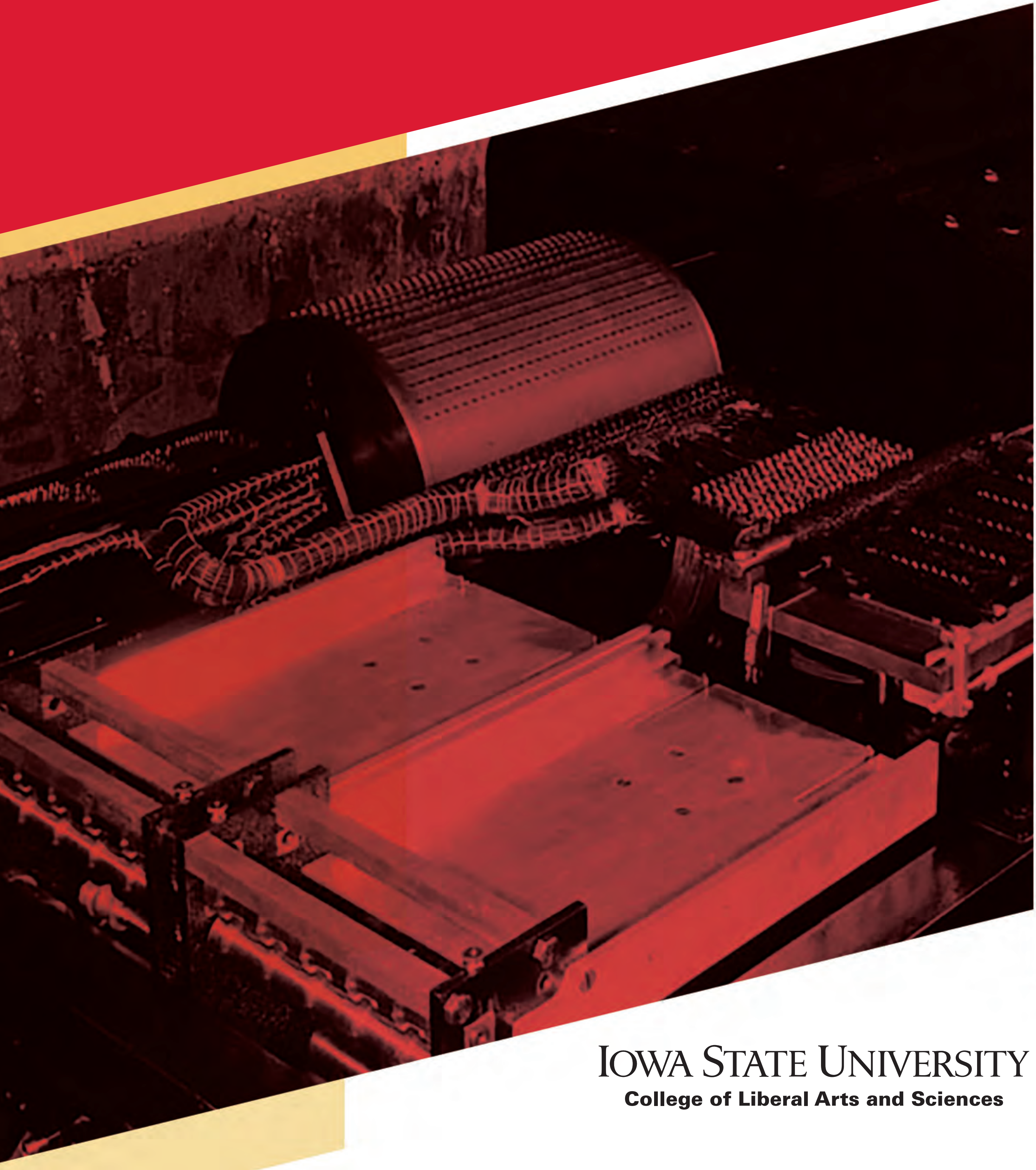
Quanta&Cosmos

Department of Physics and Astronomy | 2019 Newsletter



Iowa State University
College of Liberal Arts and Sciences

A Message from the Chair

It is time for an update from the Department of Physics and Astronomy. The year 2019 marks some positive changes — we are onboarding three new tenure track faculty members as part of our effort to build a cluster in theoretical and computational physics. Computational techniques are playing an increasing role in physics and astrophysics research, helping one provide the missing link between analytical, numerical, and algorithmic approaches for solving fundamental problems in theoretical physics. The department has a long tradition in developing computational techniques to solve physics problems going back to the 1930s. Just 80 years ago (IEEE milestone), John Vincent Atanasoff, with his student Clifford Berry, designed and constructed the first electronic digital computer, the Atanasoff-Berry Computer, which included electronic switches, a capacitor array, and a moving drum memory to solve systems of linear equations. Today's digital revolution was made possible by the early pioneers of computing, including Alan Turing, John von Neumann, Konrad Zuse, John Atanasoff, and many others, and it continues to enable and accelerate scientific research and our digital lifestyle of today. Clearly, past long-term investments in education and research have paid off.

Our graduate and physics majors programs also received a boost this year with 17 incoming graduate students and 25 new physics majors. This brings our total numbers to 90 graduate students, 120 physics majors, and 27 postdoctoral associates. Having that many early career scientists in the department just starting their academic paths makes for an exciting learning/research environment. As we are trying to grow our physics majors program, we have now introduced several Physics+ options for our majors to carve out individual paths that suit their interests outside the classic physics track—the department now also offers a track of Physics+ with an emphasis on computer science. The efforts and work of our junior scientists are investments in the lives of future generations, and I hope that you will continue to support us in this important enterprise.

Warm Regards,

Frank Krennrich

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

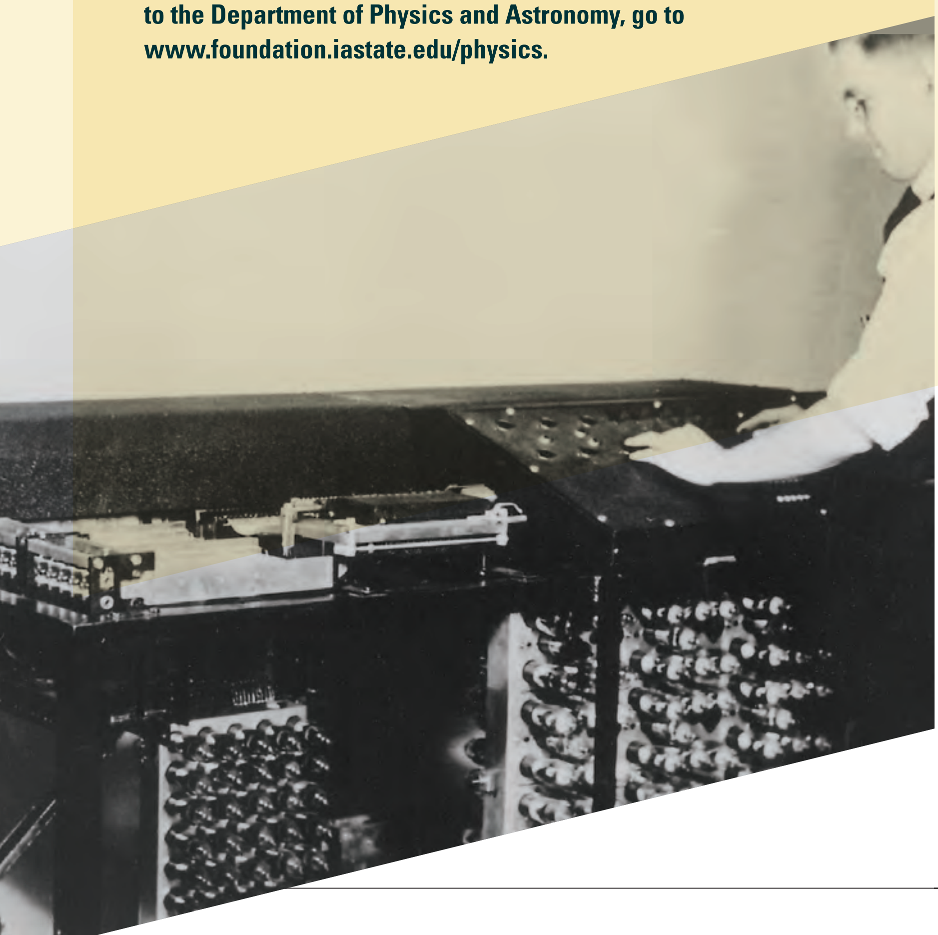
OPPORTUNITIES TO GIVE

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 (e.g., a theory coffee room).
2) Contributions to the Zaffarano Lectureship fund allow us to sustain the event over years to come.
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 in Astronomy and Astrophysics. 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.



