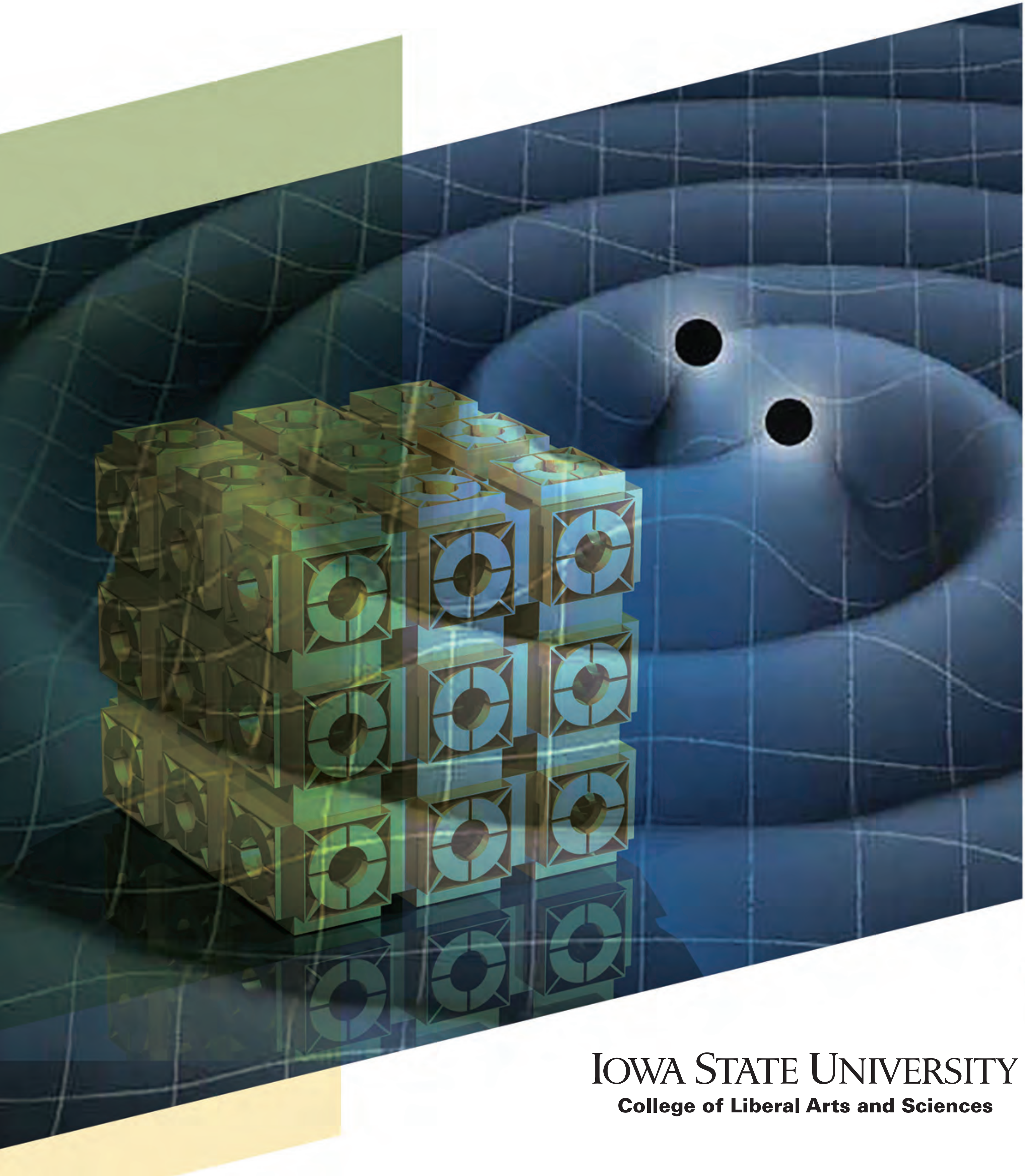
Quanta&Cosmos

Department of Physics and Astronomy | 2018 Newsletter



Iowa State University
College of Liberal Arts and Sciences

A Message from the Chair

It is time to reflect and to provide you with an update from the department. We hosted several major events relevant to the future path of the department.

The first was the septennial external review of the department. The Iowa Board of Regents requires that each program be reviewed every seven years. The review included a visit by an external committee including three members of the National Academy of Science. It is a joy to inform you that the committee views the department in high regard and its evaluation is best characterized by its summary statement: "Overall the department is very good. With moderate investment it can become excellent and the leading science department in the university." The key recommendation is to hire a cluster of faculty in theoretical physics with a focus on computational approaches to address fundamental problems.

In January 2018 we hosted an event intended as a stepping-stone to help many undergraduate female students plan for a successful career in physics and astronomy. With your generous donations and support from Iowa State University, we were able to host a Conference of Undergraduate Women in Physics (CUWiP). Outstanding speakers and several panel discussions brought 160 undergraduate women to Iowa State University and the department.

We also hope to attract more female graduate students to our research community in 2019, the time when CUWiP participants will be applying to graduate schools across the nation. However, our 2018 recruitment effort was hampered by a recent budget shortfall prompted by a mid-year state budget reversion. In fact, state funding for Iowa's research universities has been shrinking substantially over the last decade, in spite of a national need to educate more science and engineering majors. We remain hopeful that this trend of decreasing state support will be reverted soon and that higher education will become a priority again. In the meantime, we ask your help. One of the strongest recruitment tools we have is provided by two graduate student fellowships. These fellowships have helped us to compete with top national research universities in recruiting graduate students (see the section on Opportunities to Give).

When I meet with our alumni from the Department of Physics and Astronomy, I am often impressed by the exciting and successful professional paths they have taken. A BS, an MS, or a PhD are promising avenues to a rewarding career in industry, government, or academia—as many of you well know. Similar to last year, we continue to feature some of those outstanding individuals in our section on alumni in this newsletter.

Scientifically, our department continues to flourish in a wide range of research areas. This is enabled by the excellence of our faculty, who continue to be successful in getting research grants. Our faculty deserve great recognition for their research, publications record, and grantsmanship! A subset of our research efforts is highlighted in this newsletter. Professor Paul Canfield discusses work that revealed a missing link to novel superconductivity, a world-leading effort at the Ames Laboratory and our department. Professor Thomas Koschny highlights the prominent role of metamaterials and describes his work, done jointly with Professor Costas Soukoulis. A theoretical perspective is given by Professor Kerry Whisnant on recent developments in neutrino physics, now also a major effort in our department. Professor Robert McQueeney offers his insight and experiences as a participant in the Department of Energy's Oppenheimer Sciences and Energy Leadership Program.

