17, 2017, LIGO detected a ``chirp" signal like those we have seen several times from binary black hole mergers. But unlike those signals, which lasted hundreds of milliseconds, this signal lasted more than a hundred seconds. And it was so strong that we can actually see the last thirty seconds in a time-frequency plot (Figure 1) without any enhancement. The length of the signal told us that the total mass of the two merging objects was 2.8 times the mass of the sun rather than several dozen times, as the others were. Such a low total mass is difficult to square with gravitational-wave or x-ray observations of black holes, but it is precisely the value radio astronomers have seen for all previously known neutron star binaries (which are far from merger).

We got amazingly lucky with this event in several ways, including the fact that the Virgo interferometer in Italy had just joined LIGO, which was about to shut down for upgrades. Virgo did not detect the signal, which was very useful. Each detector has blind spots, and since Virgo is far away from the two LIGO sites in the United States, the curvature of the Earth tilts Virgo with respect to LIGO and puts its blind spots in different parts of the sky. For the first time, joint LIGO-Virgo data constrained the sky location of the source to a small enough area - a couple dozen square degrees - that optical telescopes were able to quickly find the counterpart and its host galaxy. (For the rest of the story see Alessandra Corsi's article in this issue.) We were also able to get a quick distance measurement of 40 megaparsecs, or 130 million light years. That is astonishingly close by the standards of these events and explains why the signal was so loud.

That distance measurement led us to something even more exciting - an independent measurement of the Hubble constant, which describes the expansion rate of the universe. For generations there have been two independent ways of measuring this constant based on long chains of inferences from electromagnetic (light) observations. These methods disagreed from the beginning because their inferences are subject to many systematic uncertainties. But with gravitational waves, the distance is easy to read off: The amplitude of the signal depends on the mass and the distance, and the mass is measured precisely from the chirp rate, so you get the distance. Compare this to the redshift of (electromagnetic) spectral lines in the host galaxy and you get the Hubble constant, which measures distance vs redshift. As you see in Figure 3, the LIGO-Virgo error bar does not yet decide the issue. But it is free of those systematics and will improve relatively quickly with more detections.

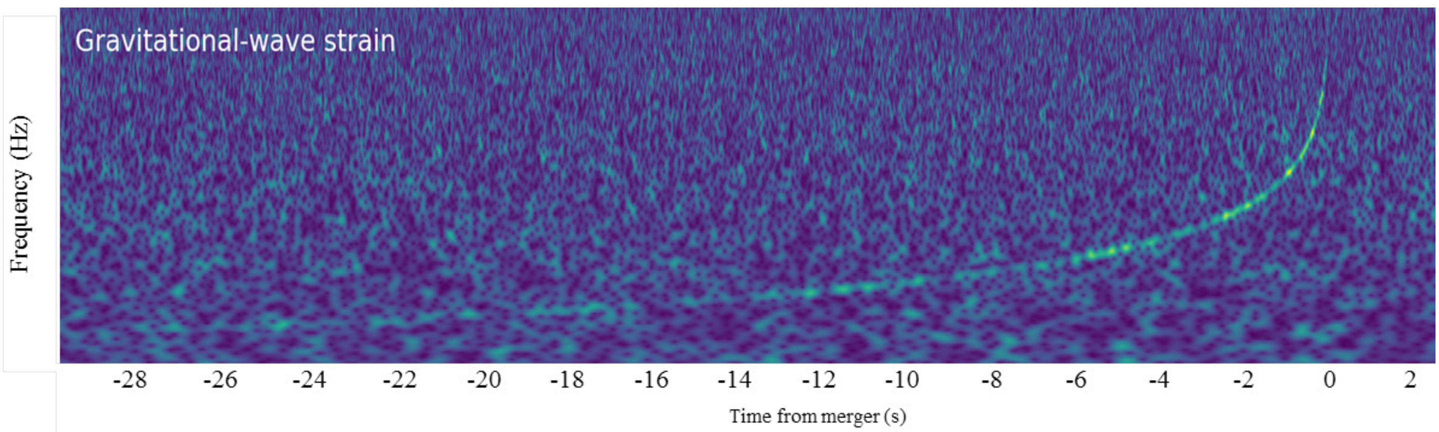


Figure 1: Color corresponds to partial signal-to-noise ratio at a given time and frequency. Speckles are detector noise. The line is the ``chirp" signal growing louder and sweeping up in frequency until it is lost in high frequency laser noise shortly before it ends. Credit: LIGO Lab/Caltech/MIT.

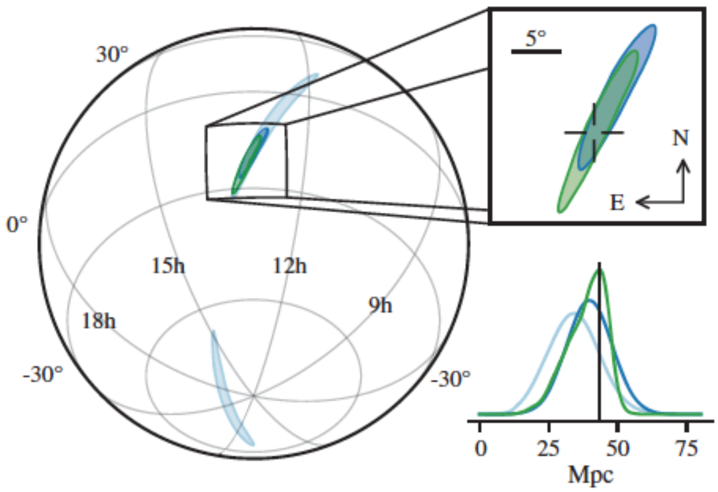


Figure 2. Three-dimensional LIGO-Virgo localization of GW170817. Credit: LIGO Scientific Collaboration and Virgo Collaboration, Phys. Rev. Lett. 119, 161101 (2017).

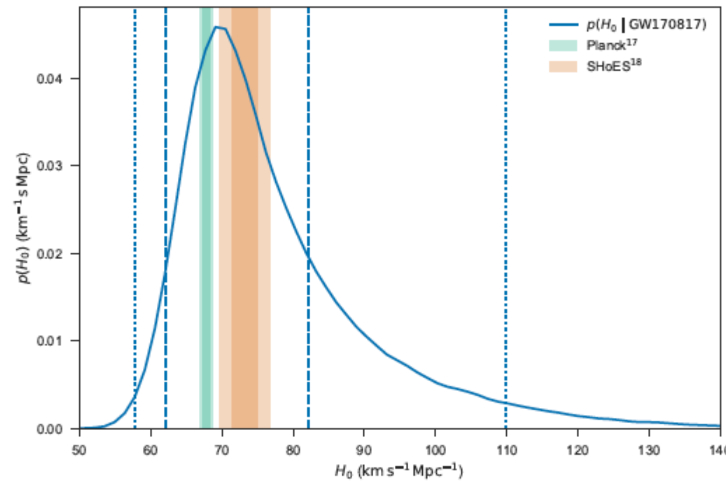
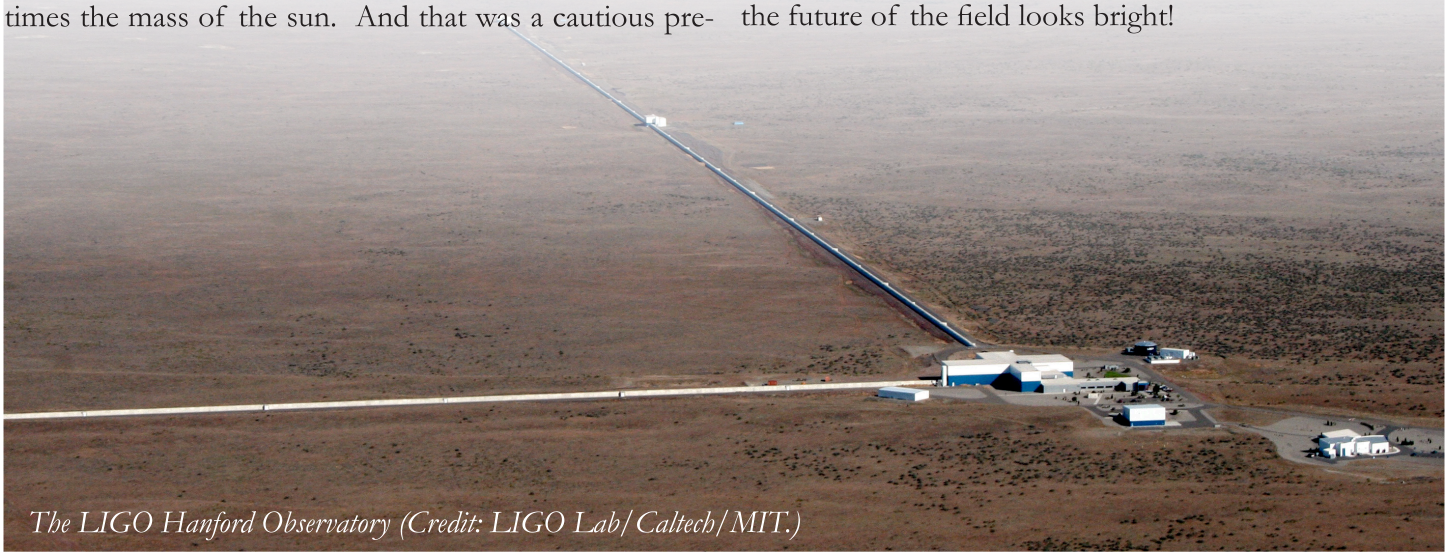


Figure 3. LIGO-Virgo measurement (posterior probability) of the Hubble constant, compared to the best electromagnetic-based measurements and their errors. Credit: LIGO Scientific Collaboration and Virgo Collaboration et al., Nature 551, 85-88 (2017).

In addition to the neutron star masses and spins (which seemed to be pretty low), the gravitational wave signal can tell us - in very rough terms - the radii of the stars via their mutual tidal deformations. As with the Earth and Moon, when stars near each other, they raise tides on each other, and these tides can change the gravitational field enough to make the chirp rate noticeably faster. This tells us about the equation of state of matter at and beyond the density of atomic nuclei, a topic about which particle and nuclear theorists have been arguing for generations: If nuclear matter is "stiff," it resists compression due to gravity more, resulting in bigger radii and a bigger tidal effect. We thought we would wait to accumulate dozens of signals to get a tidal result, but this signal was so loud that we got an interesting upper limit from it alone. We ruled out the stiffest equations of state, roughly corresponding to radii more than 14 km for a neutron star 1.4 times the mass of the sun. And that was a cautious preliminary constraint - better analyses are underway.