FACULTY PROFILES

NOBEL

TEACHING LABS/HISTORY

ALUMNI/NEW FACULTY

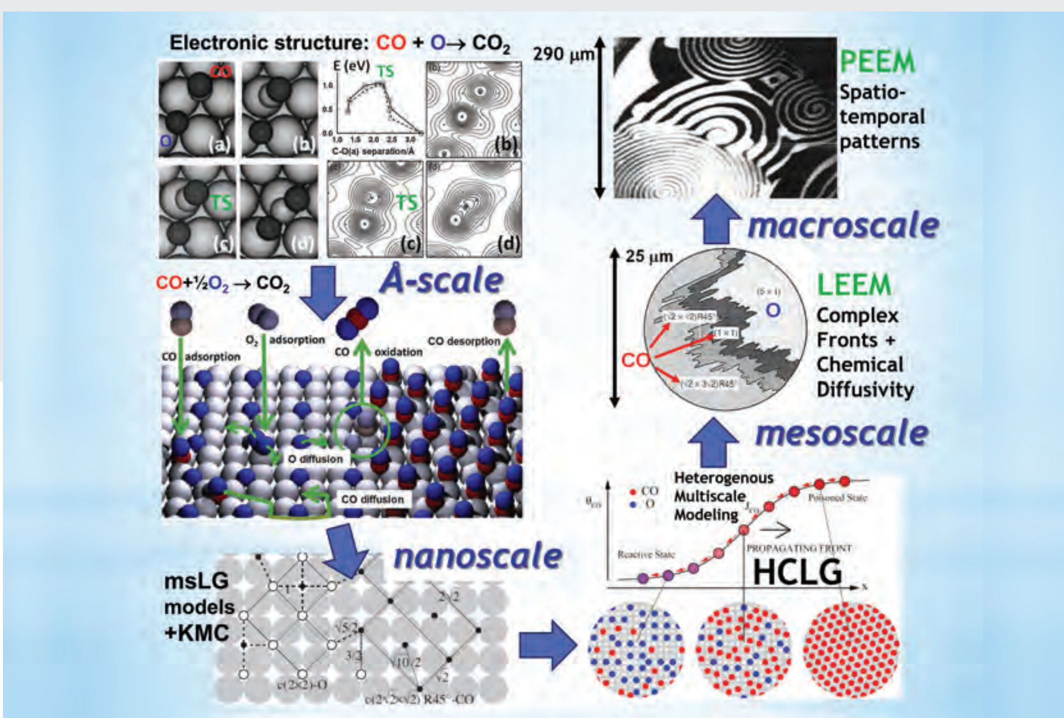
AWARDS/ZAFFARANO

Characterizing systems far-from-equilibrium *by James Evans*

Analysis of equilibrium systems has a long history, going back to pioneers including J. Willard Gibbs in the 19th century. There exists a well-established thermodynamic free energy framework in which to interpret behavior. However, for systems out-of-equilibrium, no such general framework exists, creating a challenge for analysis but also allowing the possibility of more diverse behavior. Jim Evans' group analyzes two general classes of non-equilibrium systems by a combination of theoretical development and simulation: (1) self-assembly or growth of nanoclusters and their post-synthesis stability; (2) "open" non-linear reaction-diffusion systems.

For the first class of systems, self-assembly requires mobility of aggregating atoms or molecules, thus typically occurring either by deposition on smooth surfaces or in the solution-phase. There is an additional key factor: if restructuring of aggregated components is slow on the time scale of aggregation, then the growing nanocluster cannot achieve its equilibrium form. For example, if diffusion of atoms around the periphery of the nanocluster is inhibited, then fractal shapes can arise as opposed to geometric equilibrium Wulff shapes. If intermixing is inhibited for multi-component nanoclusters, then, for example, core-shell structures can be synthesized as opposed to alloyed equilibrium structures. Thus there is the opportunity to tune synthesis or growth conditions to generate a diverse variety of non-equilibrium structures that optimize desired properties, for example, for plasmonics or catalysis. However, ability to synthesize is insufficient for functionality as non-equilibrium nanostructures are intrinsically metastable, so assessment is also needed of their robustness against evolution back to equilibrium.

For 2D metallic nanoclusters formed by deposition on smooth surfaces, we have developed a formalism to allow description with ab-initio Density Functional Theory (DFT) level precision of the kinetics of self-assembly of nanoclusters, as well as their relaxation back to equilibrium. Incorporation of DFT energetics into stochastic simulation by scientist Yong Han has allowed characterization and elucidation of many self-assembly and relaxation processes observed experimentally with scanning tunneling microscopy. Recent efforts have shifted to focus on solution-phase synthesis of 3D metallic nanoclusters or nanocrystals, where there have been immense advances in the last two decades allowing targeted nanosynthesis. We have chosen to focus on the post-synthesis stability of such nanostructures against relaxation back to equilibrium. Simulation studies by graduate student King (Alex) Lai have characterized the

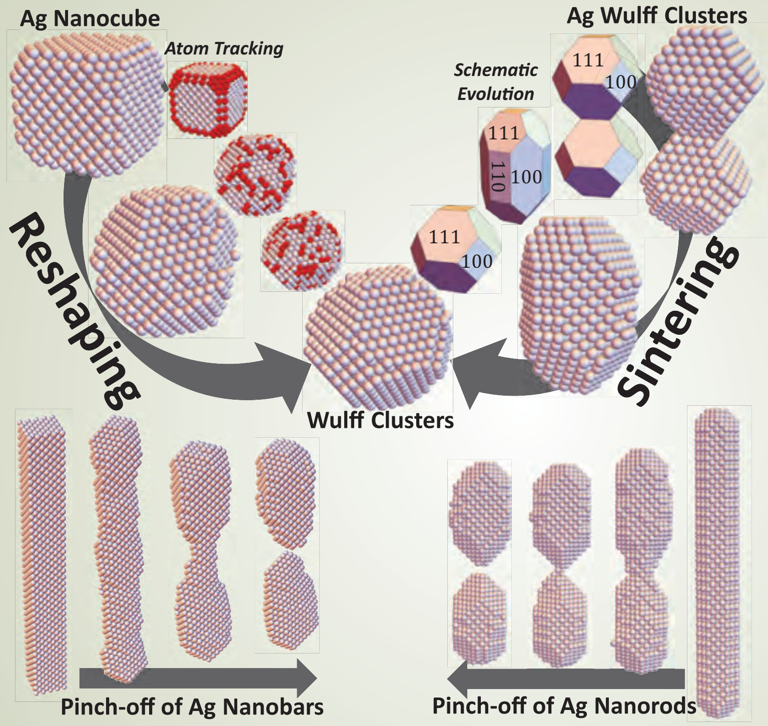


Schematic overview of multiscale modeling of catalytic CO-oxidation on a Pt-group metal(100) surface: from molecular-level analysis of reaction energetics to nanoscale description of adsorbed reactant layers to mesoscale and macroscale description of spatiotemporal behavior.