Finally, an article by Professor Curt Struck on last year's Nobel Prize in Physics awarded for the Detection of Gravitational Radiation provides a perspective on testing Albert Einstein's century-old theory on gravity waves using modern state-of-the-art laser interferometers. Incidentally, last year's Zaffarano Lecture was given by Professor Roger Blandford from Stanford University, a world expert on how to convert gravitational energy into the highest energy particles. He discussed the link between gravity waves and gamma-ray bursts. The Zaffarano Lecture is intended to provide a glimpse of current topics in the physical sciences and discuss relevant applications, philosophical implications, and relation to broader human affairs. Last year's topic coincided with the Nobel Prize in Physics and provided a very timely event for the general public and our students to appreciate science and the long-term commitment required for exceptional discoveries.

The next Zaffarano Lecture will be given by Professor Anton Zeilinger from the University of Vienna on the topic of quantum information. A preview can be found in the Alumni/Zaffarano section. We would be thrilled to see you at the next lecture on April 30, 2019, at Benton Auditorium in Ames!

Warm Regards,

Frank Krennrich

Frank Krennrich, Professor and Chair, Department of Physics and Astronomy
515-294-5442 | Krennrich@iastate.edu

OPPORTUNITIES TO GIVE

We hope that you would designate your contribution directly to the Department of Physics and Astronomy. Please feel free to call Frank Krennrich (515-294-5442), department chair, to discuss possibilities to donate or if you have questions about the different endowment funds.

1) Contributions to the Physics and Astronomy Unrestricted Fund provide the department with the greatest flexibility to finance awards and projects.

2) Contributions to the Zaffarano Lectureship fund allow us to sustain the event over years to come. This year, we will benefit from a donor pledge of matching donations at a 2:1 ratio.

3) Inaugural contributions to the Postdoctoral Prize Fellowship in Astronomy and Astrophysics will allow us to establish the fellowship fund.

If you are considering making a significant gift, you could establish a new endowed fund for a purpose that you designate—e.g., the Postdoctoral Prize Fellowship. For details and guidance, please refer to Eric Bentzinger, Director of Development (call 515-294-7490 or e-mail ericb@iastate.edu).

To donate online and designate your contribution directly to the Department of Physics and Astronomy, go to www.foundation.iastate.edu/physics.

Getting to know the neutrino

by Kerry Whisnant

The neutrino has long been the most mysterious of the Standard Model particles. It was originally hypothesized by Wolfgang Pauli in 1930 to preserve conservation of energy and angular momentum in beta decays. In 1934, Enrico Fermi wrote down the first viable description of beta decay, the four-fermion interaction $n \rightarrow p + e^{-} + \bar{\nu}_e$, which included the antineutrino as one of the decay products. Since such a neutral particle participating in the weak interactions had to be very light, Fermi named it the "neutrino," ("little neutral one" in Italian). Fermi's theory also showed that the antineutrino could be discovered via the inverse beta decay process $\bar{\nu}_e + p \rightarrow e^{+} + n$; because neutrinos interact only weakly, it was not until 1956 that it was found experimentally. A second neutrino type, the muon neutrino, which was paired in the weak interactions with the muon, was discovered in 1962. The discovery of the tau charged lepton in 1975 strongly suggested that there was a tau neutrino, although its first direct detection did not occur until 2000.

The minimal Standard Model does not require that neutrinos have mass, and it was often assumed that they did not. Direct detection of neutrino mass, such as by measuring the missing energy in beta decays, is difficult due to its small value. However, the smallness of neutrino mass opened up the possibility of a process called neutrino oscillations, which relies on quantum-mechanical interference of different neutrino states. If the flavor eigenstates (i.e., those associated with the electron, muon, and tau lepton in the weak interactions) are nontrivial linear combinations of the mass eigenstates (the stationary states of the free Hamiltonian), then a neutrino created as one flavor can "oscillate" to another flavor after propagation over a sufficient distance. The probability that one neutrino flavor is later observed as a different flavor is given by

$$P(\nu_\alpha \rightarrow \nu_\beta) = \sin^2 2\theta \sin^2\left(\frac{\delta m^2 L}{4E}\right), \qquad (1)$$

where θ is a neutrino mixing angle, δm^2 is the difference of neutrino mass-squares, L is the distance traveled, and E is the neutrino energy. Since $P > 0$ requires $\delta m^2 \neq 0$, the existence of neutrino oscillations necessarily requires that at least one neutrino type has nonzero mass. With three neutrino types, the mixing matrix that relates the flavor states to the mass eigenstates has three neutrino mixing angles and one charge-parity (CP)-violating phase angle that can be measured in neutrino oscillation experiments.

Although there has been speculation about the possibility of neutrino oscillations since the 1960s, firm experimental confirmation did not occur until the last two decades. In 1998, the Super-Kamiokande experiment clearly indicated that muon neutrinos created in the atmosphere were oscillating to (primarily) tau neutrinos, with a characteristic δm^2 of $2.5 \times 10^{-3}\ eV^2$. The possibility of solar neutrino oscillations had been considered ever since the first solar neutrino experiment showed a deficit of solar neutrinos compared to theoretical expectations. The definitive proof that solar neutrinos oscillate came in 2001, when the SNO experiment measured both neutrino charged-current (CC) and neutral-current (NC) interactions; the CC signal was due only to ν_e, while the NC signal came from all three neutrino flavors. The value of δm^2 associated with solar neutrino oscillations was $7.5 \times 10^{-5}\ eV^2$. The mixing angles associated with the atmospheric and solar neutrino oscillations are both large (approximately 45° and 34°, respectively).

The above experiments utilized neutrinos created in nature. Subsequent experiments with man-made neutrinos (reactor neutrinos in KamLAND and accelerator neutrinos in K2K, MINOS, T2K, and NOνA) confirmed the oscillation hypothesis, including the numerical values of the δm^2 and mixing angles determined from atmospheric and solar neutrinos. With the recent results of the Daya Bay reactor experiment, a precise value of the third mixing angle has been determined (about 9°).

Even after so many years, and considerable progress, there are still a number of things we don't know about neutrinos. There are indications that the CP phase may be maximal or near-maximal, but a more definitive measurement is needed—CP violation in the lepton sector could help explain the matter-antimatter asymmetry in the universe. The neutrino mass spectrum has two closely spaced masses with a third mass further away—current oscillation data cannot determine if the third state is above or below the other two. The future long-baseline experiment DUNE, which will detect neutrinos in a neutrino beam going from Fermilab to a deep mine in South Dakota, could provide an answer to these questions. Despite being discovered over half a century ago, there is still much to be known about the neutrino, and it seems likely that the mechanism for creating neutrino mass involves new physics beyond the Standard Model. Because of its unique nature, the more we know about the neutrino, the closer we will be to finding a unified theory of all fundamental particles.