That was an incredibly lucky event, to be sure, but it was not unique! We already know that the rate of binary neutron star mergers is on the optimistic side of pre-detection estimates. LIGO and Virgo are both being upgraded and will resume running next year at greater sensitivity. In a couple of years, filled with more upgrades and more observing runs, LIGO and Virgo will be joined by other detectors. For sure we will find more binary neutron stars and black holes, maybe a mixed binary, and maybe we will start detecting more exotic signals, including some from pulsars, which are continuously emitting. LIGO and its kin will show us more and more about black holes, the behavior of gravity, the behavior of matter under extreme conditions, and the structure of the universe. Although gravitational waves are invisible to human eyes, the future of the field looks bright!



The LIGO Hanford Observatory (Credit: LIGO Lab/Caltech/MIT.)

Biophysics Research of Cell Membranes

Juyang Huang

Biophysics is an interdisciplinary science that applies the approaches and methods of physics to the study of biological systems. Biophysical research is often conducted through collaboration among scientists from many different fields, such as biochemistry, physical chemistry, nanotechnology, bioengineering, computational biology, biomechanics, and systems biology. The research activities of my group have been focused on the biophysics of cell membranes and the application of liposome technologies. In particular, I am interested in the roles of cholesterol in controlling the biochemical and biophysical properties of lipid membranes.

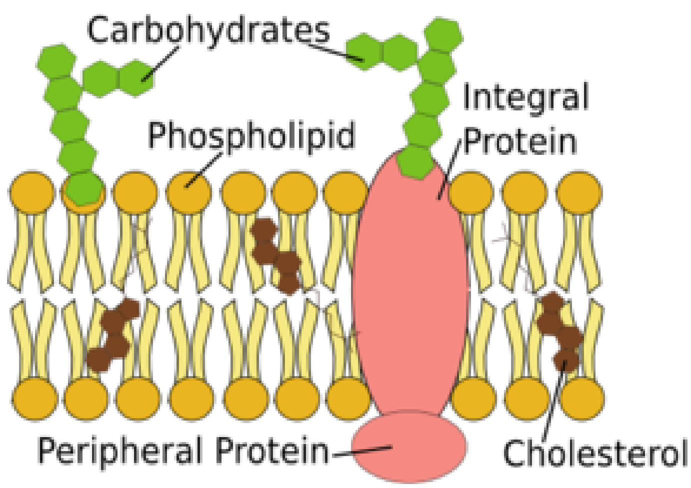


Figure 1. Structure of cell membranes

A cell plasma membrane separates the interior of a cell from the outside environment. It consists of a lipid bilayer with embedded proteins. The basic function of the cell membrane is to protect the cell from its surroundings, and it controls the movement of ions and organic molecules in and out of the cell. A lipid bilayer is made of two layers of amphiphilic lipid molecules. Phospholipids, which have hydrophilic headgroups and hydrophobic acyl chains, are the major component of lipid bilayers. Another important lipid is cholesterol, which has a small hydrophilic OH group and a large hydrophobic sterol ring body.

Many people have the perception that cholesterol is bad for their health. However, we are not talking about cholesterol in the form of lipoproteins in the circulatory system, such as LDL or HDL, but rather the plain cholesterol molecule. In membrane biophysics, cholesterol is a superstar: It is the most important and interesting lipid molecule in cell membranes. Cells would not be able to survive if cholesterol were removed from their membranes. Cholesterol directly affects fundamental properties of cell membranes. For example, it makes cell membranes tighter and reduces unwanted leakages of water, ions, and other biomolecules. Also, cholesterol often associates with certain lipids and proteins to form the membrane domains called "lipid rafts," which are essential for the proper functioning of many membrane proteins and ion channels. Thus, a clear understanding of the key cholesterol interaction with other membrane molecules can reveal why cholesterol has such "magic" power.

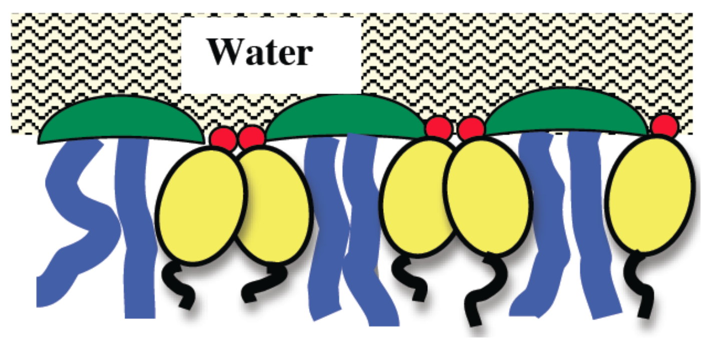


Figure 2. The Umbrella model. In a lipid bilayer, cholesterol's small hydrophilic headgroup (red dot) cannot completely protect its large hydrophobic body (yellow oval) from water. The large hydrophilic headgroups of neighboring phospholipids (green) act like umbrellas that help to cover the cholesterol's bodies.

Cholesterol has been extensively studied in the past few decades. There are several competing theories about the roles of cholesterol in biomembranes. A decade ago, I proposed a model of cholesterol-lipid interaction, named the "Umbrella Model." Today, it has become the leading conceptual model in the field. Cholesterol has a large hydrophobic steroid ring body and a relatively small hydrophilic hydroxyl headgroup. On the other hand, many other membrane lipids have far larger hydrophilic headgroups. When cholesterol molecules are incorporated into a lipid bilayer, their small hydrophilic headgroups cannot completely shield their large hydrophobic bodies from water. Thus, the headgroups of neighboring lipids, acting like umbrellas, provide "cover" to shield the hydrophobic part of cholesterol from exposure to water to avoid the unfavorable free energy. This is illustrated schematically in Figure 2. Because the space under the headgroups of phospholipids is now tightly packed with both acyl chains and cholesterol, the well-known "cholesterol condensing effect" and reduction of permeability to ions and other molecules are the results. Also, cholesterol would prefer to associate with large headgroup lipids with straight chains, and this is the driving force of the formation of "lipid rafts." Although many predictions of the model have been verified by various groups, there is one intriguing prediction of the model that remains unverified: at high cholesterol concentration, instead of forming large bulky clusters, cholesterol should form a fascinating distribution pattern that strongly resembles English hedge mazes. The model predicts that the maze pattern is the only distribution at high cholesterol concentration by which all the cholesterol molecules can still be effectively covered by phospholipid headgroups.

Recently, two graduate students in my group, Yu Mao and Xin Chen, used Molecular Dynamics (MD) simulation to investigate whether such maze patterns could exist. They used a coarse-grained model to construct lipid bilayers containing a large number of cholesterol and phospholipids. For this long and challenging simulation task, they took advantage of the powerful computational resource at TTU's High Performance Computing Center (HPCC). The simulations took many months, and they often used hundreds of computer nodes at a time. The result was astonishing: They found that cholesterol indeed forms the predicted maze pattern with a 3-fold symmetry in lipid bilayers (Figure 3). They not only confirmed the maze pattern prediction but also directly verified the umbrella coverage of cholesterol by phospholipids. The study shows that fundamental cholesterol-lipid interaction can result in a crystal-like molecular organization in two-dimension fluids without any rigid chemical bonds between molecules. Some cell membranes, such as the lens membrane in a human eye, have extremely high cholesterol content. The study can help us to understand some unique properties of lipid membranes that contain high cholesterol.

Another area of our research is the liposome-based drug delivery system. Liposomes are spherical vesicles made of lipid bilayers. Phospholipids and cholesterol are the major components of the liposomes. Thus, a good understanding of the molecular interactions among cholesterol, lipids, and proteins would allow us to design a better drug delivery system. Drug delivery liposomes of sizes 50 nm to 100 nm have been used to deliver gene medicines, as well as anti-cancer, anti-fungal, and anti-inflammatory drugs. Compared to other drug delivery systems, liposomes are much safer. We have been collaborating with research groups at the TTU Health Science Center on drug delivery liposomes for cancer treatment and gene therapy. In addition to phospholipids and cholesterol, lipid-anchored polyethylene glycol polymers (PEG) were used to increase the circulating time of liposomes so that they would not be prematurely cleared by the body's immune system. Also, the liposomes contained ligands to target delivery of drugs to certain types of cells. The fluorescence microscopy images in Figure 4 show that our customized liposomes successfully delivered an anti-cancer drug into prostate cancer cells.

Our lab is well equipped to make various types of liposomes, such as small unilamellar vesicles (SUV), multi-

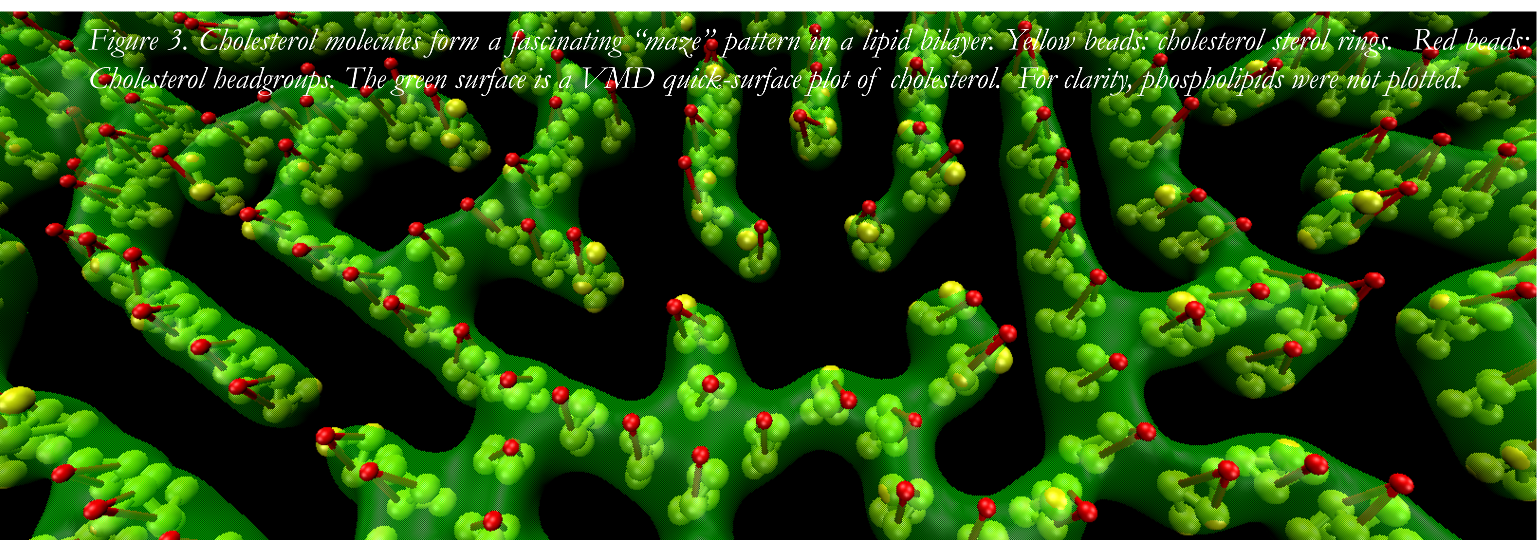


Figure 3. Cholesterol molecules form a fascinating "maze" pattern in a lipid bilayer. Yellow beads: cholesterol sterol rings. Red beads: Cholesterol headgroups. The green surface is a VMD quick-surface plot of cholesterol. For clarity, phospholipids were not plotted.

