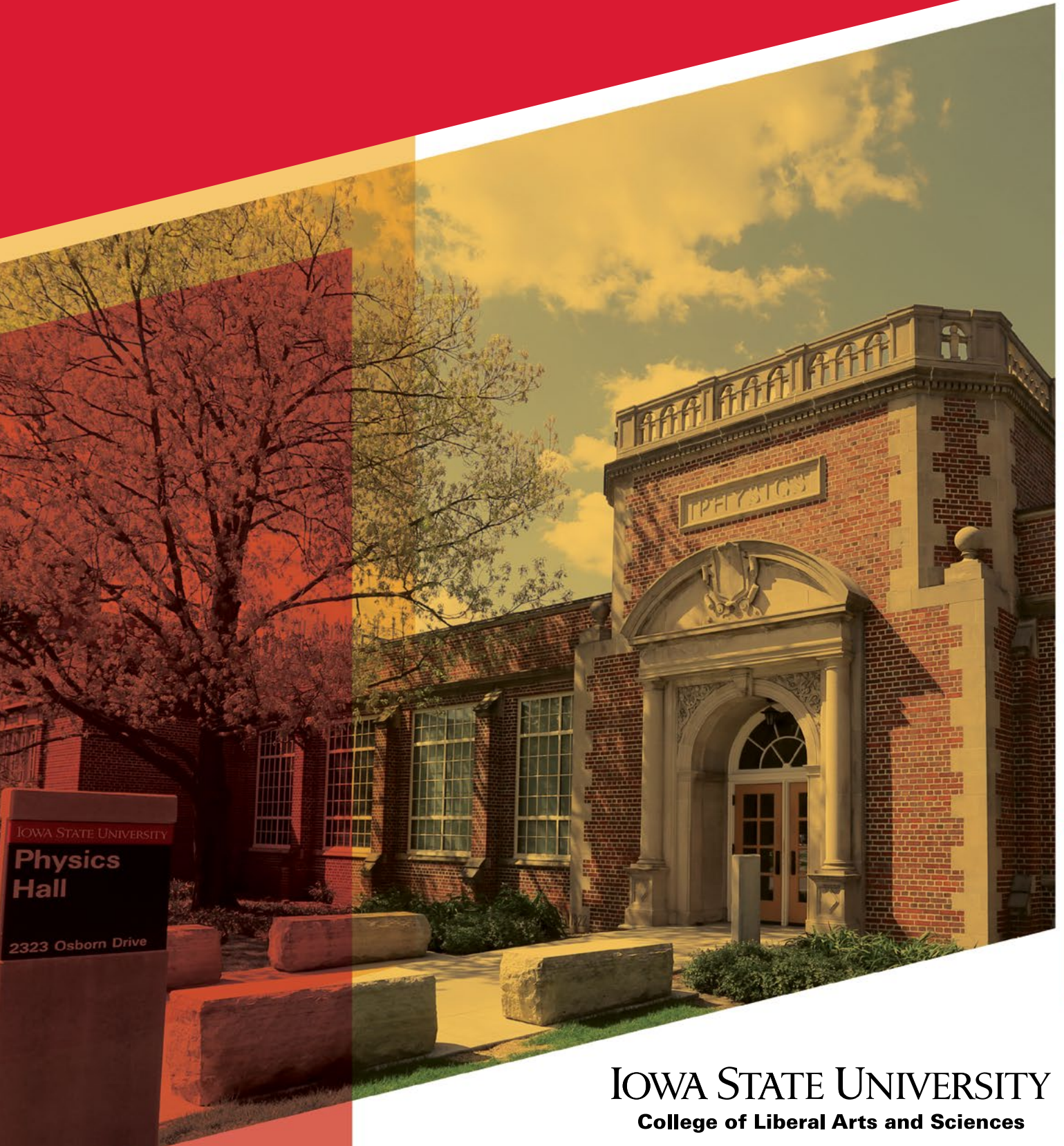


# Quanta & Cosmos

Department of Physics and Astronomy | 2021 Newsletter



**IOWA STATE UNIVERSITY**  
College of Liberal Arts and Sciences



## A Message from the Chair

With the pandemic in its second year, there may be better times ahead of us. Scientific research, rational thought, and international collaboration have been the key to showing us a path out of a global health crisis, which in principle bodes well for public support of fundamental research and higher education. The pandemic has shown us that R1 institutions such as Iowa State University and the Department of Physics and Astronomy are good investments into the future to provide the environment to train the next generation of well-informed citizens and researchers.

It was a very difficult year for experimental laboratory-based research with essentially all of our experiments affected by either limited operations or a complete shutdown for a significant part of 2020. It is difficult to predict the reverberations from the pandemic for faculty research over the next few years. It has become clear that the last year has created a significant amount of stress and anxiety for many, but particularly for graduate students, postdocs, and junior faculty who find themselves in a critical phase of their careers. It should also be recognized that employees with young families and children were most affected by telework, online teaching, and the complex arrangements for childcare and schooling.

As of fall 2021, it is notable that campus is starting to wake up again, with groups of prospective students visiting and our research facilities and buildings becoming alive once more. Should you choose to come visit Iowa State sometime in 2022, it is my hope that you will see our campus back to its usual self with its broad range of exciting academic, teaching, and cultural activities.

Our faculty continue to receive recognitions at the national level. Awards in the last year include the election of Paul Canfield to the American Academy of Arts and Sciences, the election of Mayly Sanchez to Fellow of the American Physical Society, and recognitions of our outstanding junior faculty, including an NSF CAREER award to Zhe Fei, a Cottrell Scholar award to Peter Orth, and a DOE CAREER award to Sri Sen. Also, the first John and Mary Weaver professorship was awarded to Rob McQueeney.