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A glimpse into the depths of the Daya Bay Neutrino Experiment. Each detector consists of two inner-nested transparent acrylic cylinders filled with clear liquid scintillator. The detectors will reveal antineutrino interactions by emitting very faint flashes of light. Sensitive photomultiplier tubes line the detector walls, ready to amplify and record the telltale flash.
Image courtesy of Roy Kaltschmidt, Lawrence Berkeley National Laboratory

Neutrino mass eigenstates for normal and inverted mass ordering are shown.
Image courtesy of Berkeley Lab

Metamaterials *by Thomas Koschny*

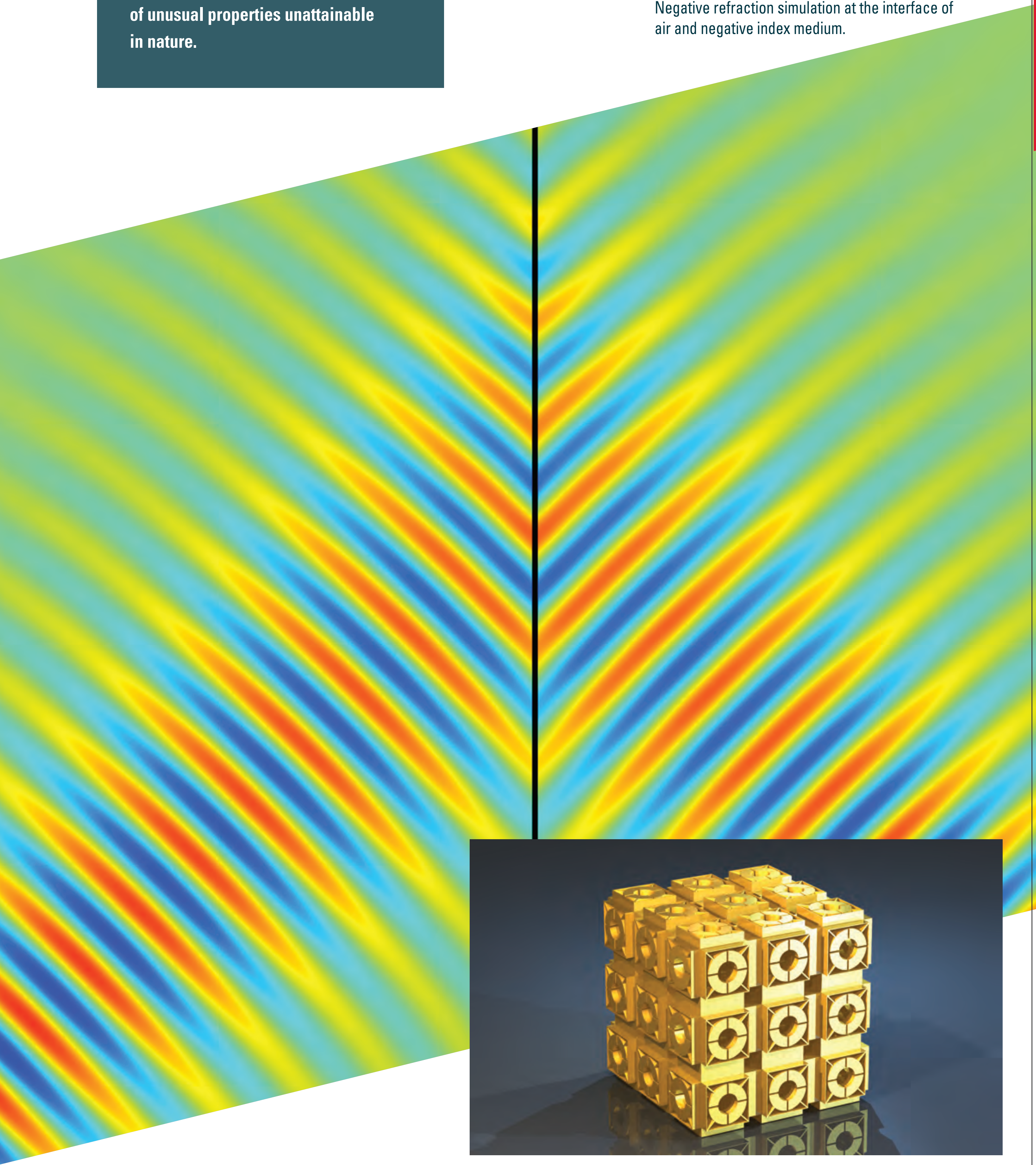
Many of the technologies that underpin our modern economy and enable our standard of living depend on advanced materials. Therefore, the engine for progress in many disciplines is the discovery and understanding of new materials, and their properties. Metamaterials are novel artificial materials that enable the realization of unusual properties unattainable in nature.

The fundamental concept behind electromagnetic metamaterials is the notion of an effective homogeneous medium supporting wave propagation buildup of purposefully designed, typically resonant local scatterers with a structural length scale much smaller than the wavelength of the propagating fields inside the medium. Under such conditions, the propagating fields do not see the individual scatterers as distinct particles but rather interact with a spatially averaged response of their local—much like visible light of about half a micron wavelength propagating inside a block of glass does not "see" individual Na, Ca, Mg, and SiO_2 atoms and molecules with distances at the order of a few angstrom, but rather a smooth average electric polarizability characterized by the refractive index of the glass. It turns out, metamaterials made from spatial arrangements of sub-wavelength building blocks or scatterers, commonly referred to as "photonic atoms" or meta-atoms, at length scales of at least one order of magnitude below the propagating field's wavelength homogenize in a similar way and can be characterized by smooth effective electric permittivity and magnetic permeability, or, equivalently, an effective material refractive index and impedance. The second crucial concept in metamaterials is that the sub-wavelength meta-atoms they are made of are artificial, engineered particles that derive their local electromagnetic properties from their geometry rather than from the materials they are made of. This allows for a tremendous degree of freedom in constructing electromagnetic response that is simply unavailable in naturally occurring materials: ring-shaped conductors allow to create magnetism at optical frequencies, metallic nano-rods allow to create hugely anisotropic materials with different signs of the electric permittivity in different directions resulting in effective materials with hyperbolic band-structure, spiral-shaped meta-atoms allow to create materials with huge chirality that exhibit optical activity of hundreds of degrees of polarization rotation per wavelength. Lastly, designing the meta-atoms to be resonant gives us even more degrees of freedom in designing the spectral response and dispersion of the effective material parameters.

The history of modern metamaterials started with Russian physicist Victor Veselago, who in 1967 published a theoretical paper concerning "The Electrodynamics of Substances with Simultaneously Negative Values of ε and μ", which predicted that not only wave propagation should be possible in materials with simultaneously negative permittivity and permeability, but also that these so-called left-handed materials would show truly novel and exotic physical properties, such as negative refraction, negative radiation pressure and stress, reverse doppler effect, and reverse direction of Cherenkov radiation. This remained an obscure theoretical contemplation until just before the break of the new millennium when John Pendry suggested the first practical way to experimentally implement resonant meta-atoms that allowed the construction of metamaterials with simultaneously negative effective ε and μ at microwave frequencies. Meshes of thin metallic wires approximating a dilute plasma provided negative permittivity, while arrays of sub-wavelength metallic rings with gaps, implemented local LC-resonators in which the ring current provided a resonant magnetic moment that allows the magnetic permeability to become negative just above the resonance frequency. Our own group at Iowa State led by Costas Soukoulis developed effective parameters retrieval and refuted early claims of causality violation by negative index materials.