The Evans group analyzes diverse far-from-equilibrium behavior developing a variety of novel theory and simulation approaches.

shape evolution of synthesized Ag nanocubes back to Wulff shapes, the sintering of pairs of Au nanoclusters to form a larger nanocluster (matching transmission electron microscopy observations), and the pinch-off of elongated Ag nanorods (see images).

In the second class of "open" systems, one can regard "reactants" as being fed into a system at a prescribed rate and "products" formed by some reaction being removed. This scenario applies in catalytic flow reactions where the system is a reaction chamber that could incorporate a Pt-group metal surface or a functionalized mesoporous material that catalyzes (enhances) the reaction. One anticipates that such systems settle down to steady state (which is not described by equilibrium theory given that the system is open). Nonetheless, this steady state can exhibit behavior seemingly analogous to equilibrium systems such as phase transitions, as some control parameter is varied. However, our analysis reveals some subtle differences such as the breakdown of the famous Gibbs phase rule for equilibrium systems. It is also known that such open systems can exhibit self-sustained oscillations and spontaneous pattern formation not seen in equilibrium systems. For surface reactions, our modeling by scientist Da-Jiang Liu provides a detailed molecular-level treatment of non-linear reaction kinetics and a multiscale description of patterns incorporating reliable DFT energetics. For mesoporous systems, we assess the dramatic effect of inhibited transport in narrow pores on reducing product yield.



Kinetic Monte Carlo simulation with realistic surface diffusion kinetics of the post-synthesis evolution of Ag nanocrystals: reshaping of nanocubes to equilibrium Wulff clusters (upper left); sintering of pairs of Wulff clusters (upper right); pinchoff of nanobars and nanorods (bottom).

Superconductors in the terahertz spotlight *by Peter Orth*

Superconductivity is among the most fascinating physical phenomena, and it is a direct manifestation of quantum mechanics at the macroscopic scale [1]. The electrons inside a superconductor team up into pairs, synchronize their phases, and act as one giant, coherent electronic wavefunction. The wavefunction amplitude describes the superconducting pair density, and the gradient of its phase corresponds to the coherent flow of pairs. As a result, a superconducting material conducts electric currents with zero resistance and expels magnetic fields from its interior (Meissner effect), except in quantized amounts, leading to magnetic flux quantization. These unique properties have important applications. For example, they allow the construction of powerful electromagnets that require huge currents and are used in magnetic resonance imaging machines and particle accelerators. Flux quantization can be exploited in precise magnetic field sensors using superconducting quantum interference devices (SQUIDs), or quantum computers based on superconducting qubits.

Macroscopic phase coherence also leads to fascinating properties if a superconductor is strongly perturbed, for example, by an external laser field. Such non-equilibrium situations are at the center of attention today. They are fundamentally interesting and can lead to new insights into the superconducting state, for example, about the origin and symmetry of electronic pairing. In addition, the rapid and dynamic control of superconductivity may contribute to the design of the next generation of ultrafast electronic devices.

Ultrafast control of superconducting coherence is made possible by recent technical advances in the development of intense and coherent light sources in the terahertz regime. In a recent collaboration between our theoretical group and the experimental group of Professor Wang (Iowa State University and Ames Laboratory), we have investigated the effect of exposing the commercially important superconductor Nb3Sn to ultra-intense terahertz (THz) pulses with electric fields strengths of up to hundreds of kilovolts per centimeter. As described in our joint publication in *Nature Materials* [2], the THz pulse can drive the superconductor into a long-lived metastable state that is characterized by unusual coherent transport behavior, which has never been observed before.

In another study that was performed together with the Wang group and the theory group of Professor Fernandes at the University of Minnesota, we have investigated the dynamics of the superconducting state under multi-cycle THz pulses [3]. One important property of a superconductor is the spectral gap D, which develops as a result of electronic pairing. Following a strong and non-adiabatic perturbation, the gap amplitude can perform coherent oscillations, which is nothing but the famous Higgs mode known from particle physics. Studying Higgs dynamics in superconductors provides direct insight into the pairing symmetry and nearby electronic phases. In our recent work, published in *Physical Review B*, we have developed a semi-phenomenological theory that includes damping of the Higgs mode to quantitatively account for the experimental observations. We have also investigated Higgs dynamics in multi-band superconductors and revealed that the gap oscillations are more rapidly damped compared to the single-band case due to additional scattering channel to the other Fermi sheets [4]. This opens the possibility of distinguishing single and multi-band superconductors using non-equilibrium pump-probe spectroscopy.

Finally, light can also control superconductivity indirectly by creating a non-thermal state of lattice vibrations. As we have shown in a recent article published in *Physical Review B*, this can be used to control phase competition between a superconducting and a density wave phase in unconventional superconductors such as the iron pnictides [5].

Looking ahead, “superconductors in the THz spotlight” will continue to challenge our imagination and provide plenty of opportunities for controlling and possibly enhancing their properties on ultrafast picosecond timescales.

References:

[1] S. J. Blundell, *Superconductivity: A Very Short Introduction*, Oxford University Press (2009).

[2] X. Yang et al., *Nature Materials* 17, 586 (2018).

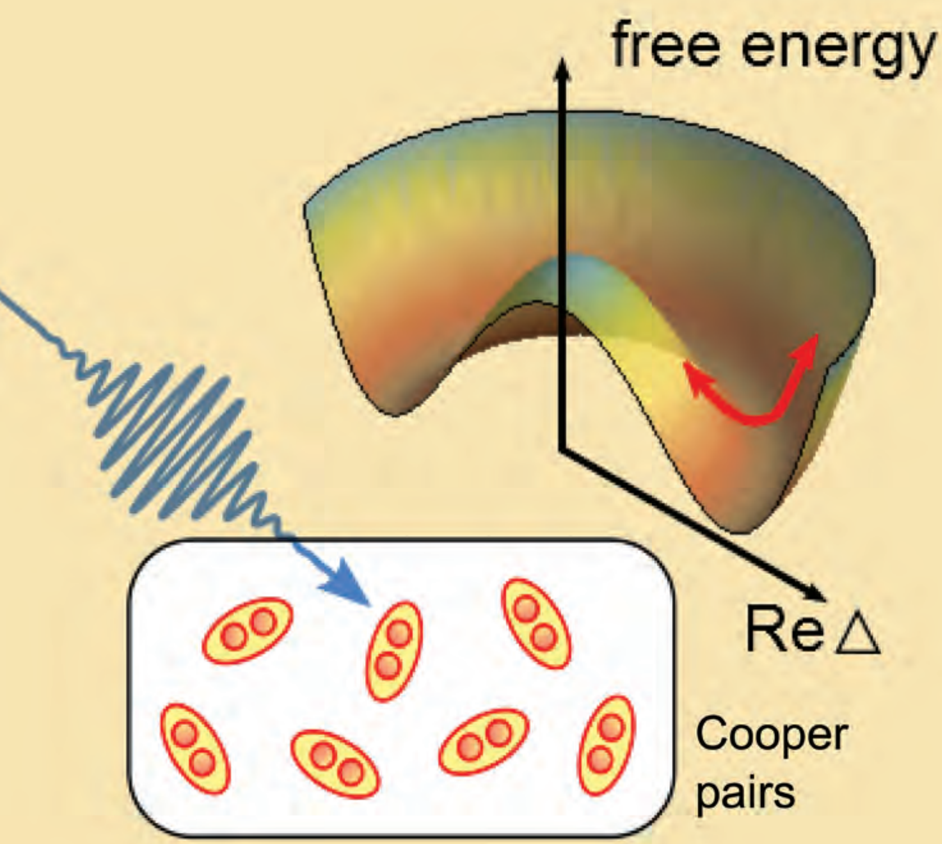
[3] T. Cui et al., *Phys. Rev. B*, in press (2019); see also arXiv:1802.09711.