On behalf of the Department of Physics and Astronomy, I would like to thank you for your continued support.

*Frank Krennrich*

Frank Krennrich, Professor and Chair, Department of Physics and Astronomy  
515-294-5442 | [Krennrich@iastate.edu](mailto: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 Michael Gens, Executive Director of Development (call 515-294-0921 or email [mgens@iastate.edu](mailto:mgens@iastate.edu)).**

**To donate online and designate your contribution directly to the Department of Physics and Astronomy, go to [www.foundation.iastate.edu/physics](http://www.foundation.iastate.edu/physics).**

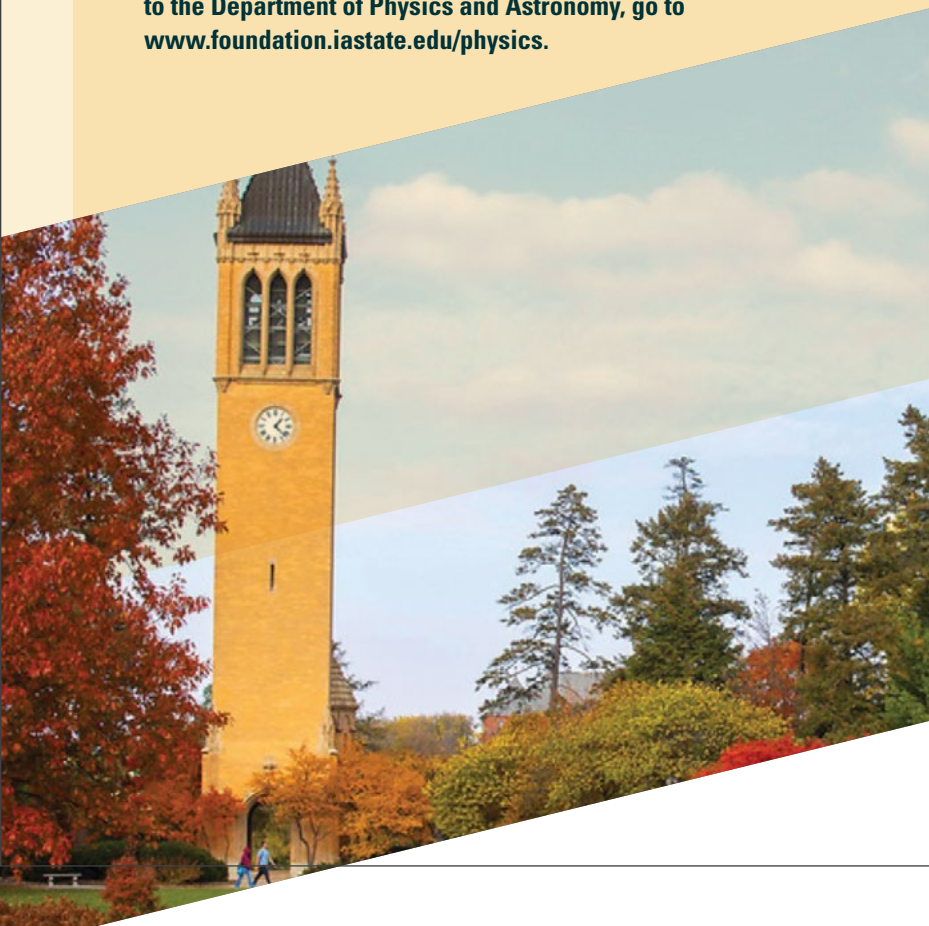
FACULTY PROFILES

NOBEL

TEACHING

AWARDS

HISTORY/ZAFFARANO



# Beautiful Physics with Belle II

by Soeren Prell

For the first decade of this century, the BABAR experiment at the SLAC Linear Accelerator Laboratory in Stanford, California, and the Belle experiment at the KEK laboratory in Tsukuba, Japan, vastly improved our knowledge of the charm and bottom quarks [1], the heavy, short-lived relatives of the up and down quarks that make up the protons and neutrons in atomic nuclei. In the collisions of electrons and positrons, the two experiments discovered many new and exotic composite particles, new quantum-mechanical processes, and the violation of charge-parity symmetry (CP violation) in the decay of B mesons (particles composed of a bottom antiquark and a light quark) [2]. The latter led to the awarding of part of the 2008 Physics Nobel Prize to M. Kobayashi and T. Maskawa, the theorists who first described the underlying mechanism of this CP violation. Understanding the nature of CP violation is important because it is a necessary ingredient for the evolution of the universe from a matter-antimatter symmetric state at the time of the Big Bang to today's matter-dominated universe.



The Belle II experiment is the successor to BABAR and Belle. The KEK electron-positron collider complex has been upgraded to the new SuperKEKB accelerator. The design collision rate has been significantly increased by squeezing the particle beams from micrometer to nanometer diameters. SuperKEKB has recently passed the world-record particle collision rate held until then by the Large Hadron Collider (LHC), and it will increase the rate until the design is reached in 2026. Ultimately, Belle II will collect fifty times the data of Belle, including  $10^{11}$  bottom quarks,  $10^{11}$  charm quarks, and  $10^{11}$  tau leptons. Although some parts of the Belle experiment have been reused in Belle II, many have been replaced with improved technology to be able to cope with the increase in data rate, radiation levels, and background processes.