The significance of modern metamaterials for fundamental physics and next-generation technologies is their potential to provide complete control over the electric and magnetic response and their spatial distribution, impedance match and zero reflectivity at interfaces, negative and zero index of refraction, control over metamaterial dispersion, and optical magnetism!

Metamaterials are novel artificial materials that enable the realization of unusual properties unattainable in nature.



Negative refraction simulation at the interface of air and negative index medium.

Dimensional isotropic design for optical negative index material suitable for direct laser writing application.

Missing link to novel superconductivity revealed at Ames Laboratory *by Paul Canfield*

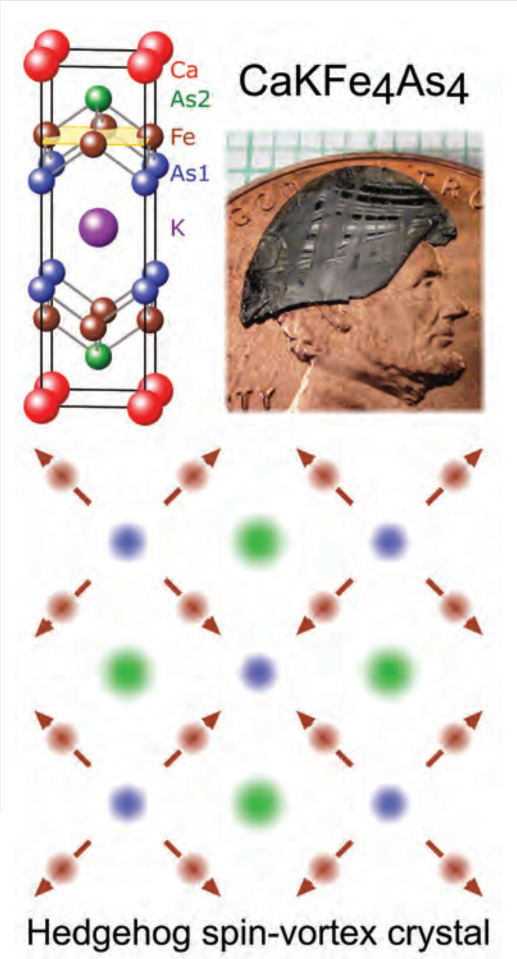
Iowa State physicists, supported in part by the U.S. Department of Energy's Ames Laboratory, have led an international collaboration that has discovered a state of magnetism that may be the missing link to understanding the relationship between magnetism and unconventional superconductivity. The research, recently published in *npj Quantum Materials*, provides tantalizing new possibilities for attaining superconducting states in iron-based materials.

"In the research of quantum materials, it's long been theorized that there are three types of magnetism associated with superconductivity. One type is very commonly found, another type is very limited and only found in rare situations, and this third type was unknown, until our discovery," said Paul Canfield, a senior scientist at Ames Laboratory and a Distinguished Professor and the Robert Allen Wright Professor of Physics and Astronomy at Iowa State University.

The scientists suspected that the material they studied, the iron arsenide $CaKFe_4As_4$, was such a strong superconductor because there was an associated magnetic ordering hiding nearby. Creating a variant of the compound by substituting in cobalt and nickel at precise locations, called "doping," slightly distorted the atomic arrangements that induced the new magnetic order while retaining its superconducting properties.

"The resources and collaborations that are fostered within the Department of Physics and Astronomy and Ames Laboratory were essential for providing for the diversity of techniques needed to reveal this new magnetic state," said Canfield. "We've been able to stabilize it, it's robust, and now we're able study it. We think by understanding the three different types of magnetism that can give birth to iron-based superconductors, we'll have a better sense of the necessary ingredients for this kind of superconductivity." This work has been built on the decade-long Iowa State effort to discover, grow, understand, and master Fe-based superconductors. The discovery of $CaKFe_4As_4$ was made possible by the 2008 Iowa State discovery of the parent compound $CaFe_2As_2$.

The research is further discussed in the paper "Hedgehog spin-vortex crystal stabilized in a hole-doped iron-based superconductor" authored by William R. Meier, Qing-Ping Ding, Andreas Kreyssig, Sergey L. Bud'ko, Aashish Sapkota, Karunakar Kothapalli, Vladislav Borisov, Roser Valentí, Cristian D. Batista, Peter P. Orth, Rafael M. Fernandes, Alan I. Goldman, Yuji Furukawa, Anna E. Böhmer, and Paul C. Canfield and published in the journal *npj Quantum Materials*.



$CaKFe_4As_4$ unit cell, single crystal on a penny and magnetic structure inferred from diverse data sets.

Oppenheimer Science and Energy Leadership Program—One year on *by Rob McQueeney*

I had the great opportunity to participate in the inaugural Oppenheimer Science and Energy Leadership Program (OSELP) last year. This annual program is hosted by the U.S. Department of Energy (DOE) and its National Laboratories. The idea of the program is to expose a small cohort of early and mid-career scientists, administrators, and managers to the role that the DOE plays in basic research, energy security, and nuclear security through its complex network of national labs, universities, state and federal government entities, and industrial stakeholders. We visited several National Laboratories, including the SLAC National Accelerator Laboratory, Lawrence Berkeley, Los Alamos, Sandia, Lawrence Livermore, National Renewable Energy Laboratory, and the National Energy Technology Laboratory and toured many of the great achievements in U.S. scientific infrastructure. At each site, we learned about the primary missions of the national labs in science, energy, and nuclear security and their web of industrial and university partnerships. We also spent a week in Washington, D.C., where we were able to discuss different perspectives on these matters with officials at the DOE, Congress, Office of Management and Budget, Office of Science and Technology Policy, NASA, and Pentagon. Our cohort was mentored by current and former scientists and administrators familiar with the DOE system. In addition to learning the complexities of the DOE system, the cohort was challenged to analyze and critique the system and develop ideas for improving the research climate at DOE National Laboratories. This exercise also provided the opportunity to develop and enhance leadership skills and networking among the cohort and the DOE. This culminated in the cohort's presentation of "think pieces" to the National Laboratory Director's Council at the DOE Big Ideas Summit in Washington, D.C. Our cohort presented four think-pieces on the future DOE workforce, international partnerships, science networking, and regional lab outreach. These ideas were well received by the lab directors and are being refined and expanded upon by the second OSELP cohort.