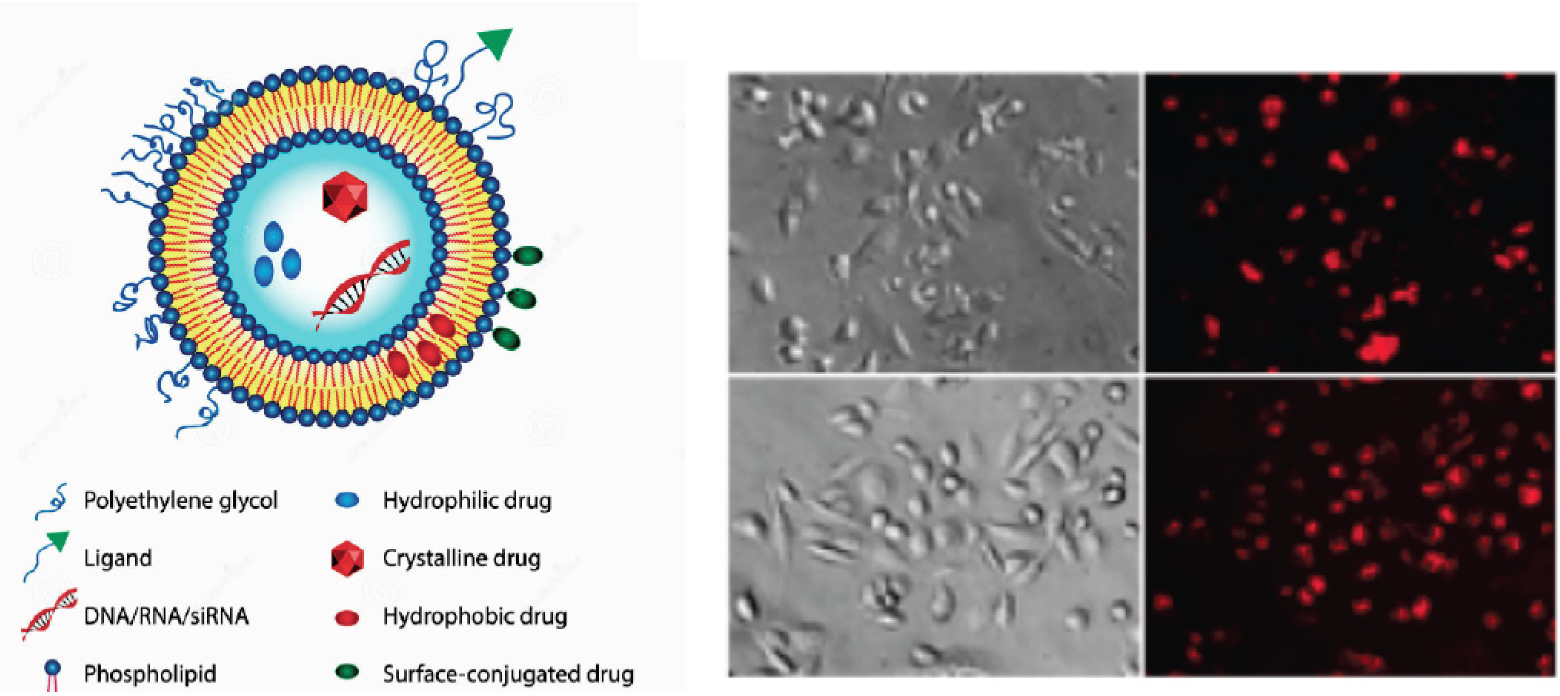


Figure 4: (Left) Drug delivery liposomes. (Right): Microscopy images of prostate cancer cells. The red fluorescence indicates that the drug was successfully delivered into the cells.

lamellar vesicles (MLV), and giant unilamellar vesicles (GUV). Students in my group use fluorescence microscopy, fluorescence spectroscopy, light scattering, protein activity assay, and computer simulation techniques to carry out various research projects. We have active research collaborations with faculty members in the biology and engineering departments, as well as at the TTU Health Science Center. Since I arrived at TTU, more than 30 graduate and undergraduate students have received biophysics training in my lab. The department currently has two graduate-level courses in biophysics. I am looking forward to an expansion of biophysics programs in our department.

SPS members on a field trip to Los Alamos

Statistical Problems in Particle Physics

Igor Volobouev

I am writing this piece in the wake of an excellent article by Louis Lyons in *Physics Today* that does a superb job of outlining the major statistical techniques employed in particle physics with minimal math [1]. I heartily recommend reading Lyons' article before this one. Here, I attempt to dig a little deeper into two hard problems: how we can make sure that our discoveries are not fake and how we can present experimental results so that they can be easily used for developing and tuning theoretical models. You will see that, for these problems, the current state of the art in statistical methodology is quite far from the blissful "everything just works" and that substantial further developments are needed.

In particle physics, the experimental data records are called "events." These are the snapshots of energies and momenta of particles produced in high energy collisions as they traverse particle detectors. Every such snapshot is distinct, and we always assume that these events are statistically independent – that is, the probabilities and final state outcomes of the reaction that happens at time t_1 are independent from another reaction that happened earlier at time t_0. Moreover, we also assume that several reactions that happen at the same time but in a slightly different place proceed independently from each other. While these assumptions are somewhat approximate, at the basic physical level they are very well justified by the short range (roughly, the size of the proton) of the strong interactions and by the fact that the speeds of incoming and outgoing particles produced at high energy accelerators, such as the Large Hadron Collider (LHC) at CERN, are only slightly below the speed of light.

Frequentist statistical methods are very well suited for the analysis of collections of independent events. In these methods, the definition of probability involves postulating ensembles (as opposed to priors in Bayesian statistics) and then relying on the law of large numbers and on the uniformity of time to identify long-term frequencies with probabilities.

Signal Significance: In the frequentist statistical inference, the significance of the observed signal is expressed in the language of hypothesis testing. Two hypotheses, traditionally denoted by H_0 and H_1, are tested against each other on the basis of experimental observations. Usually, H_0 (the null hypothesis) represents the status quo, that is, the absence of the signal. H_1 represents the alternative: the signal is present. H_0 and H_1 are mutually exclusive (both can not occur simultaneously) and jointly exhaustive (one of them must be true). Let T be some function of the data, called the test statistic, and W be the space of all possible values of T. This space is partitioned into two regions: the critical region W_1 and the region of acceptance W_2, complementary to W_1 ($W_1 + W_2 = W$). If the observed value of T, t_{obs}, falls inside W_1, the null hypothesis is rejected and the alternative is accepted. If t_{obs} falls inside W_2, H_0 is declared to be true. Testing H_1 vs. H_0 thus amounts to choosing a test statistic and its critical region.

Usually, one adjusts the critical region to produce a desired level of significance α defined as the probability of t_{obs} falling inside W_1 when H_0 is true: $P(t_{obs} \in W_1 | H_0) = \alpha$. α is thus the probability to reject H_0 when it is valid. In the statistical literature, this rejection is called the error of the first kind.

The usefulness of the test stems from its behavior when H_1 is true and H_0 is false. It is characterized by the probability of t_{obs} falling inside W_2 when H_1 true: $P(t_{obs} \in W_2 | H_1) = \beta$. In this case, the outcome of the test is the error of the second kind: the null hypothesis is accepted when it is false. The number $1 - \beta$ (the probability that the alternative hypothesis is accepted when it is true) is called the power of the test. The table below summarizes the situation:

	H_0 is true	H_1 is true
$t_{obs} \in W_2$, accept null hypothesis	Correct decision, $P = 1 - \alpha$	Error of the 2nd kind, $P = \beta$
$t_{obs} \in W_1$, reject null hypothesis	Error of the 1st kind, $P = \alpha$	Correct decision, $P = 1 - \beta$