Compared to the LHC, the collision energy of Belle II is less than one thousandth. Yet Belle II is sensitive to potential new physics particles that are too heavy to be produced, even at the LHC. The access to new physics comes through rare loop processes where heavy hitherto undiscovered particles could briefly

come into existence as allowed by Heisenberg's Uncertainty Principle and thus alter the measurements of decay rates, CP asymmetries, or lepton flavor universality from theoretical predictions. Through loop processes, Belle II's sensitivity reaches energies far beyond the masses of new particles that could be produced at the LHC or in fact at any future manmade particle collider. Several recent measurements by Belle and other experiments deviate from their Standard Model predictions by a few standard deviations. Belle II can improve on several of those measurements and make complimentary ones to test New Physics models that propose to resolve those discrepancies, such as leptoquarks, dark matter, and supersymmetry [3].

The Iowa State high-energy physics (HEP) group of Professors Chunhui Chen, Jim Cochran, and Soeren Prell joined the international Belle II collaboration in fall of 2019, just shortly before the start of the Covid-19 pandemic. Since then, members of the group have made significant contributions to detector operations and data taking (also through remote data-taking shifts from Ames), physics analysis, and improvement of the data quality. Once travel restrictions are eased, the group will increase its presence at the KEK laboratory, providing invaluable experience in the HEP research career of Iowa State graduate students and postdocs.

- [1] The bottom quark is often also referred to as beauty quark. The Belle experiment is named after the French word for "beautiful."
- [2] "Physics of the B Factories," A. Bevan et al., Eur. Phys. J. **C74** (2014) 3026.
- [3] "The Belle II Physics Book," E. Kou et al., Prog. Theo. Exp. Phys. **12** (2019) 029201.

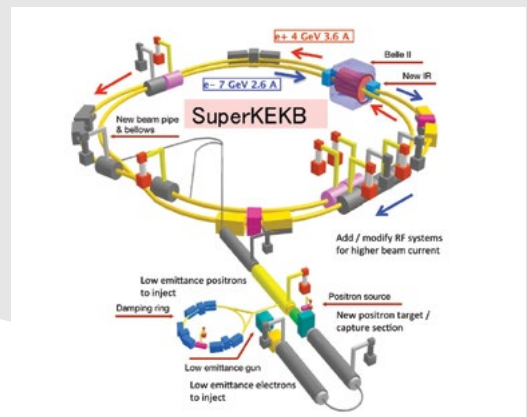


Figure 1: The SuperKEKB accelerator complex that provides electron-positron collisions at a world-record collision rate.

The Belle II experiment at the KEK laboratory in Japan is on its way to collect 50 times the data of its predecessor, Belle. The Iowa State HEP group of Professors Chen, Cochran, and Prell will study the large samples of bottom and charm quarks and tau leptons to search for evidence of new fundamental particles and interactions.

Figure 2: The Belle II experiment records particles produced in the electron-positron collisions. The various detector components measure the momentum and/or energy of the collision products and determine their particle identity (electron, muon, pion, kaon, or proton).