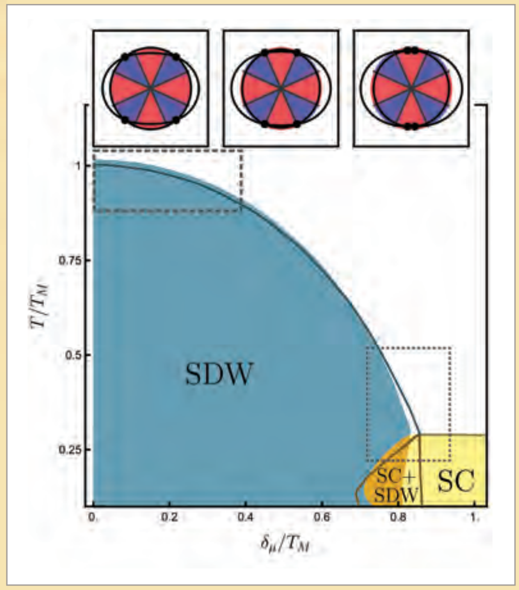
[4] T. Cui et al., to be submitted (2019).

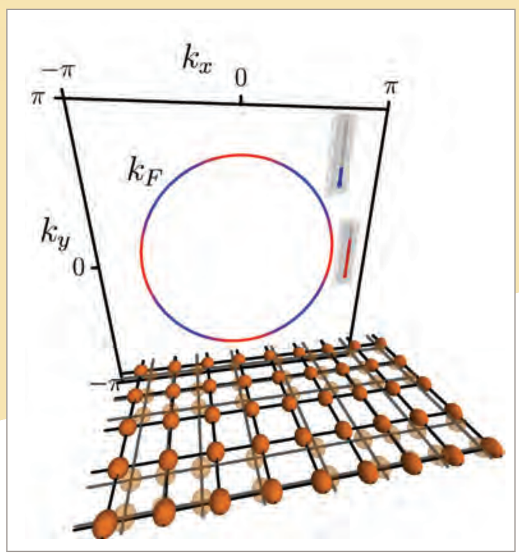
[5] M. Schuett et al., *Phys. Rev. B* 97, 035135 (2018).

Our theoretical research shows that exposing superconductors to intense light pulses can yield new insights into superconducting materials and produce new quantum states of matter.

LEFT: Schematic drawing depicts resonant excitation of Higgs amplitude mode of the complex gap D (red arrows) with intense resonant THz light. Free energy landscape of superconductor as a function of complex gap D takes the form of Mexican hat potential. **BELOW:** Momentum-dependent effective electronic temperature generated by non-equilibrium acoustic phonons. The lower panel illustrates the instantaneous distortions on a square lattice caused by the excitation of an acoustic phonon mode. Scattering by nonequilibrium acoustic phonons promotes a momentum-dependent redistribution of electronic quasiparticles, which is translated as a steady-state effective temperature profile that varies along the Fermi surface depicted in the upper panel (blue and red represent local temperatures that are colder and hotter than the average, respectively). Adapted from Ref. [5]—M. Schuett et al., *Phys. Rev. B* 97, 035135 (2018).







Nonequilibrium steady-state phase diagram for competing superconductivity (SC) and spin-density wave (SDW). The inset shows the superimposed circular holelike and elliptical electronlike Fermi pockets. Adapted from Ref. [5]—M. Schuett et al., *Phys. Rev. B* 97, 035135 (2018).

Petabyte Scale Data at the Large Hadron Collider

by James Cochran

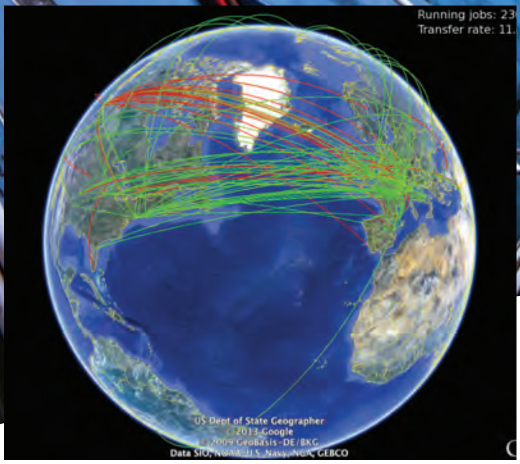
Since its earliest days, the field of elementary particle physics has pushed the boundaries of computational science. Modern experiments in high-energy physics (aka "elementary particle physics") are no different and generate huge challenges in both their data rates and volumes. The basic goal is, of course, to find something new that will give us a deeper understanding of the universe. For the past 20 years, the Iowa State University high-energy physics group has been working on the ATLAS experiment at the Large Hadron Collider (LHC) at CERN in Geneva, Switzerland, straddling the Swiss/French border. The collider occupies a tunnel 27 km in circumference that is 100 m underground. The LHC is currently the highest energy particle accelerator in the world and collides protons with protons at an energy of 13 Tera electron-volts [TeV] (that's 10^{13} eV). For reference, 1 TeV is about the energy of motion of a flying mosquito. What makes the LHC so extraordinary is that it squeezes this energy into a space about a million million times smaller than a mosquito. Since the overwhelming majority of proton-proton collisions are uninteresting, it is necessary to generate a vast number of collisions if we are to find and confirm something new. This is accomplished by colliding dense beams of protons. To appreciate just how much energy is involved, it is worth noting that the total energy stored in one proton beam is equivalent to the kinetic energy of the USS *Harry S. Truman* aircraft carrier traveling at 5.6 knots.

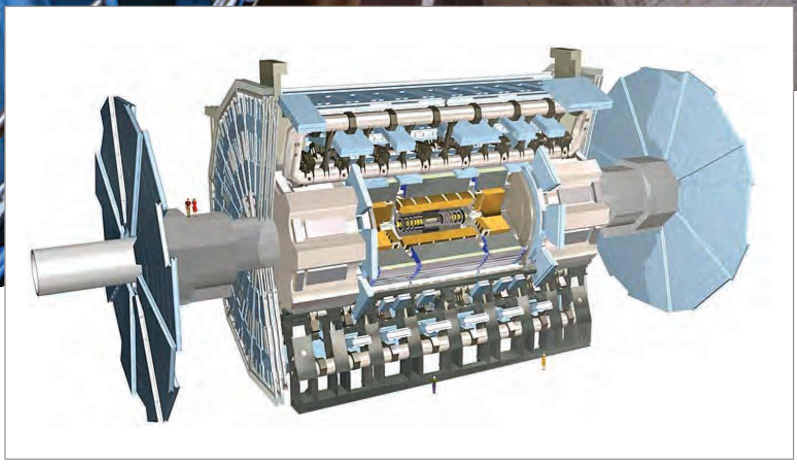
The ATLAS detector, which took 17 years to design and build and which began taking data in 2010, was created to study these collisions and to date has published nearly 900 scientific papers. The detector is as high as a five-story building with a length of half a football field. With the most recent LHC collision rate, the ATLAS detector generates data at a rate of 64 Tera bytes [TB] per second. That's equivalent to 100,000 CDs every second and would require 18 Boeing 747 flights every day to deliver this data to Ames. To address this issue, ATLAS developed a sophisticated triggering system that very quickly decides if a given collision should be recorded or not. This reduces the data rate to ~10 TB/day, which is still a few petabytes per year. While this is manageable, it is quite challenging because extensive computing resources are required to convert the raw data into a format that is usable by the physicists and tremendous amounts of simulated data must be created to fully analyze the data. Recognizing that even the computing capacity of a facility like CERN would not be sufficient to meet the tremendous computing needs of the LHC, in 2005 a worldwide LHC Computing Grid was created linking, via high-speed connections, all the universities and laboratories collaborating on the LHC. This proved to be a huge success and pushed the boundaries of distributed computing far beyond their previous limits.