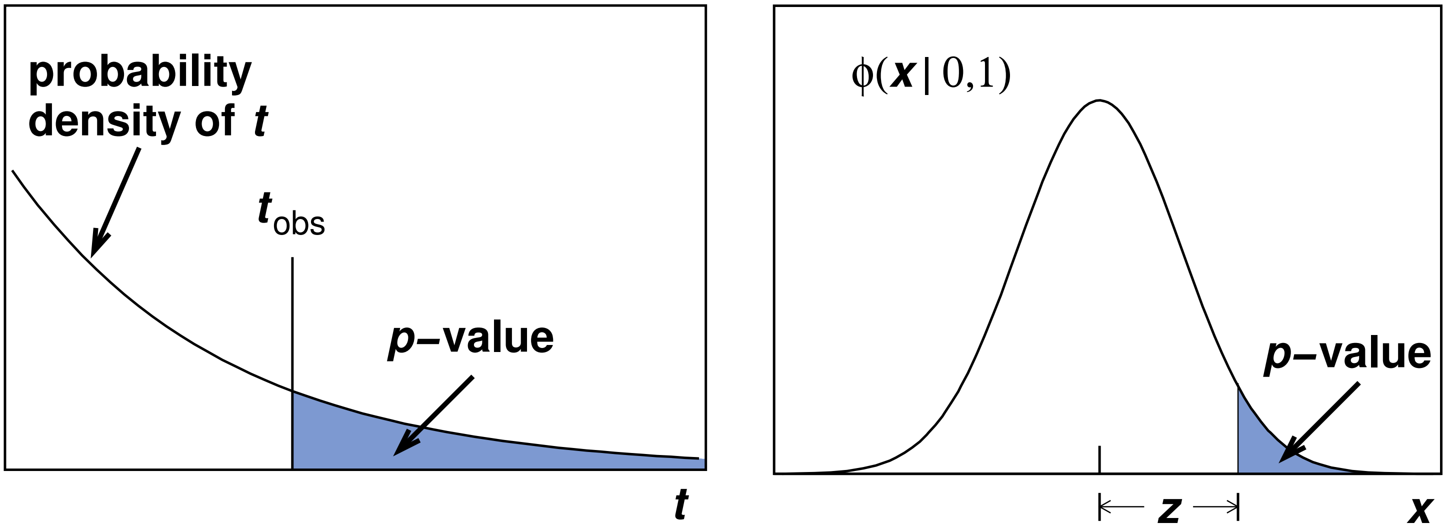


Figure 1. (Left panel) p-value for the observed value of a test statistic. (Right panel) definition of the statistical significance in terms of the normal distribution.

Obviously, for a given α, the test with higher power (and, therefore, smaller probability of the error of the second kind) should be preferred. Assuming that T has a continuous distribution, in 1933 statisticians J. Neyman and E. Pearson proved that the most powerful choice of W_1 is based on the likelihood ratio. Nowadays, this statement is referred to as the Neyman–Pearson lemma.

In most situations of practical importance, the statistic T is monotonous. That is, if one observes values t_1 and t_2 in two independent and identical realizations of the same test, $t_1 < t_2$ is always interpreted as more evidence in favor of H_1 in the realization yielding t_2, no matter what the actual values of the statistic are. In this case, regions W_1 and W_2 are contiguous, and they are separated by a single decision boundary, z. In such situations, there is one-to-one correspondence between z and α (as well as between z and β), and one can deduce the functional dependency $\alpha(z)$ (called the survival function) and its inverse, $z(\alpha)$. It then becomes possible to invert the hypothesis testing logic and define the significance of the observed value of statistic as $\alpha\,(t_{\text{obs}})$. In this case, $\alpha\,(t_{\text{obs}}) = P(t \geq t_{\text{obs}} \,|\, H_0)$; that is, the probability to observe the value of statistic is at least as large as t_{obs} given that H_0 is true. This probability is known as the observation p-value. For continuous T, this is the area under the tail of the statistic probability density function above t_{obs}, as illustrated in Figure 1.a.

It is worth emphasizing that the frequentist treatment does not assign probabilities to the hypotheses themselves. A common mistake, termed the "p-value fallacy," is to interpret the observation p-value as the probability that H_0 is true. In the frequentist framework, such a probability is simply undefined. Instead, the role of p-values is to provide guidance to the researcher as to which hypothesis to accept. It is possible to assign probabilities to hypotheses in the Bayesian framework, but discussion of Bayesian hypothesis testing methodology would take us too far afield.

For very small p-values, it becomes convenient to represent the significance in terms of the number of "standard deviations." This concept is related to the normal (also called Gaussian) distribution whose probability density is given by

$$\phi(x|\mu,\sigma^2) = \frac{1}{\sqrt{2\pi}\sigma} e^{-\frac{(x-\mu)^2}{2\sigma^2}}$$

where μ and σ are the mean and the standard deviation, respectively. A very special status is bestowed upon this distribution by the central limit theorem: a sum of many random variables with finite variances will have an approximately normal distribution no matter how individual variables are distributed. The normal distribution, therefore, becomes an almost universal asymptotic for various results involving large amounts of data, and it appears ubiquitously across various statistics and data analysis methods. $\phi(x|0,1)$, according to which the quantity $(x-\mu)/\sigma$ is distributed, is called the standard normal density, and practitioners quickly acquire a lot of experience using it. The following definition of significance then becomes rather intuitive: this is the value of the inverse survival function calculated at the observed p-value (that is, $z(p\text{-value})$) for a hypothetical ideal statistic distributed with density $\phi(x|0,1)$ (Figure 1.b). When significance is defined in this manner, it no longer matters what actual distribution of T looks like. As long as it is known, it is converted into the standard normal.

The above exposition describes testing of "simple hypotheses," that is, H_0 and H_1 are fully and unambiguously specified. Unfortunately, in practice it is by far more common that H_1 and/or H_0 are not completely known and that some of their features must be determined from observations. The testing procedures must therefore be adapted to handle such "composite hypotheses." This is where the statistical treatment has to become substantially more sophisticated and where significant potential for misinterpretation and mistakes is added. The most common difficulty consists in proper accounting for the number of tests that were effectively made. In particle physics applications, this is known as the "look-elsewhere effect." The statistical and biomedical terms for this effect are "multiple comparisons problem" and "control of false discovery rate."

To appreciate the look-elsewhere effect in a somewhat simpler and more entertaining context, consider the following Halloween-inspired problem. A wicked fairy stepmother tells Cinderella, "I am attending the Royal Ball tonight. I will take you with me if you accomplish a chore. Here, pick one hundred daisies from this meadow before sunset." Cinderella, surprised by the simplicity of her assignment, starts collecting the flowers. She notices that on average she finds one flower per minute, and that the time intervals between her picks are exponentially distributed. "This is easy" she thinks. "It was eight hours before sunset when I started." However, after a while the flowers in her basket start to disappear! The girl has an excellent visual memory, and she quickly figures out that each flower disappears exactly one hour after it was picked. She decides to continue anyway. "I have my smartphone with me. As soon as I have one hundred flowers, I'll take a photo of them." Assuming that the photo will be accepted as the evidence that her task was completed, determine the probability p_s that Cinderella will be taken to the Royal Ball by her stepmother. (If you are adventurous, try to solve this problem yourself before reading the next two paragraphs.)

How should this problem be approached? Apparently, the girl will succeed if the number of flowers she picks during some time interval $[t, t + 1 \text{ hour}]$ reaches 100 for any $t \in [0, 7 \text{ hours}]$. The average number of flowers she collects per hour is $\lambda = 60$, and, in any given hour, the probability to collect exactly n flowers is given by the well-known Poisson distribution: $p(n) = \lambda^n/n!\, e^{-\lambda}$. The probability to succeed in any given fixed hour is then $p_1 \approx 1.48\times10^{-6}$, and the probability to fail is $1-p_1$. Now, how can we account for the number of hours? If we assume that there are eight independent attempts then the success probability is given by $p_8 = 1-(1-p_1)^8 \approx 1.19\times10^{-5}$, where $(1-p_1)^8$ is the joint probability of all eight failures. However, the correct success probability obtained by an uncomplicated computer simulation is $p_s = 1.74\times10^{-4}$, almost 15 times higher. One can convert this probability into the effective number of independent tries, a.k.a. the look-elsewhere "trial factor," by solving the equation $1-(1-p_1)^\gamma = p_s$. This gives the trial factor value $\gamma \approx 117$.

While this result is somewhat enigmatic (where does the number 117 come from and why is it so large in comparison with 8?), it is not difficult to understand why the naive p_8 formula fails. The number of flowers collected at the intervals $[t_1, t_1 + 1 \text{ hour}]$ and $[t_2, t_2 + 1 \text{ hour}]$ are not independent from each other if these intervals overlap (that is, if $|t_1 - t_2| < 1$ hour). The fluctuations of the flower collection rate inside the overlap affect the probability of success for both intervals. This correlation of success probabilities must be taken into account in the p_s calculation.

p_s is the direct analog of α (probability of the error of the first kind) in testing for signal presence when the signal location is unknown and derived from data. It is also called the "global p-value," as opposed to the "local p-value" given by p_1. Naturally, misinterpreting p_1 as p_s with the trial factor reaching into hundreds or thousands can lead to drastically wrong conclusions about the signal significance.

Even though the Cinderella problem is unambiguous and easy to state, I am not aware of any method from statistics or from queueing theory that would allow us to calculate the exact values of p_s and γ using either a closed-form expression or a series expansion. The situation becomes simpler if, instead of the discrete Poisson distribution of counts, one has to deal with an approximately normally distributed continuous statistic. There, recent advances in the theory of Gaussian random fields come to the rescue. While it is still not possible to solve the problem exactly, a good approximate technique does exist, as was illustrated in 2010 by E. Gross and O. Vitells [2]. Prior to that, the look-elsewhere trial factor was either calculated by direct simulations (extremely CPU-consuming for low p-values) or not estimated at all. In combination with wide model and parameter coverage of various new particle searches, absence of such estimates has led to a perception that a strong particle discovery claim should be substantiated by the significance of at least 5 standard deviations (p-value $=2.87\times10^{-7}$).

Of course, even though Cinderella will almost surely fail the wicked stepmother's task, a deus ex machina benevolent fairy will help her to shine at the Royal Ball anyway. The situation with graduate students and their thesis advisers is somewhat different. A small fraction of their scientific findings is going to be generated by statistical fluctuations, at times leading to rather remarkable consequences. For instance, on December 15, 2015, both CMS and ATLAS collaborations at CERN reported an excess of events in the distributions of the invariant mass of two photons at about 750 GeV. The "local" significance excess was estimated to be 2.6σ by CMS and 3.6σ by ATLAS. The global significances of these measurements were reported as well: 1.2σ and 2.0σ, respectively. However, the theory community largely ignored the global significances, concentrating instead on the local ones and on similarity in the bump locations. Motivated by this excess, over 600 papers were produced [3]. Meanwhile the LHC continued collecting data, and by August 2016 it became obvious that the new particle candidate was just a statistical fluctuation.

Proper calculation of statistical significance remains a thorny problem. Some of the author's recent work performed in collaboration with Alex Trindade from the TTU Department of Mathematics and Statistics clears another hurdle in the significance estimation. In our study, we derive improved theoretical models of various test statistics for signal plus background mixtures. These models enable application of the theory of Gaussian random fields for small data samples [4].