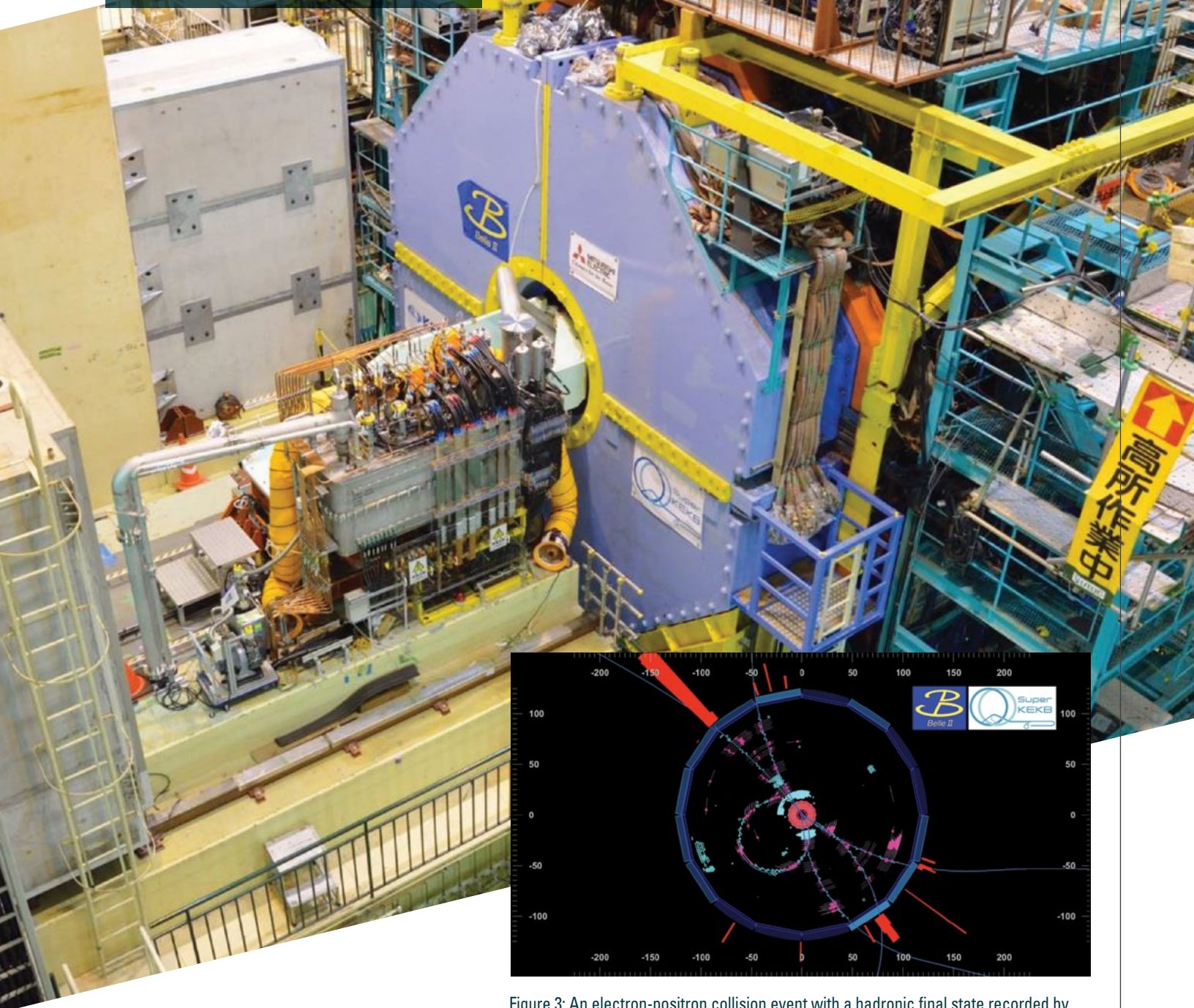


Figure 3: An electron-positron collision event with a hadronic final state recorded by the Belle II experiment is shown. The trajectories of the charged collision products are clearly visible. They are curved due to a solenoidal magnetic field surrounding the collision point in the center.

# Organic LEDs (OLEDs) *by Joe Shinar*

Thin film OLEDs (anode ~ 100 nm,  $\pi$ -conjugated organic layers ~ 150 nm, cathode ~ 100 nm) have advanced spectacularly since first reported in 1987, from barely visible emission that dies within a minute to spectacular displays and solid-state lighting fixtures with continuous operating lifetimes that far exceed the 10,000 hours commercialization threshold. They now dominate Samsung smartphones, tablets, and Apple iPhones; flat and curved 55" and larger LG OLED TVs are now available in increasingly competitive prices. Perhaps even more importantly, they

are poised to share the spotlight of the new Solid State Lighting (SSL) paradigm with inorganic LEDs.

Our group has made numerous contributions to this field for over 30 years, from very basic to applied research.

With Ames Laboratory funding, we pioneered optically and electrically detected magnetic resonance (ODMR and EDMR) studies of these materials and devices. These studies revealed the central role of exciton quenching processes that are responsible for the drop in the internal quantum efficiency of the devices at high injection currents and prevent lasing by carrier injection (i.e., diode lasers), described in a comprehensive review (Fig. 1). The intrinsic issue of exciton quenching processes inspired alternate OLED architectures, namely stacked tandem OLEDs and OLEDs with graded junctions, to spread the emission zone to a relatively thick region of the device, thus lowering the carrier density in that region and consequently reducing these quenching processes.

Together with Dr. Ruth Shinar of the Microelectronics Research Center and Department of Electrical and Computer Engineering,

1) We discovered and studied strong ~30 nsec-wide electroluminescence (EL) spikes in small molecule OLEDs following 1  $\mu$ s – 1 ms bias pulses. We showed that the spikes are due to recombination of correlated charge

pairs, and that the ms EL tails are due to recombination of uncorrelated charges. We also showed that at low temperature the spikes are universal, and they are absent only when there is efficient energy transfer to a long-lived phosphorescent guest emitter.

2) We studied green and blue small molecule OLEDs with improved cathodes and anodes, notably OLEDs with a transparent organic polymer salt anode that can successfully replace the dominant yet problematic transparent indium tin oxide (ITO) anode. In particular, we showed that the external quantum efficiency of these OLEDs can be more than 60% higher than those with an ITO anode. We also developed and studied record-setting intense white OLEDs. We pioneered the development of combinatorial matrix arrays of intense red-to-blue and UV-violet OLEDs, opening the way for spectrometers-on-a-chip based on microcavity designs (Fig. 2).

3) We invented structurally integrated OLED/luminescent chemical and biological sensor arrays (see Fig. 3 for a Lab-on-a-CD that also incorporates microfluidic channels). The highly integrated design provides a new sensor platform, and it should enable extremely compact arrays of sensors for various chemical compounds and biological agents. We developed this new platform for molecular oxygen (gas-phase and dissolved  $O_2$ ), glucose (blood sugar), hydrazine (an extremely toxic but essential propellant for space shuttles), anthrax, and a multianalyte sensor for dissolved  $O_2$ , glucose, lactate, and ethanol. We obtained significant funding to develop this platform and founded Integrated Sensor Technologies Inc. (ISTI) for this purpose.

Finally, in recent years Ruth Shinar and I secured U.S. Department of Energy (DOE) funding totaling nearly \$3M to focus on the issue of light outcoupling from OLEDs. In a typical OLED, only ~20% of the light generated inside the OLED is emitted into the forward (viewing) hemisphere. By fabricating OLEDs on flexible corrugated plastic substrates, we demonstrated outcoupling efficiencies greater than 50%, approaching the DOE's goal of 70%. We are currently demonstrating similar achievements for OLEDs in which the corrugation is buried under a high refractive index planarization layer.