Looking toward the future, of course, finds new challenges. The LHC and the ATLAS detector are in the process of undergoing a series of upgrades to greatly increase the data rate and thus the discovery potential. The predicted computing needs following these upgrades exceeds by approximately a factor of four the worldwide computing capacity that would be allowed by a (by now optimistic) Moore's law extrapolation of the current computing budget. This is a serious concern and is being addressed by an active R&D effort in which the U.S. segment of ATLAS is playing the leading role. In addition to efforts to overhaul the ATLAS software and computing model, numerous collaborations have been formed with industry (most notably Google) to explore all possible solutions. As with the World Wide Web and distributed computing, the solutions will likely have benefits far beyond the field of high-energy physics.

Doing science at the smallest scale requires access to computing at the largest scale. Processing and analyzing the initial years of data from the Large Hadron Collider necessitated the creation of a dedicated worldwide computing grid. Planned upgrades to the accelerator and detectors will result in more than an order of magnitude increase in the data. This is a tremendous challenge to the available computing capacities and budgets.

Magnets in the Large Hadron Collider tunnel.





LEFT: Map of the high-speed data links between sites on the World Wide LHC Computing Grid (WLCG). **RIGHT:** The ATLAS detector is as large as a five-story building (25m x 46m), weighs 7,000 tons, and has ~100M electronic readout channels.

Center for the Advancement of Topological Semimetals

by Rob McQueeney

The recent discovery of topological semimetals (TSMs) has opened an exciting scientific frontier at the intersection of magnetism and electronic band topology. TSMs are materials whose low energy electronic states possess a linear (massless) dispersion with topological and symmetry protection. TSMs can be thought of as a three-dimensional version of graphene. These novel electronic states are predicted to have exceptional and tunable transport and optoelectronic properties that can serve as a materials platform to deliver the next generation of quantum functionalities. Magnetism plays a critical role in unlocking the potential of TSMs.

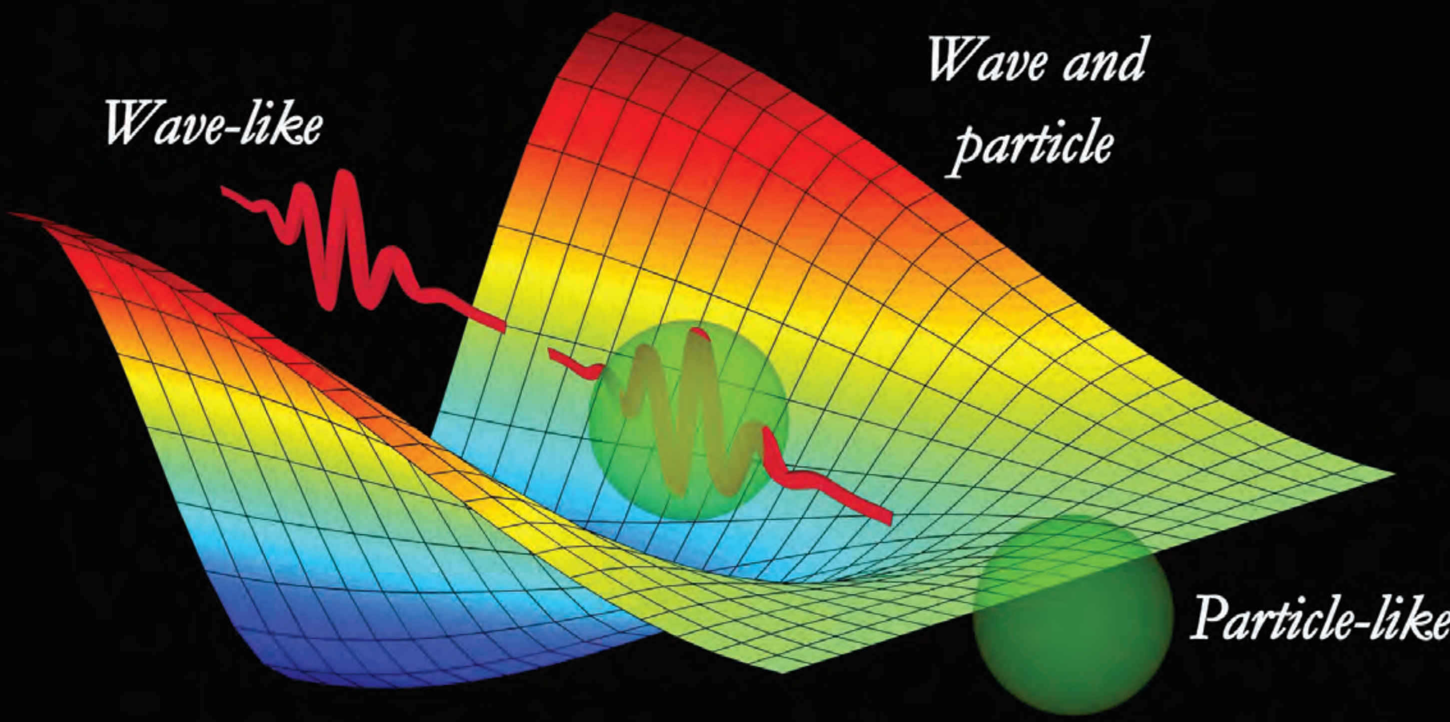
Magnetic order (the breaking of time-reversal symmetry) in TSMs can generate a Weyl semimetal. Weyl semimetals have topologically protected bulk chiral electronic states and surface electronic states that can be controlled by coupling to external magnetic fields. Magnetic Weyl semimetals can serve as a robust platform for the emergence of a variety of topological states with dissipationless edge modes, such as the quantum anomalous Hall state.

To stimulate the development of these materials, Ames Laboratory (operated by Iowa State University) recently received a four-year $10.75M research grant to lead the Center for the Advancement of Topological Semimetals (CATS). CATS is an Energy Frontier Research Center funded by the Department of Energy's Basic Energy Sciences. CATS' mission is to understand and discover new quantum phenomena and functionality in topological semimetals. To fulfill this mission, Ames Laboratory (operated by Iowa State University) capitalizes on its rich history of developing magnetic materials to lead a collaboration of world-leading experts in topological materials and magnetism from Ames Laboratory/Iowa State University, Argonne National Laboratory, Harvard University, Los Alamos National Laboratory, Massachusetts Institute of Technology, University of California–Santa Barbara, and the University of Waterloo. CATS is directed by Iowa State University Physics and Astronomy Professor Rob McQueeney. In addition, Iowa State Physics Professor Paul Canfield, Professor Adam Kaminski, Assistant Professor Peter Orth, and Ames Laboratory Scientist Linlin Wang are CATS Principal Investigators. There are 17 PIs, 12 postdocs, and 2 graduate students and a myriad of experimental and theoretical capabilities that are spread out over all seven CATS institutions. More information about CATS can be found at cats.ameslab.gov.

CATS' long-term research goals are to (1) predict, discover, and understand magnetic TSMs and new topological states of matter; (2) establish the ability to control transitions between different topological electronic states; and (3) reversibly manipulate the response of topological systems using external fields. Ames and its CATS institutional partners are using a materials discovery approach to form a feedback loop of predictive theory and modeling, synthesis and growth, and characterization of topological materials. Static or quasi-static control methods (such as doping, quantum confinement, electrostatic gating or magnetic fields) are applied to demonstrate the mastery required to place a system in a particular quantum state with desirable properties or unusual responses. CATS also seeks methods to enable switching between trivial and non-trivial topological states, in particular utilizing time-dependent fields or currents to dynamically manipulate the response.

With these approaches, the CATS team hopes to overcome many challenges and answer vexing questions in the field of topological semimetals in order to increase their potential for application in spintronics, optoelectronics, quantum sensing, and classical (Beyond Moore) and quantum computing. For example, although magnetic Weyl semimetals have been theoretically predicted more than five years ago, potential realizations of these materials have been identified only recently. Discovering new magnetic Weyl semimetals will greatly aid in their understanding and use. Another important challenge is to utilize TSMs to provide an alternate route to the quantum anomalous Hall state. This topological phase has been observed in thin films of dilute ferromagnetic topological insulators at very low temperatures (<100 mK). Magnetic TSMs provide the possibility for generating the quantum anomalous Hall state at high temperatures, even room temperature, which could lead the way to dissipationless electronics.