Unfolding: If you are a particle phenomenologist, you definitely want to test predictions of your favorite models and their parameterizations against the data. As the first step, you add your models to an existing Monte Carlo generator of particle reactions or write your own. After this, two options become available: 1) convince your experimental colleagues to simulate the detector response for the events produced by your model and compare these events with experimental observations and 2) compare distributions of some variables produced by your generator with experimental distributions in which the detector effects are removed. Perhaps you also wonder whether you can simulate the detector response yourself, but then you quickly discover that high quality particle detector simulators are unique and not standardized, they are implemented within different arcane software frameworks, and that access to the detector configuration and calibration databases is restricted to members of the corresponding experimental collaborations. On the other hand, in case of 2, you are in control of the statistical analysis, so there is no need to wait, and the data produced by different experiments can all be used in the same manner. You decide that option 2 is more appealing and become a consumer of unfolded results.

"Unfolding" is a term used by particle physicists to denote techniques used to solve statistical inverse problems. A typical problem of this kind can be stated as follows: We observe a sample of independent and identically distributed points y_i, $i = 1, 2, \ldots, N$, drawn from a distribution with unknown density $q(y)=1/Z \int K(y,x)\lambda(x)dx$. Here, x are the "true" multidimensional quantities that characterize the final state of some particle reaction in its original phase space, and y are the detector measurements. $K(y,x)$ is the detector response function that encodes detector resolution and efficiency. Particle detectors are not deterministic, so $K(y,x)$ is actually the probability density to measure y when a known final state x is injected into the detector. The efficiency factor (that is, the probability to measure anything at all instead of just losing the event) is also included into $K(y,x)$. Z is a normalization term that ensures that $\int q(y)dy = 1$. The goal is to determine the "unsmeared" density $\lambda(x)$ together with its appropriate uncertainties, thereby removing the effect of detector response.

Experimentalists are happy to unfold their distributions whenever possible, but the path to glorious detector-independent results is full of traps and pitfalls. To begin with, the problem is ill-posed: $\lambda(x)$ is an infinite-dimensional parameter, indexed by x. Naturally, the value of such a parameter can not be determined from a finite amount of data, and therefore some dimensionality reduction assumptions must be made. Introduction of such assumptions into the problem is called regularization. The need for regularization can also be inferred from the observation that detector response functions are notoriously difficult to invert. $K(y,x)$ typically operates as a smoothing filter, removing high frequency components of $\lambda(x)$ (see Figure 2). The inverse, therefore, should be a sharpening filter, amplifying high frequencies. However, the smooth $q(y)$ function is not directly observable. Instead we can only see the points y_i which include plenty of high frequency statistical sampling noise. Application of a sharpening filter to that noise would simply drown the signal

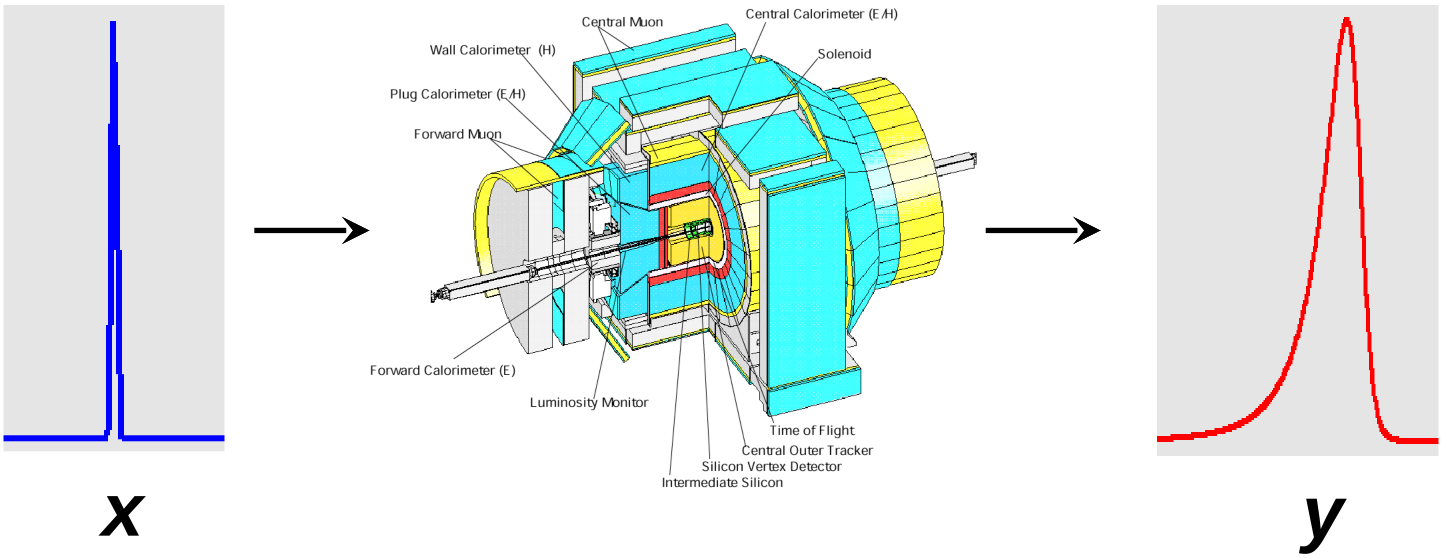


Figure 2. Detector smearing particle information.

in it, so this noise has to be suppressed. But neither noise nor signal spectra are known in advance, so we must assume something about them.

Unfortunately, the effect of various regularization assumptions is almost always undesirable. If the assumptions are incorrect, they introduce a bias into the solution. In addition, due to a reduction in the number of degrees of freedom, these assumptions typically lead to the loss of information present in the data.

The bias problem is especially detrimental. The statistical uncertainties of biased estimators are not subject to the Cramer-Rao bound and do not represent the total error. The statistical covariance matrices of biased estimates, determined by linear error propagation, become ill-conditioned or singular. While in principle the bias can be accounted for by an appropriate systematic uncertainty, in practice determination of this uncertainty is difficult and very subjective. The degree to which underestimation of the total uncertainty affects scientific conclusions is difficult to predict, as it depends on the subsequent use of the unfolded result.

A commonly used method of regularizing the unfolding problem, called Tikhonov regularization, can be set up to penalize deviations of the unfolded result from some initial guess, so at the end the result is biased towards that guess. This is, indeed, how Tikhonov regularization is implemented in the unfolding software packages popular in particle physics data analysis. The initial guess is often created using an existing Monte Carlo event generator. As the generators are tuned to reproduce past results, this practice leads to another insidious bias. The new results are no longer independent from the old ones, so they become difficult to combine properly.

Some of the problems just mentioned affect all regularization methods and can not be alleviated by simply educating the researchers about better techniques. I am deeply convinced that our understanding of unfolding must be radically improved. This will likely involve a substantial paradigm shift. One can imagine, for example, deferring the regularization step to the very end, so that it is performed by phenomenologists fitting their models rather than by experimentalists. When the physical model is specified, one can quantify how regularization assumptions affect model parameters and tune the analysis to that particular model. However, regularization at such a late stage obviously precludes determination of $\lambda(x)$, so the goal of unfolding must be reformulated. Instead of $\lambda(x)$, one can determine some of its functionals (for example, a few terms in the orthogonal series expansion) together with their unregularized uncertainties. Then the models can be tuned to reproduce these functionals.

[1] L. Lyons, "Discovery or fluke: statistics in particle physics," Physics Today 65, issue 7, p 45 (2012)
[2] E. Gross, O. Vitells, "Trial factors for the look elsewhere effect in high energy physics," The European Physical Journal C 70, p 525 (2010)
[3] http://jsfiddle.net/adavid/bk2tmc2m/show/
[4] I. Volobouev and A. Trindade, "Improved Inference for the Signal Significance," arXiv:1609.00752, [physics.data-an] (2017)

GRASP

Sueli Skinner-Ramos

We are proud to announce that our first year as a graduate student organization has been remarkably productive and full of accomplishments. Under new leadership, the GRASP family would like to thank the previous executive board members and faculty advisor for their efforts and commitment to the organization. Their work and tenacity has laid the foundation of our organization for years to come. We would also like to welcome our new board members and faculty advisor and wish them the very best as they take our organization in a new and inspiring direction. Our Executive members are Sueli Skinner (President), Charles Ramey (Vice President), Jigesh Patel (Treasurer), Mahsa Servati (Secretary), Alex Gordienko (SORC/Department Representative), and Dr. Juyang Huang (Faculty Advisor).

The main goals of our organization are to seek ways to improve the graduate experience in the Department of Physics and Astronomy, and to serve as a representative body for physics graduate students. Since the inception of GRASP, we have organized and participated in a variety of events that have brought the graduate students closer together and instilled a sense of camaraderie among our colleagues in the department. In particular, our organization has focused on arranging academic sessions to enrich and broaden the graduate student experience, outreach activities to promote our department, and social events to improve departmental interaction and cohesion.

Undoubtedly, one of the most rigorous challenges a graduate student undergoes is the Preliminary Examination for the Physics PhD. To aid in the exam preparation, GRASP organized oral examination practice sessions directed by current Ph.D. candidates who successfully completed the test in the past. In a similar vein, to enhance oral presentation skills, we have instituted the Graduate Research Talks (GRT's) that have been taking place every week in the last two semesters. There is a two-fold purpose of these sessions: to expand awareness of current research taking place in the department and to help students practice answering questions in a formal setting, similar to a thesis defense or conference presentation.

GRASP has participated in several outreach activities this year, including "Stare at the Stars" at Stewart Elementary, the "SunDay" activity (part of Global Astronomy Month) at the TTU SUB, and "STEM Night" at Wester Elementary. We also hosted 50 high school students from Monterey High School for a physics Demo Day, actively participated in the TTU Arts & Sciences Day, and worked with SPS in the "TTU Science Made Easy Saturday."

To stimulate departmental camaraderie, GRASP has sponsored social events like a welcome BBQ for incoming graduate students, a hiking trip to Palo Duro Canyon, and an August post-prelim pizza party celebration in recognition of students' efforts this past exam cycle. We have also overseen the arrangement of the Departmental Colloquium refreshments for about a year now, where we are determined to include healthy yet delicious options.