One year later, there has been some time to digest what was learned and to utilize these new leadership and networking skills to further the DOE mission. This has inspired me to lead the Ames Laboratory's effort in a multilaboratory "Beyond Moore Computing" initiative and to lead a multilab, multiuniversity DOE Energy Frontier Research Center proposal, "Center for the Advancement of Topological Semimetals," that is currently under consideration for funding. In addition, the second OSLEP cohort has just "graduated." The program has been successful and rewarding for the cohorts, the DOE, and the labs, and there is great interest and momentum to convene a third cohort. Probably the biggest message to take home from this experience, and a testament to the DOE lab system, is that leadership and teamwork can result in great scientific achievements.

Inaugural OSELP cohort with Congressman Bill Foster on Capitol Hill.

Going big with online classes: Teaching one of the core introductory physics classes online

by Paula Herrera-Siklody

Online classes offer a lot of flexibility and are becoming a more and more common option in higher education. The Department of Physics and Astronomy has already been offering some online courses for a few years (Astro 102/103), but this is the first major service course (5 credits) that will be offered in this format. There are in fact few examples of similar courses both at Iowa State or at peer institutions, so this is quite a pioneering venture.

The challenges of the adaptation of such complex courses are multiple. The goal is, of course, to develop a course that will allow students to participate without necessarily being on campus, but with a very strict constraint: the level of the instruction or the expectations cannot be lowered.

By far the largest effort was the production of the lectures. It was clear from the beginning that these lectures could not be a passive recording of a standard lecture delivery, or a voice over a static slide. Who hasn't heard students complain (justifiably) about instructors who "just read off the PowerPoints"? We broke down our regular PHYS 222 syllabus into 105 video segments, each 10 to 15 minutes long. Even though our lectures are PowerPoint based, there is a very strong emphasis on a dynamic presentation. Below are some of the most attractive features.

Lecture demonstrations: More than 100 demonstrations were videotaped so they could be included. Some experiments benefit enormously from the new format—pieces of equipment can be labeled and zoomed in, processes can be slowed down or sped up, we can draw and write on the image, etc.

Problem solving: Examples are solved step by step, letter by letter, on a whiteboard, with hand-written calculations, just like they would on the board in a traditional class.

Interactive lectures: Every videocast contains at least one interactive segment in the form of a mini-quiz to help students process the material and test their understanding. There is careful synchronization of audio and video, especially during problem solving.

Accountability: We can keep track of whether students are watching the lectures and completing every task.

Lectures are, of course, just one of the components of the course. Students will work on the same homework as the on-campus class, and interactions between students and instructors will be take place regularly through Canvas conferences. Participants will be able to talk and share a whiteboard where they can write and sketch, either in groups or one on one. We hope to be able to reproduce something as similar as possible to our on-site recitation and help room sessions.

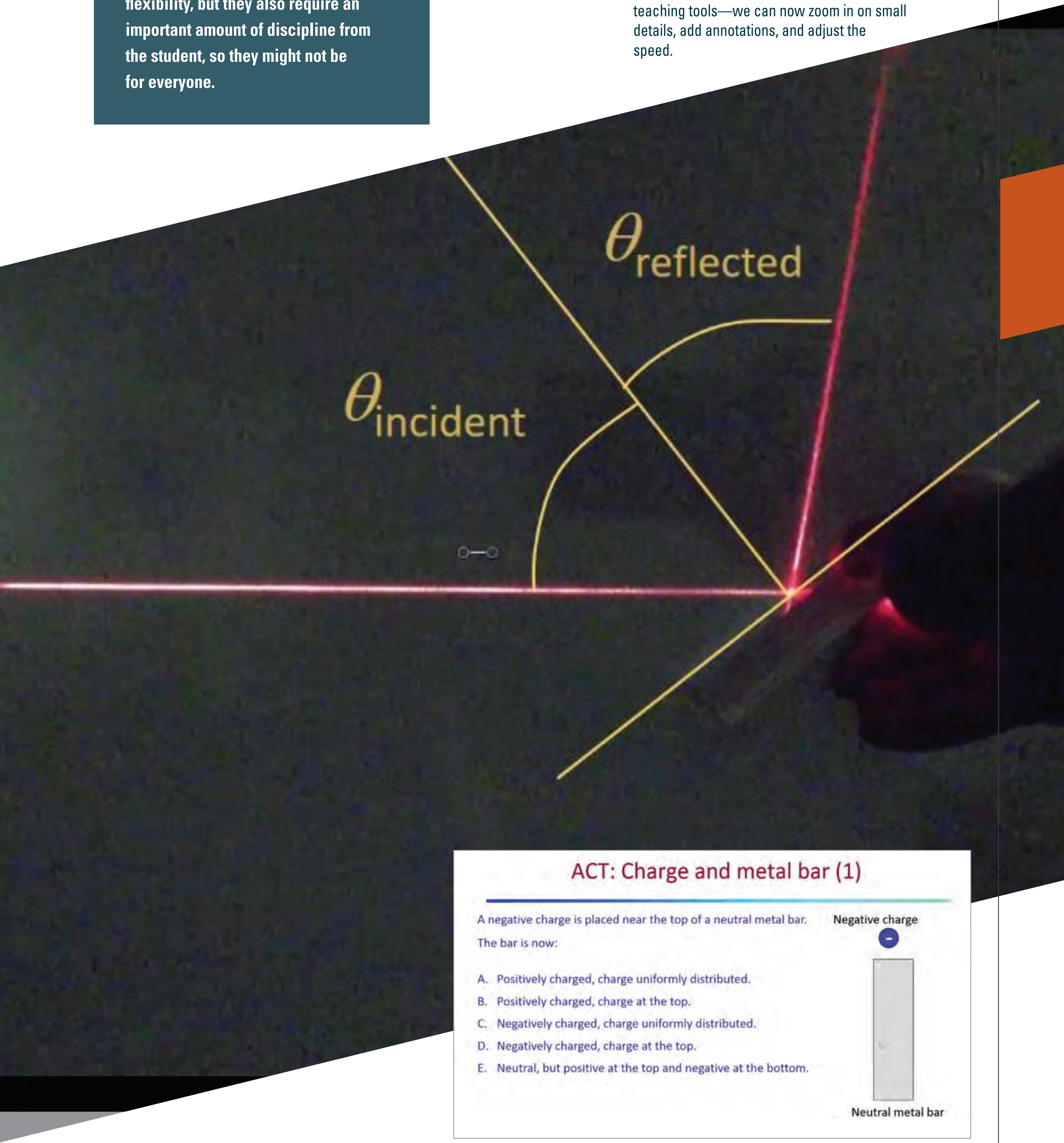
This is a relatively high-stakes class, so examinations will only take place in accredited testing centers with constant, serious proctoring.

The laboratories, by their very nature, cannot be transferred to an online format. However, we have condensed the sessions so students will only be required to be on campus four times in the semester.

Online courses offer a lot of flexibility, but they also require an important amount of discipline from the student, so they might not be for everyone. We are thriving to serve a population with diverse needs and preferences. This new option for the summer can be particularly attractive to students who need to repeat the class and have lab waivers (so they would not need to be on campus at all), and to students with very full schedules.