Ames Laboratory is leading a new program focusing on the advancement of topological semimetals in collaboration with Argonne National Laboratory and the Los Alamos National Laboratory as well as the laboratories at Harvard University, the University of California–Santa Barbara, the Massachusetts Institute of Technology, and the University of Waterloo.



Members of the CATS collaboration at the inaugural annual meeting at Ames Laboratory.

Laser Physics and Applications in Biological Science: Nobel Prize in Physics 2018

by Xuefeng Wang

Arthur Ashkin
Photo credit: Bell Labs, Alexis Cheziere/CNRS Photothèque, and University of Waterloo

Gérard Mourou
Photo credit: Bell Labs, Alexis Cheziere/CNRS Photothèque, and University of Waterloo

Donna Strickland
Photo credit: Bell Labs, Alexis Cheziere/CNRS Photothèque, and University of Waterloo

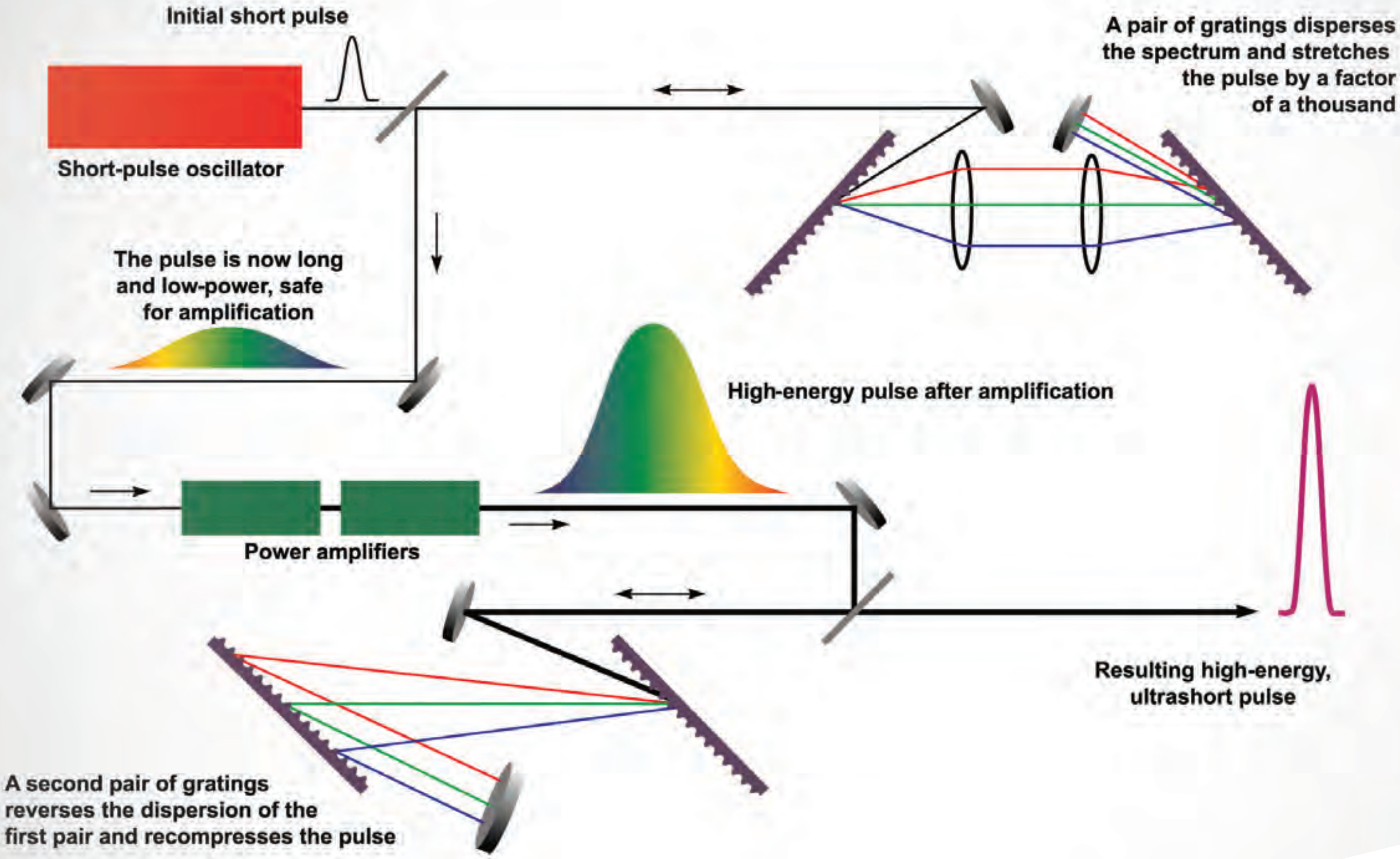
The Nobel Prize in Physics 2018 was awarded "for groundbreaking inventions in the field of laser physics" with one half to Arthur Ashkin "for the optical tweezers and their application to biological systems" and the other half jointly to Gérard Mourou and Donna Strickland "for their method of generating high-intensity, ultra-short optical pulses."

Ever since the invention of lasers in the 1960s, 30% of the Nobel prizes in physics were awarded for photonics-related research or research strongly benefited from photonics technologies. Laser, a light source that one can hardly find a counterpart of in nature, is truly an amazing creation born from humankind's knowledge and logic thinking. Laser has already found numerous applications in communications, entertainment, and medicine, leading to many Nobel prizes in the past. This time, while Mourou and Strickland devised a chirped-pulse amplification (CPA) to create petawatt laser pulses that are orders of magnitude more powerful than before, Ashkin developed the optical tweezers that convert light to force and can be used to manipulate microscopic biological specimens.

It is known that light-matter interaction can produce force on objects, as photons carry momentum and the change of momentum gives rise to counteracting force. Scientific fictions have depicted the concept of tractor beams that are used to retrieve objects, such as asteroids in space, without touching them. Unfortunately, in reality, force produced by light is usually too weak to move around macroscopic objects. However, it is feasible to manipulate microscopic objects such as atoms, viruses, bacteria, and transparent micron-sized beads with light. Arthur Ashkin envisioned and demonstrated moving microbeads with a laser beam in the 1970s. Moreover, during experiments, Ashkin observed an unexpected phenomenon: in a focused laser beam, instead of being pushed forward, the beads were drawn toward the focus where light intensity was the highest, as if the beads fell into a trap of light. This optical trap can be qualitatively understood with rudimentary geometrical optics and Newton's laws. It turns out that no matter which direction the bead at the laser focus displaces toward, the bead would refract the incident light and change its momentum with a momentum increment pointing outward from the laser focus. As a result, the counteracting force produced by light on the bead always points toward the focus, thus pulling the bead back to the center of the optical trap. With proper light intensity and wavelength, Ashkin devised optical traps to immobilize biological objects such as viruses and bacteria without touching or damaging those delicate targets. Such optical traps are used to grab those tiny objects with high spatial resolution and tunable trapping force, like a pair of tweezers.

Ashkin's invention opened a door to the study of the biomechanics of cells or even molecules in biological systems. Optical tweezers have become a standard tool in many molecular research labs and have been applied to study single molecule force and motion in a non-invasive manner. Making use of the optical tweezers, scientists investigated the mechanics of bacterial flagellum, a threadlike structure propelling the bacterium to swim, and measured the torsional compliance of the flagellum. In another highly influential research, researchers studied the pulling force and walking step length of motor protein kinesin, which transports molecular cargo inside eukaryotic cells. Even after five decades, optical tweezers are still under constant use and development, remaining an elegant physics tool in biological studies.