We find pride in being the voice of the students and the vanguard of change in our community and department. Although our organization has been very successful this year, this is only the beginning! We recognize that there is a lot more to be done to fully achieve our goals. And GRASP always appreciates your help and assistance. If you have any recommendations or suggestions for new activities, please feel free to contact anyone mentioned in this article. On the back page of this issue, you will find some GRASP merchandise for sale to help cover some of the expenses for our activities. They make great Christmas gifts (s.skinner-ramos@ttu.edu).

President's and Dean's List Scholarships & Awards

President's List (Spring 2017)

Kyle Artkop, Aashish Gupta, Michael Keeler, Madeline Lockhart, Michael McClellan, Justin Perea, Alexander James Scott, Timothy Vincent, Madeleine Wagner, Chase Withworth, Brittany Woods, and Max Zhelyeznyakov

Dean's List (Spring 2017)

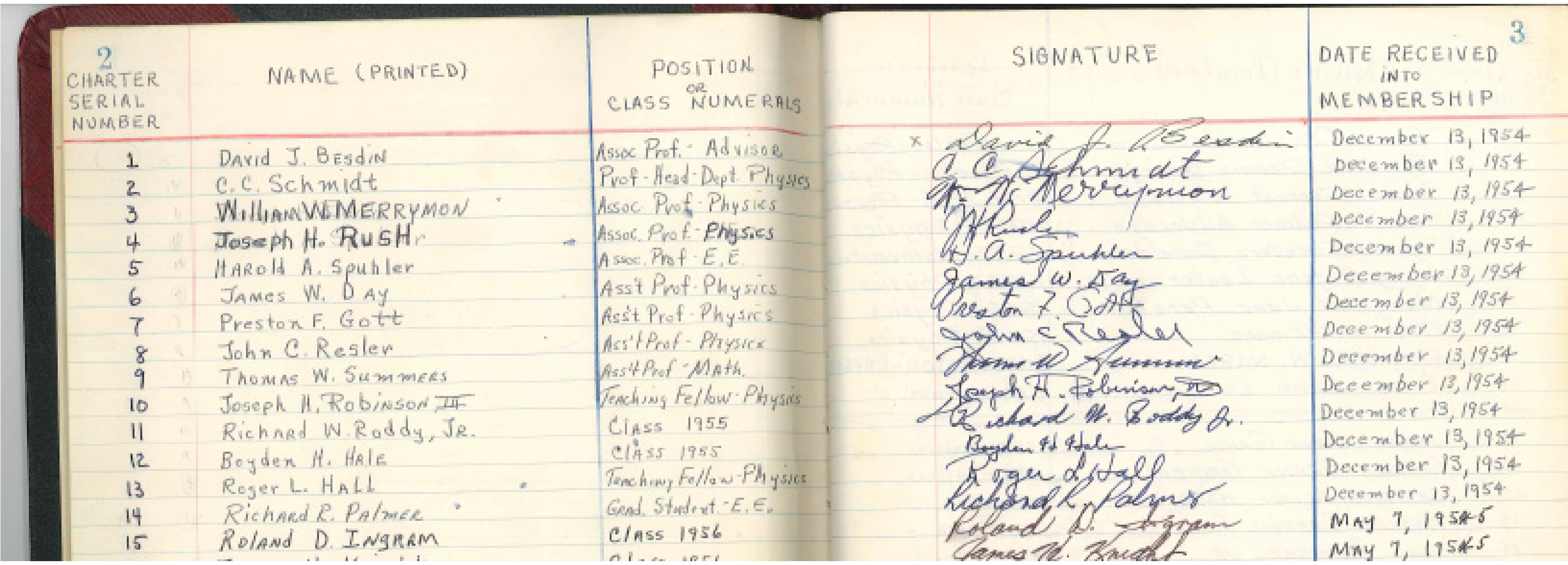
Steven Applegate, Victoria Blackmon, Ganesh Chaulagain, David Do, Juan Dominguez, Justin Edwards, Tanner Martinez, Brandon Matthews, Elijah Miller, Jace Mortensen, Jake Noltensmeyer, Deidre Reyes, James Roberts, Kenton Sanders, Gregory Skillman, Rachel Smith, Anthony Sosa, Anvar Szulczyk, Clayton Tuller, Samuel Wakil, Montana Williams, and Adrian Yearby

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 14, 2017 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 Amani Ibrahim, Anvar Szulczyk, and Blake Warner
- JW Day Award to Timothy Vincent
- Gangopadhyay Undergraduate Award to Sadman Shanto and Bridget Mann
- Gott Gold Tooth Award to Justin Perea
- Glen A. Mann Award to Bridget Mann, Anthony Rushing, and Sadman Shanto
- David Patillo Scholarship to Phillip Bouillion and Adelia Schenk
- CC & Alma K. Schmidt Award to Ian Hughes, Alejandro Ibarra, Michael Keeler, Jacob Siau, Greg Skillman, Chase Whitworth, Brody Moore, Rachel Smith, Madeline Wagnon, and Madeline Lockhart
- Hastings Family Physics Scholarships to Charles Neuendorff and Aashish Gupta
- Kenneth Sterne Award Kyle Artkop
- Roland Menzel Memorial Endowed Scholarship David Do
- Henry C. Thomas Award to Kyle Artkop
- Sidney Sundell in Astrophysics Award Justin Perea
- Bucy Applied Graduate Physics Scholarships to Michael Holcomb, Kamal Lamichhane, Samila Muthumuni, Jigesh Patel, Milind Pattannayak, and Ceren Duygu
- David Howe Award to Kavitha Arur
- Peter Seibt Award Memorial Graduate Physics Scholarship to Ceren Duygu
- The Ron and N. Miller Graduate Physics Scholarship to Chris Stanley
- Professor of the Year went to Dr. Tom Maccarone
- Outstanding PhD student went to Darshan Desai
- Outstanding MS student went to Paul Bennet
- Outstanding TA went to Charles Ramey
- Outstanding Graduating Seniors were Max Zhelyeznyakov, Roberto Espinoza, Brandon Matthews, and Rachel Smith

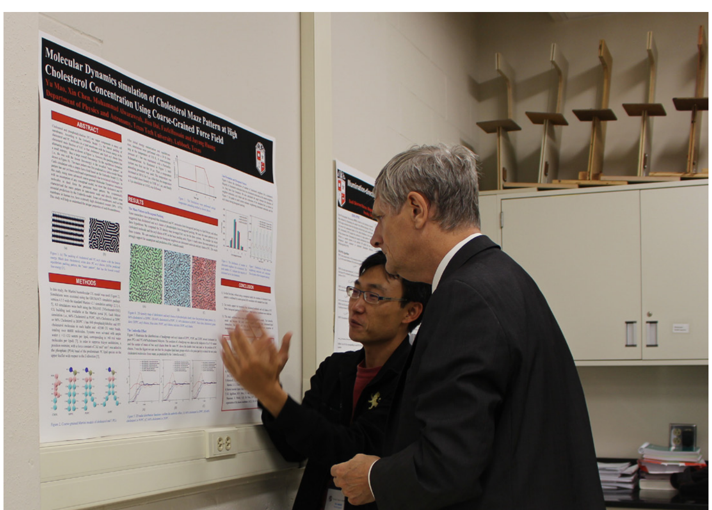
Sigma Pi Sigma

Michael Holcomb



CHARTER SERIAL NUMBER	NAME (PRINTED)	POSITION OR CLASS NUMERALS	SIGNATURE	DATE RECEIVED INTO MEMBERSHIP
1	David J. Besdin	Assoc Prof. - Advisor		December 13, 1954
2	C. C. Schmidt	Prof - Head Dept. Physics		December 13, 1954
3	William W. MERRYMON	Assoc. Prof - Physics		December 13, 1954
4	Joseph H. RusH	Assoc. Prof - Physics		December 13, 1954
5	Harold A. Spuhler	Assoc. Prof - E. E.		December 13, 1954
6	James W. Day	Ass't Prof - Physics		December 13, 1954
7	Preston F. Gott	Ass't Prof - Physics		December 13, 1954
8	John C. Resler	Ass't Prof - Physics		December 13, 1954
9	Thomas W. Summers	Ass't Prof - Math.		December 13, 1954
10	Joseph H. Robinson III	Teaching Fellow - Physics		December 13, 1954
11	Richard W. Roddy, Jr.	Class 1955		December 13, 1954
12	Boyden H. Hale	Class 1955		December 13, 1954
13	Roger L. Hall	Teaching Fellow - Physics		December 13, 1954
14	Richard R. Palmer	Grad. Student - E. E.		December 13, 1954
15	Roland D. Ingram	Class 1956		May 7, 195~~4~~5

Sigma Pi Sigma (ΣΠΣ), the National Physics Honor Society, was founded in 1921 at Davidson College, NC. It started off as a local society but began to nationalize in 1925. By 1968, ΣΠΣ had grown to 170 chapters and merged with the American Institutes of Physics, creating the Society of Physics Students (SPS). After the merger, all ΣΠΣ chapters were enrolled as SPS chapters. It was written into the SPS constitution that ΣΠΣ would continue to exist as a special group of SPS members who had excelled scholastically and been elected for membership. This relationship between SPS and ΣΠΣ is unique among honor societies, and today there are 689 SPS chapters, nearly 500 of which have active ΣΠΣ chapters.



The ΣΠΣ chapter at Texas Tech University was established December 13th 1954. Our chapter has inducted over 400 members and is currently lead by doctoral candidates Christopher Stanley, Keller Andrews, and Michael Holcomb under the guidance of the chapter's faculty advisor, Professor Sung-Won Lee. In recent years, our chapter has seen an increase in active membership, as well as an increase in its activity within the Department of Physics and Astronomy and in community outreach. Members of our chapter help yearly with the setup and judging of the South Plains Regional Science and Engineering Fair, and this year we organized and participated in the first annual departmental poster competition. Graduate students at all levels came out to participate, and posters from all branches of physics within our department were well represented.