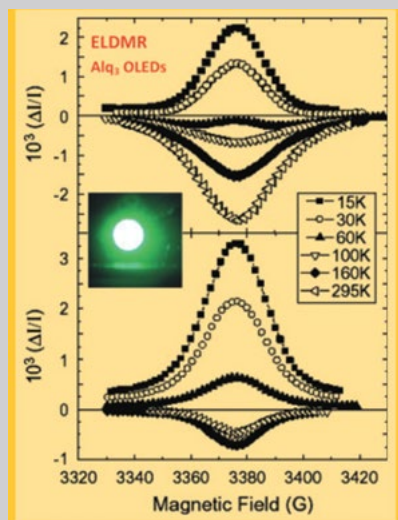


Figure 1: Comprehensive review of optically and electrically detected magnetic resonance studies of  $\pi$ -conjugated light-emitting materials and OLEDs (2012).

Organic light-emitting diodes (OLEDs) are light-emitting diodes in which the emissive electroluminescent layer is a film of organic compound that emits light in response to an electric current. OLEDs have advanced greatly since first reported in 1987 and appear in spectacular displays and solid-state lighting fixtures with more than 10,000 hours continuous operating time.

Figure 2: Blue-to-red microcavity OLED pixel array. The color is controlled via the thickness of one of the organic layers in the OLED.

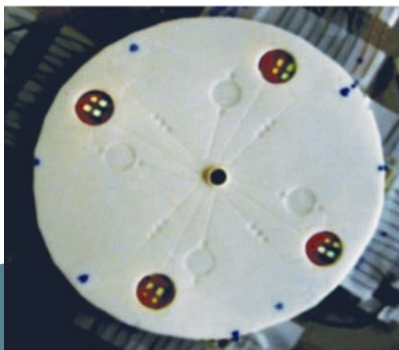
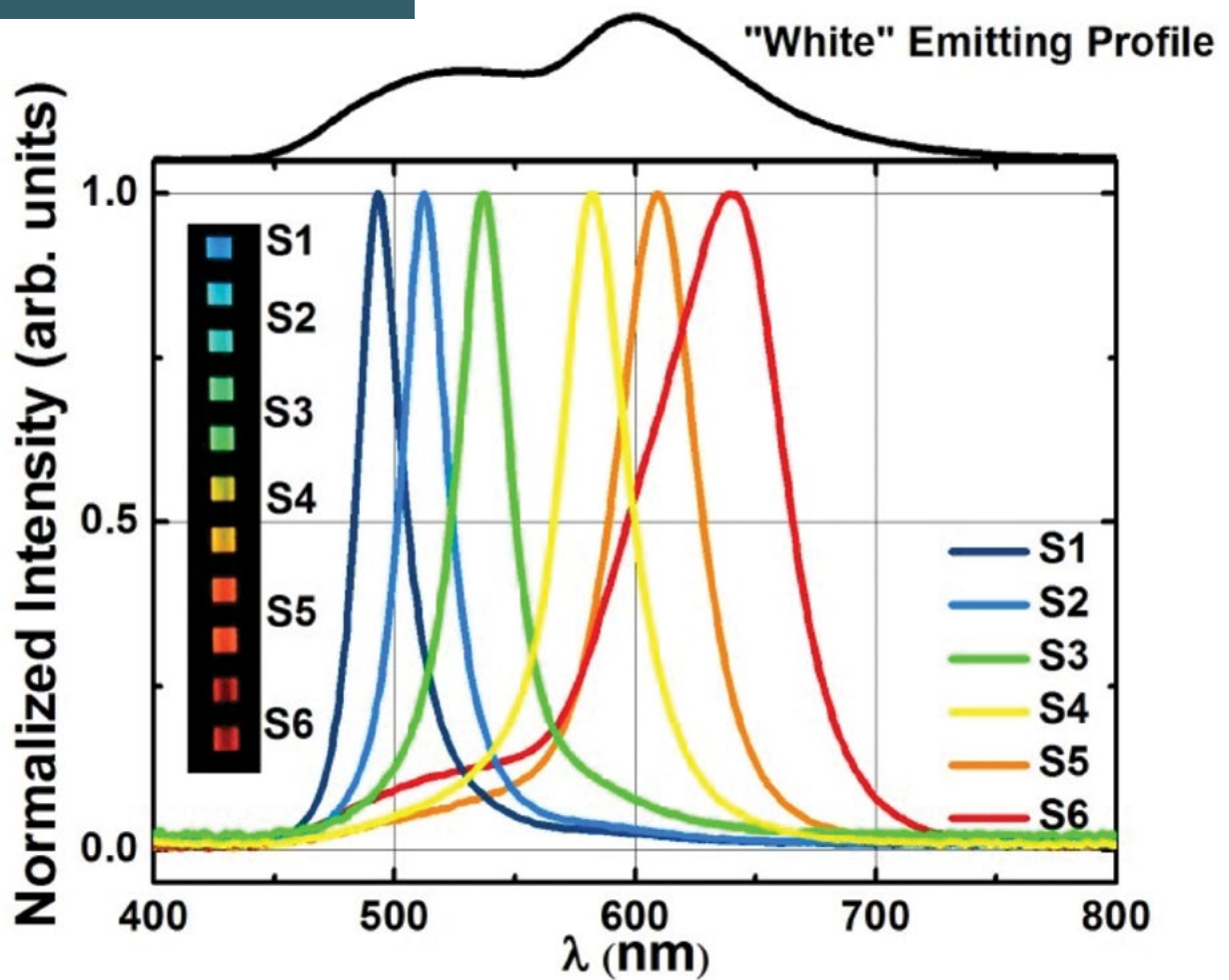


Figure 3: OLED/luminescent chemical and biological sensor Lab-on-a-CD. Note the microfluidic channels connecting the sample reservoirs and reaction chambers.