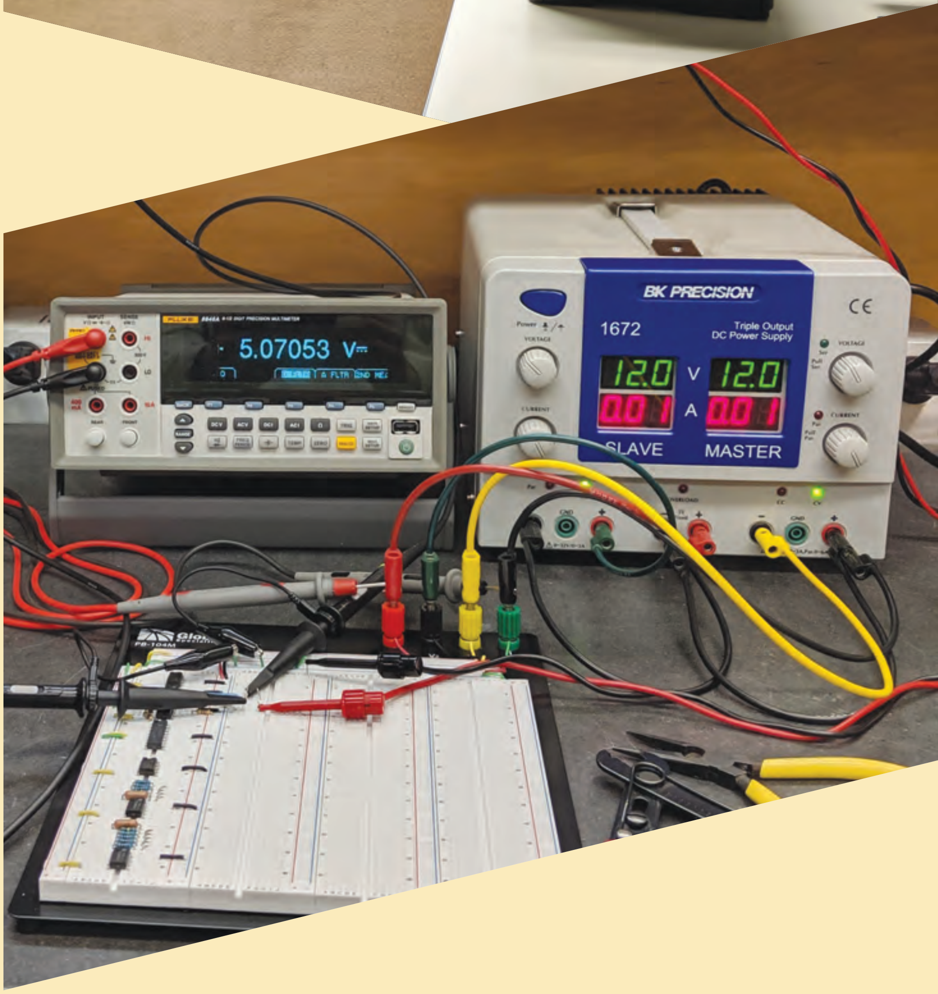
The inventions honored in 2018 have revolutionized laser physics. Extremely small objects and incredibly rapid processes are now being seen in a new light. Advanced precision instruments are opening up unexplored areas of research and a multitude of industrial and medical applications.



Junior-level teaching labs receive upgrade

This year several major improvements were introduced in the junior-level teaching laboratories. The laboratory section of "Electronic Instrumentation for Experimental Physics," Physics 310, received funding to upgrade the equipment and increase the number of setups available to allow a larger enrollment. The course covers common electrical instruments; power supplies; transducers; passive and active devices, analog integrated circuits, including filters and amplifiers; digital integrated circuits; and signal transmission and enhancement.

The Physics 310 lab uses electronic breadboards with leaded electronic components to quickly build and analyze a variety of circuits. New power supplies, oscilloscopes, breadboards, function generators, and digital multimeters will replace the outdated equipment currently used in this course. The new triple power supplies provide ±12 volts and +5 volts all in one unit to power typical analog and digital circuits. New digital 2 channel oscilloscopes provide students working experience with modern scope technology. New arbitrary function generators also expose students to modern waveform generation equipment.



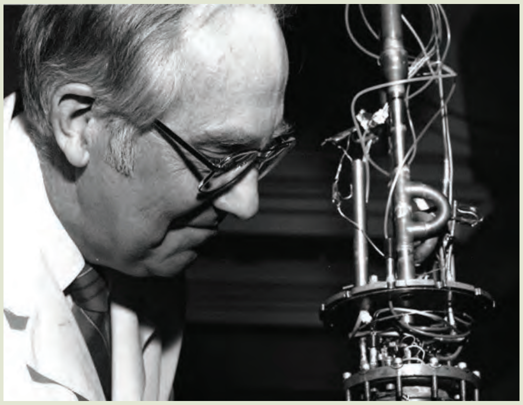
For the laboratory section of "Introduction to Modern Physics," Physics 321 and 322, new workbenches will replace the outdated benches previously used in these courses. This will allow instructors to more easily accommodate the larger enrollment and provide a better teaching environment. The new layout has more open egress that improves instructor-to-students and student-to-student communications. A new large-screen TV is an effective tool to provide feedback and lab tips in real time as the students are working in the lab.

History of the Low-Temperature Laboratory

by Doug Finnemore

If you cool a material and thus reduce the average random kinetic energy of the atoms and molecules, the material can show new phenomena and exotic new states of matter. For example, shortly after Kammerlingh Onnes first liquefied helium in 1908, he discovered superconductivity in a mercury wire at 4.3 Kelvin. In a short temperature interval of a tenth of a Kelvin, the electrical resistance drops to zero because a cooperative state of the electron gas forms in which long-range forces give a rigidity to the wave function that suppresses the scattering that leads to electrical resistance. As you heat or add energy to this correlated electron gas, the random thermal motion destroys this coherence. Other examples of this sort of long-range coherent state are the quantum Hall effect, superfluidity in 3He, and other forms of quantum coherence in the quantum spin systems.

At Iowa State, Sam Legvold pioneered work at liquid helium temperatures in 1952 with the work of his student Nancy James, in which they measured the electrical resistivity of lanthanum, cerium, praseodymium, and neodymium from 2.2K to room temperature. The Legvold group used a Collins helium cryostat located in the northwest corner room of Physics Hall to generate the liquid helium and perform the experiments. This liquefier cryostat had a wide-mouth dewar about 250 mm across with the refrigeration heat exchangers and expansion engines located on one side so that there was a space wide enough to accept a resistivity or other cryostat on the other side. They made the measurements inside the liquefier in the helium collection space. Over the succeeding fifteen years, the Ames and Oak Ridge groups teamed up for an in-depth study of magnetism in the rare earth metals. Spedding's group prepared all of the rare earth metals in very pure form, and the Legvold group learned to prepare centimeter-size single crystals suitable for neutron scattering. They used a strain anneal method in which a button of high-purity rare earth metal would be put in a mechanical vice to introduce a large amount of strain energy. Then the strained button would be annealed for weeks or months in high vacuum to relieve the strain and grow large single crystals. The Iowa State team first mapped out the basic thermodynamic and transport properties of these single crystals



TOP: Sam Legvold is discussing an experiment with a student.
BOTTOM: Clayton Swenson is working on a cryostat.

as a function of temperature and magnetic field to locate the phase transitions and fit the results to current theory. Then the crystals were shipped to Oak Ridge National Laboratory for a neutron scattering study of the detailed magnetic structures such as helical and conical phases.

In 1955, the addition of Clayton Swenson to the physics faculty provided a substantial influx of additional low-temperature expertise. He received a DPhil in 1949 with Francis Simon at Oxford, doing a dissertation studying the solid-liquid phase boundary in helium near absolute zero. At Iowa State, Swenson established a low-temperature group studying both superconductivity and physics at high pressures. In 1970 his student Tom Cetas used paramagnetic salt magnetic thermometry to show that the boiling point of helium given by T58 was too low by about 7 millikelvin. These data were not definitive, but they clearly pointed to a need for improvement in the T58 scale. This launched Swenson into a mini-career working on the Consultative Committee on Thermometry, International Commission on Weights and Measures for many years to develop an improved temperature scale that led to the scale we use today.