High academic performers among both undergraduate and graduate students are eligible for induction into ΣΠΣ on a yearly basis. As our department continues to grow, we hope to see a sustained increase in our number of active members and an increased capability to participate in more outreach. By working closely with other departmental student organizations such as our local SPS chapter and Graduate Association of Physicists (GRASP), we hope to increase the number of community outreach opportunities, particularly those that extend

to children and young adults the opportunity to become excited about physics. For example, we plan to hold regular astronomy and basic physics workshops in local elementary and middle schools.

These kinds of regular high impact community outreach opportunities are a long-term goal for ΣΠΣ and will require resource allocation, effort coordination, and a collaborative effort among all departmental student organizations and the department itself. In the short-term, we are looking to encourage more participation from our members and to engage in more joint endeavors with our fellow student organizations. We also hope to see the continuation of the departmental poster competition next year and increased participation from junior and senior undergraduate students involved in research experiences. As the next induction approaches, we are excited to see how many students we will be able to offer induction this year!

Society of Physics Students

Diane Ha

Texas Tech University's Society of Physics Students (SPS) continues to emphasize the importance of research and to promote professional growth among its expanding Chapter. The organization has been conscientiously striving to establish the Chapter as a source of academic advancement and enrichment for its members.

During the Spring 2017 semester, the Chapter made a long but rewarding trip to Houston, TX to visit the Johnson Space Center (NASA). Members were fortunate enough to be invited to tour NASA's Mission Control Center, home to the facility's space exploration flight management. This trip was made possible by previous SPS President, Alexander Cardona. Additionally, the Chapter returned to NRAO's Very Large Array (VLA) to tour the campus thanks to arrangements made by SPS member, Deven Bhakta (BS'17). Moreover, the Chapter reinstituted its biannual Star Party, made possible by the new SPS Advisor, Dr. Robert Morehead.

The semester ended with the annual events, the Sigma Pi Sigma Induction Ceremony as well as the Departmental Banquet, which was made possible by the Bucy Endowment. Six members were successfully inducted into the prestigious SPS fellowship thanks to the effective planning of Dr. Sung-won Lee, Dr. Thomas L. Gibson, and Dr. David Lamp. Scholarships and departmental awards were granted at the Departmental Banquet in addition to the Professor of the Year award, granted to Dr. Thomas Maccarone. Many thanks are given to the professors who volunteered to announce the scholarship and award recipients and to Dr. Nural Akchurin for his opening and closing remarks. The record-breaking number of students graduating within the department, with eight graduates who are SPS members, made for a historic conclusion of a triumphant academic school year.

During the Fall 2017 semester, the Chapter was graciously invited to the Los Alamos National Laboratory to tour the facility's Neutron Science Center (LANSCE)

and safeguard laboratories. Members also visited the Bradbury Science Museum and the Los Alamos Overlook Park before traveling safely back to Lubbock. Special thanks are given to SPS member, Madeline Lockhart, and the Lockhart family for making the Los Alamos trip fun, educational, and possible, for the first time in SPS history.

Major achievements during this semester include the development of SPS's Fundraising and Public Relations Committees. The Fundraising Committee, led by chairperson David Palmore, is working to establish the SPS Graduate-School-Readiness (GSR) Grant, a collection of funds that will go directly towards GRE and graduate school application fees for graduating SPS members. Special thanks are given to Amy Crumley, Director of Development of the College of Arts and Sciences, for her advice and direction in respect to our fundraising endeavors. The Public Relations Committee, led by chairperson Sadman-Ahmed Shanto, is working to contribute directly to success and academic growth within the Chapter through promotional content and events. Content and events such as the SPS Newsletter, The Quark, a Physics Competition, and a REU Info Session (led by Vice President Peter Wibert and SPS Webmaster Sam Cano) are currently in the works.

Throughout 2017, SPS continued to provide its members with engaging events that contribute to our mission to stimulate knowledge, competence, enthusiasm, and social responsibility in regards to the advancement of physics as defined by the National Society of Physics Students. Some periodic events were hosted to promote networking within the organization and to alleviate academic strains for Chapter members; these included various socials, such as Bowling Night and Game Night, and a variety of promotional and outreach events, some of which were hosted in coordination with GRASP.

Promotional events, such as the Organizational Fair, Arts & Sciences Fair, Majors and Minors Fair, and Resource Fair, were made possible by secondary advisor, Valerie Smith, who in addition to Dr. Wallace Glab, has helped us to attract the current historic number of SPS members. Outreach events, such as Science Made Simple and Tech or Treat, pushed SPS to grow from a social society to one of more depth and academic achievement, and was made possible by GRASP, specifically, Manuel Pichardo-Marcano, SPS member David Palmore, and Dr. Robert Morehead.

SPS's plans for the upcoming year include continued growth and achievement within the Chapter, attending a tour of Sandia National Lab, visiting the Museum of Nuclear Science & History, and working towards our goal of collaborating with the National Science Foundation (NSF) to host a REU program at Texas Tech University. We believe that with the continued support of the department, our advisors, and our dedicated officers, the 2017-2018 academic school year will go down in history as one of the most transformative years for our SPS Chapter.

We Hear that...

On March 9, George Laity BS 2008 (Physics), PhD 2013 (EE), discussed *Understanding Vacuum Power Flow at the Sandia Z Accelerator for Improving High Energy Density Physics Experiments* at the departmental colloquium. George is now a staff scientist at the Sandia National Laboratories.

Charles Ramey received the prestigious Duncan McBride PER Conference Award to attend the American Association of Physics Teachers (AAPT) 2017 Summer Meeting and the 2017 Physics Education Research Conference (PERC). He spoke on "Utilizing Letters to Investigate Students' Ability to Communicate Physics."

"Archeology Meets Particle Physics" appeared in *Symmetry* magazine on April 4, describing the efforts of Drs. Nural Akchurin and Shuichi Kunori and their undergraduate researchers in using cosmic muons to explore archeological structures in Asia Minor.

SPS's Annual Departmental Banquet took place on April 14 at the McKenzie-Merket Alumni Center. The featured speakers were Dr. Katherine Hayhoe from the Department of Political Science, who discussed climate change, and our own Dr. Robert Morehead, who described research opportunities at the Preston Gott Observatory. At the same event, the departmental awards were presented.

Dr. Beth Thacker attended the American Physical Society (APS) meeting in Washington, DC in January 2017 and the Transforming Research in Undergraduate STEM Education (TRUSE) conference at the University of St. Thomas Minnesota in July 2017, presenting on "Large-scale Assessment Yields Evidence of Minimal Use of Reasoning Skills in Traditionally Taught Classes" and "Promoting and Assessing Thinking Skills in a Laboratory-based Physics Course," respectively. Recently, she also began serving on the Advisory Board for the Center for Integration of STEM Education and Research (CISER) and is a Fellow in the STEM Center for Outreach, Research, and Education (STEMCORE), a Pedagogical Specialist for the STEM Teaching, Engagement and Pedagogy (STEP) Program, and as Course Coordinator for *OnRamps*, a Dual Enrollment program run in conjunction with the University of Texas.

We have had the pleasure of Dr. Tana Joseph visiting us this fall and early winter as a Fulbright Scholar. Dr. Joseph's primary area of research is understanding the extragalactic populations of binary star systems containing neutron stars and black holes. Dr. Joseph earned her PhD in 2013 from the University of Southampton and spent several months visiting Texas Tech during her thesis to work with Tom Maccarone, who moved from Southampton to Texas Tech while she was a graduate student. After that, Dr. Joseph was a Square Kilometer Array Fellow at the University of Cape Town. She currently holds the position of Outreach Astronomer at the South African Astronomical Observatory, a position that was created for her to accommodate her pursuit of research activities and efforts toward public understanding of astronomy. After leaving Texas Tech in February, Dr. Joseph will commence an Isaac Newton Fellowship at the University of Manchester in the UK.

Manuel Pichardo-Marcano, a graduate student in the department working with Tom Maccarone, has distinguished himself in two ways. First, he was recently coauthor on a paper published in *Nature Astronomy* that was based on some research in solar physics he worked on as an undergraduate. Second, he has been one of the founders and key contributors to *Astrobitos*, which is a Spanish-language version of the popular *Astrobites*, a web site for which graduate students in astronomy write summaries that are aimed at undergraduate-level students, of recent high profile research results.

Justin Perea, a senior in the department, has been accepted to work with data from the Sloan Digital Sky Survey through the Faculty and Student Teams program. This program is aimed at giving students from underrepresented minority backgrounds access to the Sloan survey for free (a great benefit to Texas Tech, as membership in the project normally costs almost a quarter of a million dollars), as well as some salary and travel support for undergraduate and graduate research work.

We are also happy to welcome to Lubbock a new postdoctoral fellow, Dr. Liliana Rivera-Sandoval, who will work in Dr. Maccarone's group on studies of double white dwarf stars in globular clusters and on a survey for very faint X-ray sources in the Galactic Bulge. She is arriving after doing her PhD work at the University of Amsterdam.

The Bucy Distinguished Lecture was delivered by Naomi J. Halas, the Stanley C. Moore Professor in Electrical and Computer Engineering, Professor of Biomedical Engineering, Professor of Chemistry, Professor of Physics and Astronomy, and founding director of the Laboratory for Nanophotonics at Rice University on May 4 at the McKenzie-Merket Alumni Center. Her public lecture was titled "Solar Steam Generation and Applications."

We had a welcoming BBQ party for our new physics majors on September 6th organized by GRASP.

On Monday, September 11, Professor Bill Poirier, adjunct professor of physics and professor of chemistry, gave a presentation and took part in a roundtable discussion as part of an event called "Physics of the Observer--A Documentary." The purpose was to discuss the role of the observer in modern physics, both in the context of cosmology and quantum physics, at a level appropriate for an educated but non-expert audience. The whole event was filmed for broadcast on the internet.

Dr. Tom Maccarone hosted an international conference of about 30 attendees at the Museum of Texas Tech University from September 18-20. Dr. Maccarone has been one of the key leaders in developing the science case for a NASA study of a possible billion-dollar space mission called STROBE-X that would provide an unprecedented sensitivity to variable sources of X-rays in the sky. The meeting aimed to collect the world's experts on X-ray variability so they could define both the key goals of the mission and key capabilities needed for the satellite.