# The Existence of Black Holes—from Einstein's Equations to Orbital Dynamics

by Jake Simon

The first concept of a black hole dates back to the 18th century when John Mitchell hypothesized that the escape velocity of a sufficiently massive object may exceed the speed of light. However, it was not until nearly 200 years later and the advent of both Einstein's general theory of relativity and telescopes that could peer through the depths of the Milky Way to its center that the evidence for these elusive objects would become undeniable.

The 2020 Nobel Prize in Physics was shared between mathematician/physicist Sir Roger Penrose and astronomers Andrea Ghez and Reinhard Genzel for their part in providing such evidence. In his 1965 paper "Gravitational Collapse and Space-Time Singularities," Penrose demonstrated that a star of sufficient mass will always collapse into a black hole; the production of such objects is an inevitable and robust outcome of Einstein's general theory of relativity. This accomplishment catapulted black holes from being intellectual and mathematical curiosities to physically realistic possibilities.

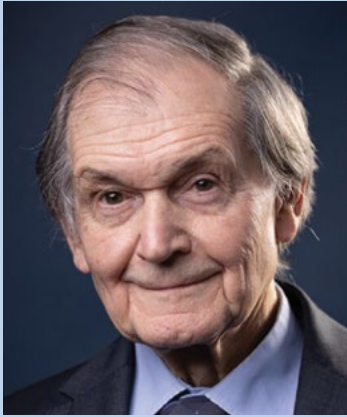
More than 30 years later, these hitherto theoretical-only objects would gain substantial observational support. In particular, in 1996, Professor Reinhard Genzel and his group published a *Nature* letter detailing infrared observations of stars near the galactic center acquired with the New Technology Telescope (NTT) of the European Southern Observatory in Chile. Their analyses focused on both the proper (i.e., in the plane of the sky) and radial (i.e. along the line of sight) motions of these stars and demonstrated that these velocities were very high. From this and

subsequent follow-up work, they were able to infer that these stars must be orbiting something very massive located within 0.015 parsecs (i.e., approximately 3,000 times the distance from the Earth to the Sun) of a compact radio source Sgr A\*.

Around the same time, Professor Andrea Ghez and her group were making observations with the Keck Observatory on Mauna Kea. As with Genzel's observations, they found that the stars' motions were very large; the highest velocity star was moving at 1,400 km/s, which is 0.5% the speed of light! Eleven other such stars had velocities of more than 500 km/s. When they fit a power law to the velocity dispersion of these stars as a function of distance from their orbital center, they found a behavior strikingly indicative of Keplerian type orbits. That is, these stars were orbiting a centralized mass, which they calculated to be larger than a million Suns (a number consistent with that of Genzel's calculations).

Both groups had found the same thing: stars near the galactic center were zipping around an extremely large mass confined to a very small region of space. While a few other hypotheses were considered for what such a mass could be, the best candidate was a supermassive black hole—a black hole with the mass of more than a million Suns squeezed into a diameter of only four times the size of the Sun! Nothing else fit the data as well (nor could there be any easy way to explain so much mass in such a small volume), and, in fact, the radio emission from Sgr A\* was consistent with such a massive black hole accreting large amounts of gas from the surrounding environment.

Thus, from an inevitable outcome of Einstein's equations to the only feasible explanation for the substantial stellar velocities at the galactic center, black holes appear to be real, if not awe-inspiring, astronomical objects. The 2020 Nobel Prize in Physics deservedly goes to those scientists who solidified their existence in our knowledge base of the Universe.



Sir Roger Penrose

© Nobel Prize Outreach | Photo: Fergus Kennedy



Professor Reinhard Genzel

© Nobel Prize Outreach | Photo: Bernhard Ludewig



Professor Andrea Ghez

© Nobel Prize Outreach | Photo: Anette Buhl



The 2020 Nobel Prize in Physics was awarded for the discovery that black hole formation is a robust prediction of the general theory of relativity and for the discovery of a supermassive compact object at the center of our galaxy.