Online courses offer a lot of flexibility, but they also require an important amount of discipline from the student, so they might not be for everyone.

Maybe seeing a demonstration on video steals some of their "real thing" charm, but the format offers great teaching tools—we can now zoom in on small details, add annotations, and adjust the speed.



Lectures always include interactive segments to keep students active and engaged.

Empowering Women in Physics and Astronomy

by Mayly Sanchez and Massimo Marengo

Earlier this year, the Department of Physics and Astronomy hosted the Conference for Undergraduate Women in Physics (CUWiP) for the Midwest region. This is a series of regional conferences aiming to encourage undergraduate women to pursue a career in physics by providing the experience of a professional conference. This includes networking with professional women physicists of all ages and professional levels, listening to plenary talks by prominent women in physics, and participating in panel discussions providing information about graduate school and career opportunities in physics. These conferences are partially supported by the National Science Foundation and by the Office of Science of the Department of Energy, and they are organized by the American Physics Society (APS). The Iowa State Conference was also supported by the Office of the Senior Vice President and Provost, the College of LAS, the Department of Physics and Astronomy, the Department of Materials Science and Engineering, the Program for Women in Science and Engineering (WiSE), the Ames Laboratory, and the Critical Materials Institute as well as many other units across campus, council members, and alumni.

The Iowa State conference was attended by more than 160 undergraduate women from around the Midwest that presented more than 45 research posters. There were plenary talks by distinguished female scientists from academia and industry, such as Professor Agnes Mòcsy, a theoretical physicist who combines the study of the theory of strong interactions and filmmaking at the Pratt Institute; Dr. Jessica Kirkpatrick, a data scientist from Slack; Professor Robin Selinger, an expert in soft matter theory and computational materials science at Kent State University; and Professor Marcela Carena, the head of the theoretical physics division at Fermi National Laboratory. The conference also featured panels, parallel sessions and workshop with career advice, leadership skill development, and discussions on intersectionality and mental health. These sessions were led by an excellent crew of leaders organized by the

Program for Women in Science and Engineering (WiSE) of Iowa State directed by Lora-Leigh Chrystal. The Professional Skills Workshop was led by Professor Sheila Kannappan from the University of North Carolina at Chapel Hill, and a very well-received historical talk was given by Professor Amy Sue Bix from Iowa State. Another highlight was a tour of Ames Laboratory, which was very well attended.

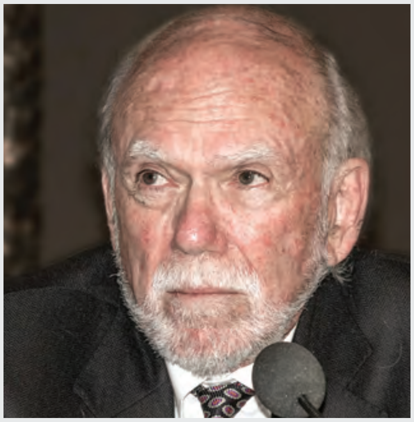
What brought this conference to Iowa State? It all started with a small group of undergraduate women that, in the Spring 2012, created a forum to share experiences and find opportunities for professional development, enhance undergraduate recruitment, and work on outreach to younger women. They met with Professor Mayly Sanchez, who had just arrived a few years earlier at Iowa State and noticed that women were severely underrepresented among our undergraduate classes. In this group were Alyssa Miller and Elizabeth Polsdofer—two alumni that today have found their path after majoring in physics at Iowa State, Alyssa as a beam operator at Fermi National Laboratory (her dream job) and Elizabeth Polsdofer by following her passion to study medical physics in graduate school. In those early days, Alyssa and Elizabeth were the driving force of this forum, helping to organize its regular meetings and establishing the tradition of an annual trip to the nearest CUWiP. Since then, group-organized trips to the conferences held at the University of Illinois Urbana-Champaign in 2013, the University of Chicago in 2014, Purdue University in 2015, and the University of Wisconsin-Madison in 2016. When this January CUWiP was finally held at Iowa State they had the opportunity to come back to their alma mater as panelists, a unique moment offering them the occasion to give back some of their hard-earned wisdom on how to succeed as women physicists. Other awesome alumni from our graduate program were also able to engage the large group of undergraduate women: Stella Kim, who is acting chief technologist and the failure analysis team lead at Boeing Satellites, and Sarah Willis, a technical staff member at MIT Lincoln Laboratory in Lexington, Massachusetts. They had a lot to say on their interesting career paths and advice for young physicists on how to reach industry jobs.

The organization of the conference was the collective effort of faculty and students in our department (Professors Mayly Sanchez, Rebecca Flint, Massimo Marengo, Craig Ogilvie, Marzia Rosati, and Alex Travesset; undergraduate students Jackie Blaum, Savannah Downing, John Mobley IV, and Claire Nelson; and graduate student Alisha Chromey) as well as WiSE director Lora-Leigh Chrystal. Many other students and faculty volunteered during the conference to make it a success.

The Detection of Gravitational Radiation: Nobel Prize in Physics 2017

by Curt Struck

Last October it was announced that Barry Barish, Kip Thorne, and Rainer Weiss were the winners of the 2017 Nobel Prize in Physics "for decisive contributions to the LIGO detector and the observation of gravitational waves." Since the first gravitational waves were only detected at the LIGO (Laser Interferometer Gravitational-Wave Observatory) sites in 2015, this is a short interval between discovery and award of the prize. On the other hand, the discovery has been a long time coming.



Barry Barish
Photo courtesy of Bengt Nyman

Kip Thorne
Photo courtesy of Bengt Nyman

Rainer Weiss
Photo courtesy of Bengt Nyman

Einstein's theory of general relativity explains gravity as the curvature of space and time. Shortly after proposing the theory in 1916, Einstein conceived the idea of gravitational waves, disturbances in space and time propagating at the speed of light. The notion that space-time can not only curve, but can also wiggle, was evidently hard even for Einstein to accept. When he returned to the problem 20 years later, he doubted their existence, but then came to believe again.

In the 1950s J. Weber and J. A. Wheeler revised Einstein's 1937 wave calculations, and Weber was inspired to undertake a multi-decadal experimental search for the waves. He claimed detections from his aluminum bar detector, but these could not be confirmed and would have had to be much stronger than the recently detected sources. Weber did consider laser interferometry as a means to detect waves, but he did not pursue it. Rainer Weiss did, beginning around 1967 at MIT. In the 1970s Ronald Drever began his own work on interferometers at Caltech, while Thorne worked on models of the wave emission from astrophysical sources. In the 1990s, with the aid of the National Science Foundation, these efforts would be combined into the LIGO project.