Debra Boyce, Academic Analyst, attended all 11 units of Raider Research University and received the 2017 Inaugural RRU Travel Scholarship award. She used these funds to attend the NCURA (National Council of University Research Administrators) regional meeting in Oklahoma. Deven Bhakta, now a graduate student in the department, received a second place award in the oral presentation category at the 2017 Texas Tech University Undergraduate Research Conference.

On September 21-22, TTU hosted our Brazilian colleagues at the International Cultural Center at the FAPESP Week. The high energy physics group presented their joint LHC/CMS project with their colleagues from the State University of Sao Paulo at this meeting.

Professors Luis Grave de Peralta and Mahdi Sanati gave invited presentations at the UMT International Conference on Pure and Applied Sciences on October 5-7 in Lahore, Pakistan. Professor Arfin Lodhi, now retired from our faculty, was the chair of the organizing committee (see photo below).

Professor Bill Poirier was a speaker at the Perimeter Institute's Quantum Foundations Seminar, on October 24 in Waterloo, Canada. He talked about "Quantum Mechanics Without Wavefunctions."

Associate Dean and Professor Jianwei Zhang from Tongji University, School of Physics in Shanghai, visited our department on November 14 to start collaborative student exchanges and research between our universities.

Dr. Tom Maccarone has a paper that was just accepted to *Nature*. He is the second author and was primarily responsible for the interpretation of the discovery made by his colleague Simone Scaringi at the University of Canterbury.

Graduate Students Sueli Skinner-Ramos, Manuel Pichardo-Marcano, Leopold Diaz, and Palmer Wilson were judges at the Oak Ridge Science Fair on December 4.

The National Council has reviewed all chapter reports and has awarded the Texas Tech University SPS Chapter as a 2016-17 Distinguished SPS Chapter on December 8.

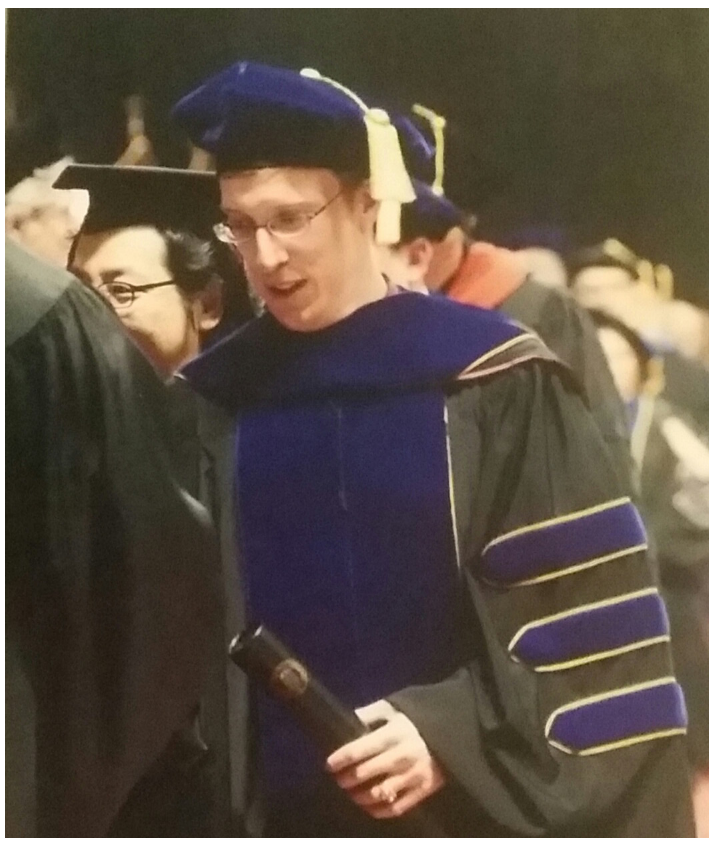
Recent PhDs

James Faulkner received his PhD in May 2016 under Dr. Sung-Won Lee's guidance. He describes his dissertation:

"Since its conception, the Standard Model (SM) of particle physics has been tested by many experiments. It describes all the known elementary particles and their means of interaction via the strong, weak, and electromagnetic (EM) forces. The SM has been extensively probed at increasing energies over the past several decades and has yielded precise descriptions of experimental data. Accordingly, the electroweak (EW) production of gauge bosons is predicted with ever decreasing cross sections as additional bosons are tied to the final state vertex, with the latest experimental measurements of semileptonic diboson production being recorded at the LHC. The extension of multi-boson production to include a third vector boson has yielded small number of events so far and restricted my analysis from measuring the production cross section. The addition of this third boson, an energetic photon, not only stretches the SM to a rarer triboson production process, but it also provides for further insight into modeling of EM radiation in the diboson processes.

Triple gauge boson production analyses inherit several key components within EW physics, such as precision measurements on gauge boson self-interactions, the EW parameters, and the mechanism of spontaneous symmetry breaking (SSB). These studies can also explore the EW symmetry breaking (EWSB) mechanisms, given they provide for the longitudinal components of $W^{\pm}$ and Z^{0}. The interaction vertex from which the multiple bosons simultaneously emerge is described via couplings. Together with triple gauge boson couplings (TGC), the SM provides four quartic gauge boson couplings (QGC). QGC analyses have been performed at several colliders; however, we still lack direct experimental confirmation of QGCs. There still lacks any significant experimental deviation from the SM, and the study of these types of interactions can further corroborate the SM predictions or grant perspective on new physics at a higher energy scale. Such new physics, expressed in a model-independent way by extending the SM Lagrangian with additional effective operator terms, leads to anomalous triple (ATGC) or quartic (AQGC) gauge boson couplings. For my PhD thesis, I searched for these anomalous couplings in data collected by the Compact Muon Solenoid in the last few years.

The High Energy Physics group at TTU provides a breadth of opportunities for a PhD candidate. If an inspired young pupil should fancy the occasional change in scenery in the course of research, there are chances to travel to the Fermi National Accelerator Laboratory (FNAL) in Illinois or to the LHC in Switzerland. For example, in preparation of the high luminosity LHC (HL-LHC), if there's a particular area of physics you are compelled to pursue, there is a good chance the HEP group can provide it."



Darshan B. Desai earned his PhD in December 2016 under the guidance of Dr. Luis Grave de Peralta. He is now Assistant Professor of physics at GSFC University in India. He is teaching physics and doing research in optics, in close cooperation with various industrial units at GSFC Ltd. He has published a book chapter and is currently working on a paper to be presented at a conference on characterization of nano-materials. He describes highlights of his doctoral research below:

"My doctoral research was directed towards developing and benchmarking novel and existing techniques of non-interferometric far-field observation of two-dimensional periodic crystals with truly high lateral resolution at visible frequencies. I began by studying the image formation and coherence phenomena in plasmonic and non-plasmonic ultra-thin condensers, which are based on illuminating the object using evanescent surface waves that can be resonantly coupled to the propagating waves for imaging with enhanced lateral resolution in the far-field region.

I studied two types of evanescent surface waves: (1) surface plasmons over metal thin-films (plasmonic condensers), and (2) reciprocal Goos-Hanchen effect related evanescent surface waves at an interface formed by two dielectric layers (non-plasmonic condensers). Further, I researched the simple and efficient condensers formed in wet-mounting setups, which can be classified as condensers formed while using a single coverslip (coverslip condenser), and condensers formed using layer of liquid sandwiched between two parallel coverslips (coverslip-sandwich condenser). Such optical condensers can be easily reconfigured to obtain a variable condenser numerical aperture. Using a series of experiments and computer simulations, I have revealed the mysterious source of the condenser-like behavior and demonstrated that such condensers can permit optical detection of two-dimensional periodic crystals that are up to eight times smaller than the Rayleigh resolution limit.

Although an experimental setup can be tweaked to obtain enhanced lateral resolution, combining numerical processing techniques with the experimental process of image acquisition leads to an even better imaging performance. Using hemispherical digital condensers that provide controllable multi-directional illumination, I studied a recently proposed imaging technique that facilitates optical observation of periodic crystals with the help of a phase-retrieval imaging algorithm, known as Fourier Ptychographic Microscopy. I have demonstrated that, in general, while imaging two-dimensional periodic crystals with single spatial periodicity, the Fourier Ptychographic Microscopy technique permits near diffraction-limited resolution. Using experiments and computer simulations, I identified the source of this limitation. To overcome this limitation, I recently proposed a novel technique for imaging two-dimensional periodic crystals, called dual-space microscopy, which uses real-plane images and Fourier plane images in a systematic manner to achieve true super-resolution images of two-dimensional periodic crystals."

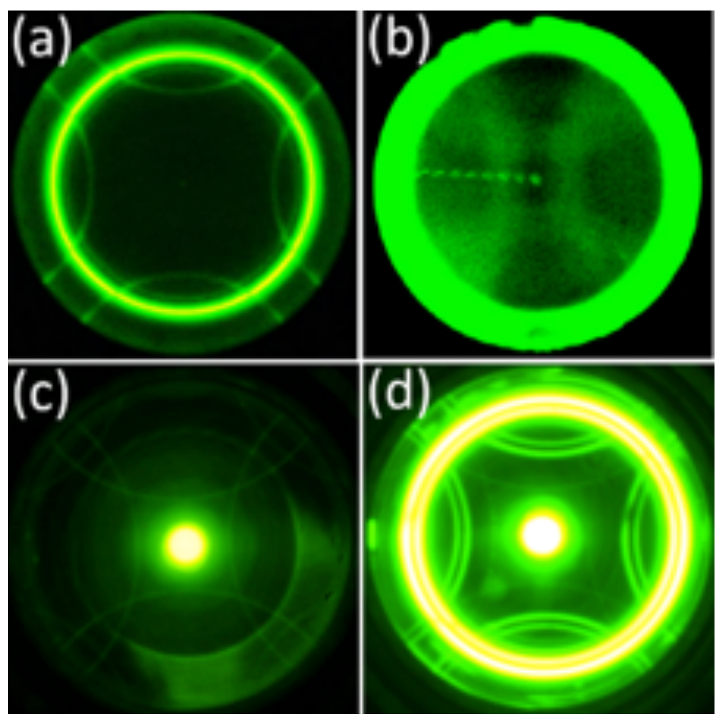


Figure: Back focal-plane images of a two-dimensional periodic crystal formed using (a) plasmonic condenser, (b) non-plasmonic condenser, (c) coverslip condenser, and (d) coverslip-sandwich condenser.

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