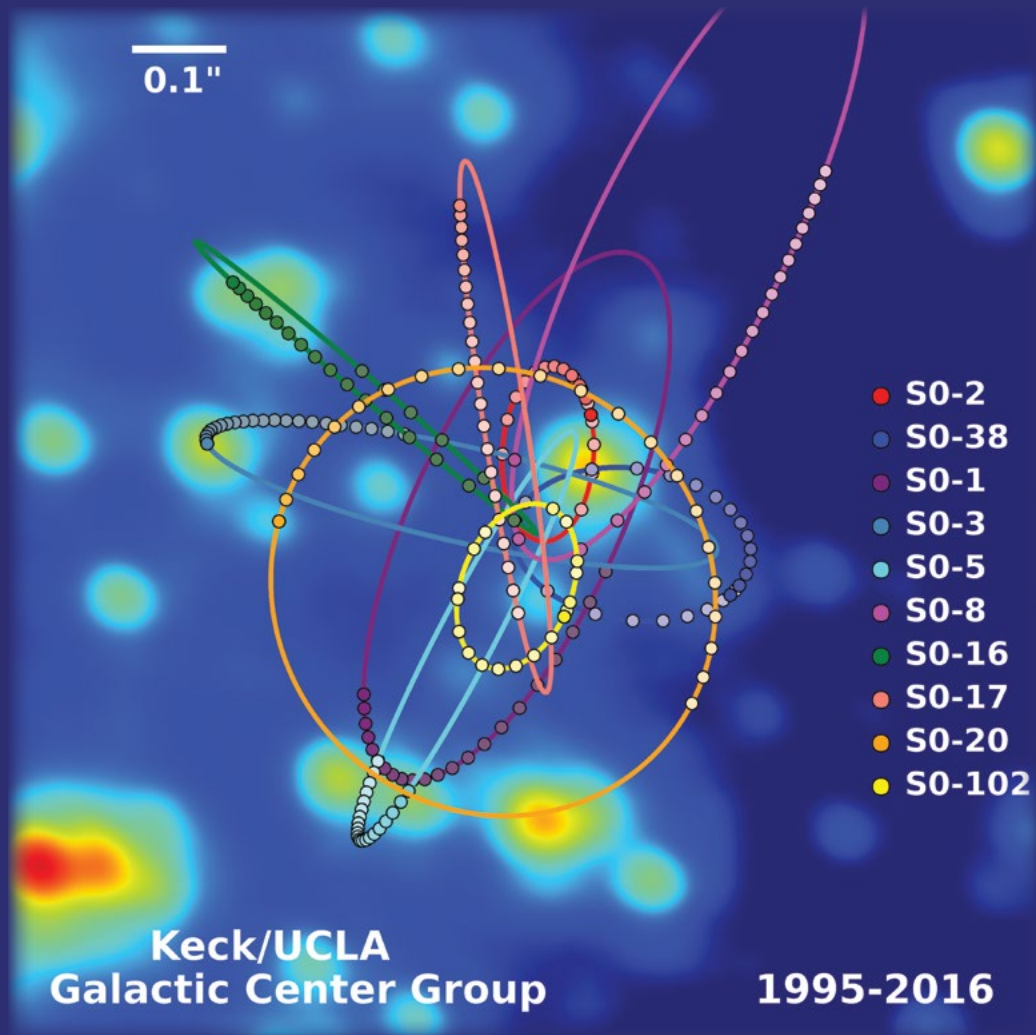


Figure 1: Yearly location of stars within 0.2 parsecs from Sagittarius A\* orbiting the common, compact radio source (A. Ghez).

# New Course in Quantum Theory of Many Body Systems *by Srimoyee Sen*

Quantum field theory plays a major role not only in describing fundamental particles in high energy physics, but also in describing many body systems in nuclear and condensed-matter physics. There are many celebrated cross-cutting ideas in quantum field theory that have impacted several different subfields of physics. Examples of such crosscutting ideas include superconductivity and Higgs mechanism, superfluidity in neutron stars and Helium superfluid, 't Hooft and Adler-Bell-Jackiw anomalies, and the physics of topological phases among others.

Recent advances in various topological quantum phases of matter have led to tremendous progress in our understanding of the structure of quantum field theory itself. For example, the notion of Landau paradigm in symmetry breaking phase transitions has been expanded to include generalized global symmetries and their anomalies. Similarly, there has been significant progress in topological quantum field theories and discrete anomalies.

Considering the success of quantum field theory in describing the natural world at various energy scales, a many body quantum field theory course is essential to the growth of any student pursuing research in many body physics. The Department of Physics and Astronomy at Iowa State thus introduced a new course in the spring of 2021 titled "Quantum Theory of Condensed Matter." This course was aimed at graduate and advanced undergraduate students at Iowa State and was offered virtually. The goal of this course was to demonstrate to the students how concepts in quantum field theory apply to many body physics. The students were encouraged to actively participate in the discussions and presented talks on several topics of current interest as part of their final evaluation. These topics included Floquet topological insulators, quantum Hall effect, Landau Fermi liquid theory, Kondo physics, and finite temperature field theory.

Although this course will not be offered in the spring of 2022, the department will offer this course in subsequent years since such a course is vital toward the development of students in theoretical physics as well as experimental physics.