LIGO is a technological masterpiece. Each of the LIGO facilities in Hanford, Washington, and Livingston, Louisana, consists of two arms 4 km long. These arms are vacuum tunnels where laser beams bounce multiple times before being combined. Changes in the inference pattern produced by this beam combination signal the passage of gravitational waves. All sorts of confounding vibrations, e.g., seismic or transportation related, are screened out as far as possible. Signal verification (and source directional constraint) require simultaneous detection at both facilities. Variations in the laser path length of 10-4 the diameter of a proton can be detected.

The ability to directly detect gravitational radiation opens the door to a completely new way of observing astronomical objects that are invisible in electromagnetic radiation. For example, the first detection was of the inspiral and coalescence of the two black holes of mass 29 and 39 times the mass of the Sun, as a result of orbital energy loss due to the gravitational radiation. Not only would it otherwise have been nearly impossible to observe black hole coalescence, but black holes in this mass range have not been detected before. Thus, we now have a direct window for observing new classes of intermediate mass black holes.

Another of the first few LIGO observations was of a merger between two neutron stars, city-size, stellar core remnants consisting

The ability to directly detect gravitational radiation opens the door to a completely new way of observing astronomical objects that are invisible in electromagnetic radiation.

Image courtesy of NASA Goddard

mostly of neutrons. Their merged remnant may well be a black hole, but in contrast to the case of two black holes, a great deal of electromagnetic radiation is seen in the merger process. This event was observed in a wide range of wavebands from radio to gamma-ray. Spectral observations detected many heavy elements, including gold, europium, and uranium. This one event resulted in the solution of the decades-old mystery of the source of such elements. From a list of many proposed sources, we now know that neutron star collisions are most likely the primary source.

The LIGO observations also put new constraints on cosmology. Comparing detailed models, like those Thorne pioneered, to the observed waveforms yields a theoretical estimate of the total emitted energy. Comparison to observed energy flux yields a distance estimate, and then an estimate of the Hubble constant and the expansion rate of the universe. Such estimates from individual sources are not too accurate, but averaging over more sources should lead to improvements.

Currently, our department is not directly involved in gravitational wave detection experiments, but the discoveries bear on work of a number of people here. For more information on this topic, I recommend a couple of articles in the December 2017 edition of *Physics Today* and the LIGO and LISA websites.

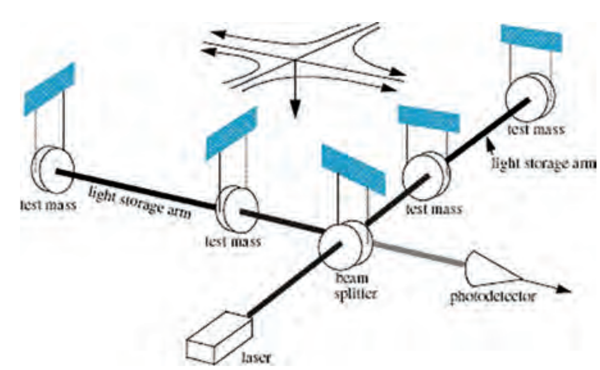


Diagram of a basic interferometer design. *Image courtesy of LIGO*

Departmental Awards 2018

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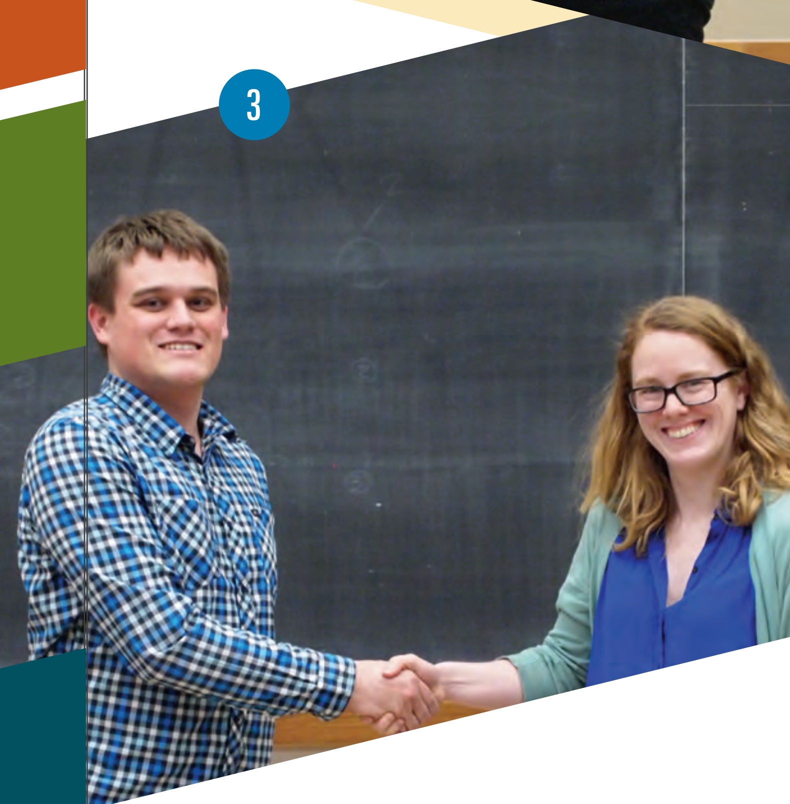

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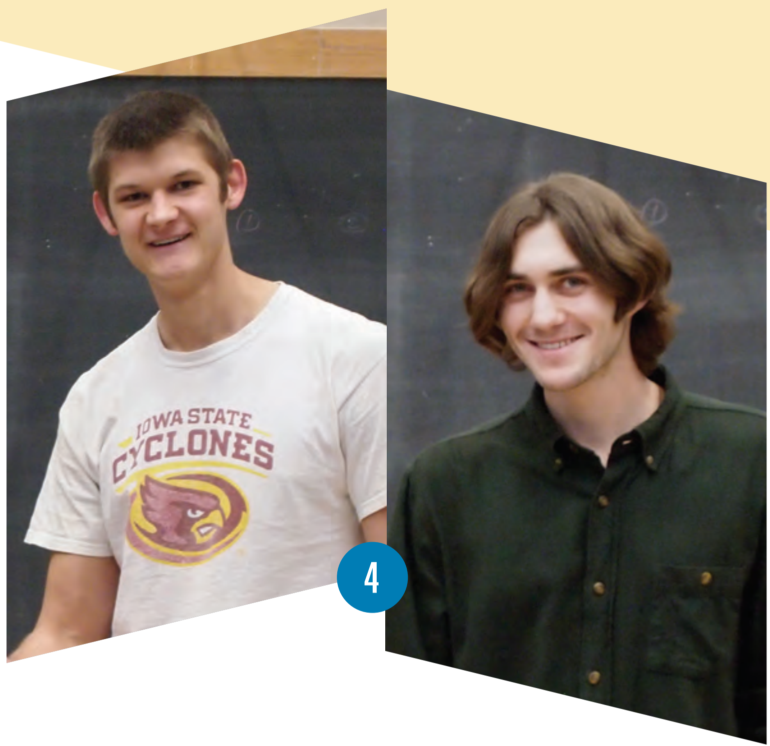