ALYSSA MILLER

Alyssa Miller graduated from Iowa State with a BS in physics in 2014 and completed three internships as an undergraduate, working at Argonne National Laboratory and Fermilab. She was hired as an accelerator operator at Fermilab in 2015 and is now an engineering physicist for Accelerator Division's External Beams Department.

As an engineering physicist, Miller typically acts as machine coordinator for one of the external beamlines, depending on the month. She manages engineers across all accelerator support groups as their maintenance and repair work relates to the machines she is responsible for.

In Miller's opinion, the best part of her job is building on her experiences to develop expert knowledge and intuition for a system she cares for. She optimizes accelerator controls and diagnostics, performs beam studies to better understand machine performance, and recently assisted in the installation of a new beamline. She also attends the U.S. Particle Accelerator School twice a year.

Miller still enjoys participating in STEM outreach as much as she did as an undergraduate. She speaks to classrooms and Fermilab tour groups, she is hosting her first summer student this year, and she spoke on a panel at the 2018 Conference for Undergraduate Women in Physics.

In her free time she enjoys photography, climbing, hiking, dancing, road trips, and exploring Chicago and its western suburbs.

JONATHAN FORTNEY

Jonathan Fortney got his BS in physics (minor in astronomy) in 1999. He went on to receive his PhD in planetary sciences at the University of Arizona in 2004. He was a postdoctoral fellow at NASA Ames Research Center until 2007, when he became a professor in the Department of Astronomy and Astrophysics at the University of California, Santa Cruz. Fortney is currently a full professor at UC Santa Cruz and leads a diverse research program that includes understanding the atmospheres, interiors, and composition of planets via theoretical modeling efforts. His work covers both exoplanets (planets around other stars) and solar system planets. At UC Santa Cruz he leads the Other Worlds Laboratory (OWL), which holds a 50-person monthlong workshop every summer to foster new collaborations in exoplanetary science.

Fortney has received significant recognition for his work, including a Sloan Research Fellowship and the Urey Prize from the American Astronomical Society. He was recently selected to be a member of the steering committee for the Astro2020 decadal survey in astronomy and astrophysics, which will set science priorities for the next decade. In Santa Cruz Jonathan enjoys running half-marathons, playing softball, and going on hikes and to the beach with his family.

ATHANASIOS PETRIDIS

Athanasios Petridis is an associate professor and chair of the Department of Physics and Astronomy at Drake University. He received his PhD in theoretical particle physics from Iowa State University in 1992.

Petridis received his BS in physics at the National University of Greece in Athens and his PhD in theoretical particle physics under Professor Ken Lassila at Iowa State. He worked for eight years for the Nuclear Physics Group at Iowa State as a postdoc and a research scientist, participating in the PHENIX and other experiments at Brookhaven National Lab. His work was on simulations, theoretical support, and other activities in the design and running of the experiments. He joined Drake University in 2001 as a visiting professor before becoming tenure-track. Petridis received promotion and tenure in 2006. During the past six years he has served as the chair of the department. He teaches many courses at all levels and has introduced several workshop-type, upper-level electives. His research is on time-dependent relativistic quantum mechanics in particle and nuclear physics, mostly quarkonia formation and propagation in QGP, non-extensive statistics, short-range correlations in nuclei, information theory, and radiation-shielding for spacecraft. It involves a lot of undergraduate students as part of the teaching process. As chair he helped renovate all department facilities and update the curriculum. He enjoys playing classical guitar and driving Italian cars.

DR. THOMAS IADECOLA

We are excited to welcome Dr. Thomas Iadecola to our department. He received his PhD from Boston University under the supervision of Professor Claudio Chamon in 2017. He was a JQI Theoretical Postdoctoral Fellow at the University of Maryland, College Park, from 2017 to 2019. Dr. Iadecola works on a variety of topics in quantum condensed matter theory, with special emphasis on out-of-equilibrium quantum systems and topological states of matter. On the nonequilibrium side, he studies properties of highly excited many-body states and the surprising phenomena they harbor that challenge deeply ingrained intuition based on quantum statistical mechanics. On the topological side, he focuses on states of matter whose properties cannot be understood within the traditional paradigm of spontaneous symmetry breaking, and which could enable the robust storage and manipulation of quantum information.

DR. SRIMOYEE SEN

We are excited to welcome Dr. Srimoyee Sen in our department. She received her PhD from the University of Maryland, College Park, under the supervision of Professor Paulo Bedaque in 2015. She was a postdoctoral research associate at the University of Arizona from 2015 to 2017 and later was a postdoctoral research associate at the Institute for Nuclear Theory at the University of Washington. Dr. Sen is exploring quantum phase transitions in dense QCD. Her research ties together modern ideas of topological phase transitions in condensed matter physics with that of nuclear and particle physics. She has expertise in lattice QCD, effective field theory, neutrino and nuclear astrophysics, and the QCD phase diagram.

DR. JACOB SIMON

We are excited to welcome Dr. Jacob Simon to the Department of Physics and Astronomy. He received his PhD in astrophysics at the University of Virginia, Charlottesville, under the supervision of Professor John Hawley in 2010. He then became a postdoctoral research associate at the Joint Institute for Laboratory Astrophysics (JILA) from 2010 to 2013, a NASA Sagan Fellow at the Southwest Research Institute from 2013 to 2016, and a senior research associate at the University of Colorado, Boulder. Dr. Simon is a computational astrophysicist applying high-performance computing techniques to the problems of turbulence and accretion in protoplanetary disks to understand how the solar system and planetary systems around other stars form and evolve.

Departmental Awards 2019

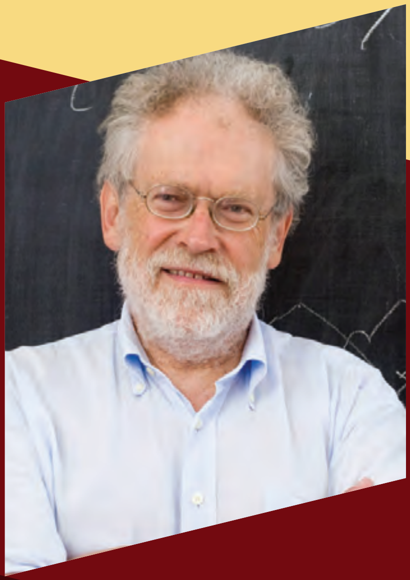
1. **MOST VALUABLE INSTRUCTOR AWARD:** Kirill Tuchin (presented by John Wilde, Grad Student Representative)
2. **DEPARTMENT OF PHYSICS AND ASTRONOMY SUPERIOR SERVICE AWARD:** Brad Dahlsten
3. **GRADUATE COLLEGE RESEARCH EXCELLENCE AWARD:** Meijian Li, Xu Yang (not pictured)
4. **GRADUATE COLLEGE TEACHING EXCELLENCE AWARD:** Sunil Ghimire, Joseph Hall, Elizabeth Macias, Balthazar Peroutka, Scott Saunders, Boqun Song
5. **AWARDS FOR SUPERIOR ACADEMIC PERFORMANCE:** Christopher Bramel, John Bunney, Benjamin Burdick, Daniel Buser, Christopher Dupuis, Charles Howell, Jacob Kautz, Mitchell Kazin, Henry Klatt, John Lawless, Samuel Leonard, Miles Lucas, Alec Mangan, Evan McKinney, Wyatt Peterson, Matthew Pham, Emily Pottebaum, Samuel Roberts, Joshua Slagle, Jacob Wisniewski

Daniel Zaffarano Lectureship

The next Daniel Zaffarano Lectureship will be held at Iowa State University in April 2020. 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), 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." The following 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***.



2020 ZAFFARANO LECTURE

Anton Zeilinger

APRIL 2020 *(see department website for details)*

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*.

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