1. **Department of Physics and Astronomy Superior Service Award:** Lori Hockett

2. **Awards for Superior Academic Performance:** Jacqueline Blaum, Andrew Chatman, Harry Crane, Alexander Criswell, Sean Donnelly, Miles Lucas, Michael Onyszczak, Matthew Pham, Joshua Slagle, Jesse Stufflebeem

3. **Most Valuable Instructor Award:** Rebecca Flint (presented by Josh Wolanyk, Grad Student Representative)

4. **Mal Iles Innovation Award:** Thomas Waltmann (left) and Andrew Eaton (right)

5. **Bernice Black Durand Undergraduate Research Scholarship:** Donia Alzayer (left) and Elaina Beck (right)

6. **Graduate College Research Excellence Award:** Omer Shafraz

7. **Graduate College Teaching Excellence Award:** Cory Schrandt (left), Evan Stewart (middle), Erik Timmons (right)

LEON CROSSMAN

I received my PhD in 1967 working with Gordon Danielson. His group focused on semiconductor materials. This background served me well as I joined Dow Corning working in their hyper-pure silicon business for the semiconductor industry. I had previously worked two summers there while an undergrad at South Dakota State University.

Little did I know that this was the beginning of a 32-year career and involvement with silicon and silicones. As a research physicist, I was fortunate to be at the beginning of the semiconductor industry working on its primary material—hyper-pure silicon. I spent 11 years there working primarily on quality (<5 ppb), characterization technologies, and productivity increases, as R&D manager for the business. At this time Dow Corning supplied 40% of the world's silicon. I then moved into a series of silicone management positions, including manufacturing, commercial operations, director of TS&D, and central (corporate) research.

To fulfill a need to rapidly introduce new elastomers at initial small quantities, with a highly flexible workforce meeting all product specifications, I was asked to create the Specialty Elastomers Business, including a new materials development and supply facility, at an independent site.

In 1991 I was made vice president and executive director of science and technology and concurrently added to the Global Operating Committee. I served in this capacity until retirement in 1999. I continue to serve on Iowa State's Physics and Astronomy Advisory Council.

JOYCE GUZIK

Time seems to have passed quickly since graduating from Iowa State in 1988 with a PhD in astrophysics. In 1986 my thesis adviser, Dr. Lee Anne Willson, arranged a visit to Los Alamos National Laboratory where I learned to simulate the evolution of the Sun. I was fortunate to work at Los Alamos as a graduate research assistant, then a postdoc, and, near the end of the Cold War, to join the Thermonuclear Applications group. I witnessed preparations for the final underground nuclear tests conducted at the Nevada Test Site (testing ended in 1992) and the transition from relying on experiment to simulation for maintaining the aging U.S. nuclear stockpile. More recently, I have been working in the area of nuclear threat assessment and nuclear forensics.

I have also continued astrophysics research in helio- and asteroseismology, the study of pulsations to determine stellar interior structure. Data from the NASA Kepler spacecraft have been particularly important, providing long-time series high-precision photometry for thousands of variable stars.

My hobbies include playing clarinet and saxophone in community ensembles and model rocketry along with my husband, Tom Beach, also an ISU physics PhD graduate who teaches at UNM, Los Alamos.

DEAN RUBY

How many Iowa State grads do you know who utilized their fine physics department education working for the first 12 years of their careers on programs that never flew? Not many I'd venture. But that was exactly the case with Dean Ruby (1953). Wanting to go into nuclear reactor analysis, he opted to work on the ANP (Aircraft Nuclear Propulsion) program at Pratt & Whitney Aircraft in Connecticut, followed by a four-year stint on the SNAP 8 (Satellite Nuclear Auxiliary Power) program at Atomics International in California.

To illustrate how well Iowa State was up to speed at that time, it had only one of about a half dozen nuclear engineering programs in the country. The prime reference work in the field for many years was Glasstone and Edlunds *The Elements of Nuclear Reactor Theory*, which was the text for part of Dr. Zaffarano's Modern Physics course.

Then, Ruby worked as a thermal and test analyst on the propulsion systems of the command and service modules of the Apollo spacecraft during the moon landings and later as a thermal analyst on the SSME (Space Shuttle Main Engines). He became manager of aerothermodynamics for the SSME and later manager of thermal analysis for the International Space Station Power Supply.

Noncareer interests have been as varied as classical numismatics (collecting ancient Greek coins), much skiing, a term on the board of directors of the ACLU of Southern California, and of course Iowa State athletics. Go Cyclones!

Daniel Zaffarano Lectureship

The next Daniel Zaffarano Lectureship will be held at Iowa State University in April 2019. This lecture series was established in 2015 and was made possible by the generosity of our alumni. The purpose of the lectureship is to bring an outstanding scholar to central Iowa and Iowa State University each year to speak on a topic in the physical sciences and discuss relevant technical applications, philosophical implications, and relation to broader human affairs.

The tradition of bringing prominent scientists to Iowa State University dates back to the John Franklin Carlson Lectures (1955–1969), which were inaugurated (see picture) by J. Robert Oppenheimer (1955), followed by Niels Bohr (1957) and Percy W. Bridgman (1957) and others. The Zaffarano Lectureship is an effort by the Department of Physics and Astronomy to revive this fine tradition.

The inaugural Zaffarano Lecture was given by Sir John Pendry from Imperial College London on the topic of metamaterials, the physics of invisibility, and practical applications such as an "invisibility cloak." Last year Professor Roger Blandford from Stanford University discussed the progress on detecting black hole mergers with gravity waves and their relation to gamma ray astronomy and relativistic astrophysics. More information about the past events can be found at ***http://www.physastro.iastate.edu/events/zaffarano-lecture***.

Contributions to the Zaffarano Lecture will benefit from a donor pledge of matching donations at a 2:1 ratio.

2019 ZAFFARANO LECTURE

Anton Zeilinger

APRIL 30, 2019, 8 P.M. • BENTON AUDITORIUM

The next Zaffarano Lecture will be given by Professor Anton Zeilinger from the University of Vienna on the topic of quantum information.

He is a quantum physicist and he has made pioneering contributions to quantum physics. His work on entanglement of particles has propelled the field of quantum information to a prominent area in applied physics. He is a recipient of the Descartes Prize and the Isaac Newton Medal, the Wolf Prize in Physics Fellow of the Royal Society, and a member of the National Academy of Germany.

Would you like to receive your copy of the report delivered promptly to your mailbox? Please fill out the Alumni Contact Information at *http://www.physastro.iastate.edu/alumni/info*.

Quanta & Cosmos is published once a year for the alumni, friends, students, and faculty of the Department of Physics and Astronomy at Iowa State University, an academic department in the College of Liberal Arts and Sciences.

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