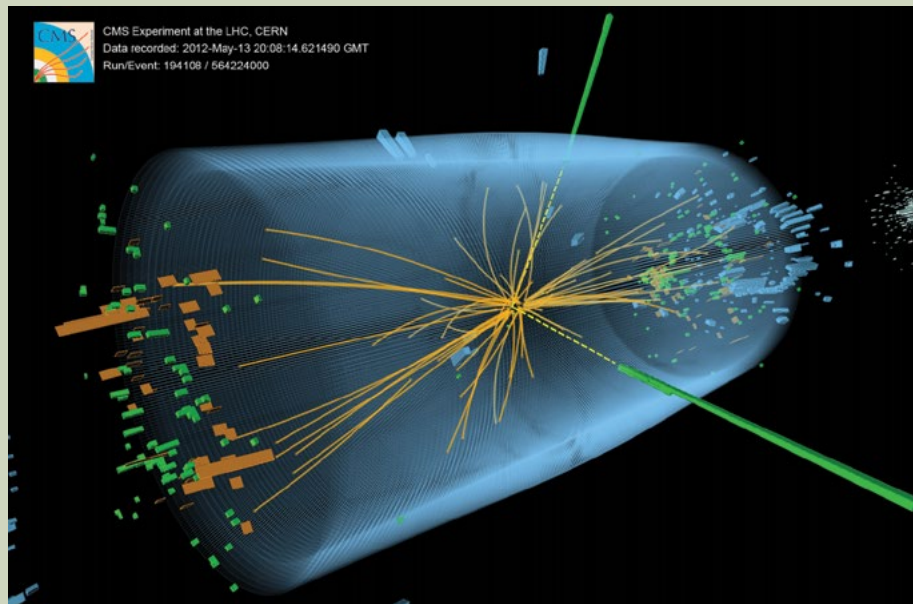
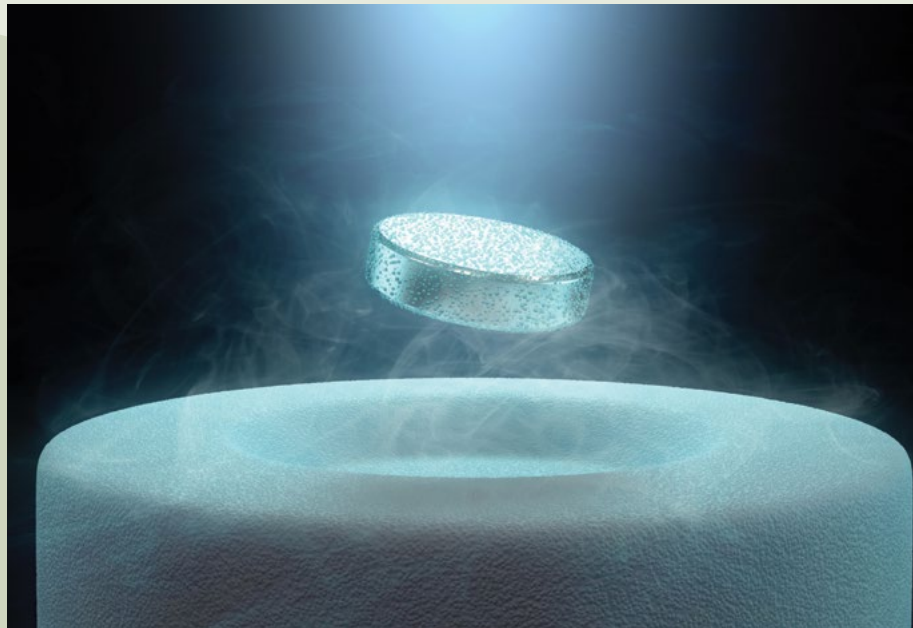


Figure 1: An example of critical superconductivity with vortices controlling the current carrying ability of the superconductor.

Figure 2: 3D view of an event recorded with the CMS detector in 2012 at a proton-proton centre of mass energy of 8 TeV. The event shows characteristics expected from the decay of the SM Higgs boson to a pair of photons (dashed yellow lines and green towers).

Picture credit: <https://www.flickr.com/photos/argonne/15693117819>, [https://commons.wikimedia.org/wiki/File:3D\\_view\\_of\\_an\\_event\\_recorded\\_with\\_the\\_CMS\\_detector\\_in\\_2012\\_at\\_a\\_proton-proton\\_centre\\_of\\_mass\\_energy\\_of\\_8\\_TeV.png](https://commons.wikimedia.org/wiki/File:3D_view_of_an_event_recorded_with_the_CMS_detector_in_2012_at_a_proton-proton_centre_of_mass_energy_of_8_TeV.png)

# Physics in a Box: Teaching Labs Online during the Pandemic

by Paula Herrera-Syklody

I used to say that the words “laboratory” and “online” should rarely coexist in the same sentence. If the transition to remote teaching was challenging for everyone, the labs were in a category of their own. As lab coordinator for most of our introductory physics courses, in spring 2020 a part of me was just scrambling to complete the semester, but I found myself having quite a bit of fun in my basement concocting real, meaningful experiments using common household items. So that semester, our students explored Bernoulli’s principle with empty shampoo bottles; used an online spectrum analyzer to study the normal modes of a string in my son’s guitar; and measured the moment of inertia of an object rolling down an incline—and what object could be more historically appropriate than a roll of toilet paper?

The next step, as we prepared for the summer and fall, was to get all students to have the same equipment. The material had to fit in a relatively small box, be available for immediate purchase in large quantities, and respect tight budgets. I adjusted the initial experiments and created new ones based on more specialized but inexpensive material, like small pulleys and springs. Strong magnetic hooks and a fridge door could replace lab stands. Some items did not need to be shipped: coins are excellent substitutes for calibrated weights.

The resulting lab kit had to be assembled and mailed to 1,000–1,500 students, including destinations throughout the globe. Theresa McLeod and Kecia Place-Fencel, our teaching lab support team, ran the operation with clockwork precision.

The kit has been successfully used for three semesters in several courses. Our students have not been analyzing fake data after watching a recorded experiment or an unrealistic animation. They have been setting up experiments and gathering their own data. We are obviously eager to teach labs in person again, but we are proud to have provided real laboratories that could be taught online. And I learned that it is possible to put those two words in the same sentence.



# Departmental Awards 2021

## **OUTSTANDING GRADUATE STUDENT RESEARCH AWARD**

The Outstanding Graduate Student Research Award is presented to graduate students with outstanding promise as professional physicists/astronomers. The award is based on quality and productivity of research as evidenced by progress, creativity, and effort toward a thesis and/or publication. This year's recipient is Zhaoyu Liu.



## **OUTSTANDING GRADUATE STUDENT COMMUNICATION AWARD**

The Outstanding Graduate Student Communication Award is presented to graduate students to recognize excellence in reporting and communicating physics and astronomy or to recognize efforts to improve the general public appreciation of science. This year's recipient is Ana-Marija Nedic.



### **MOST VALUABLE GRADUATE INSTRUCTOR AWARD**

The Most Valuable Graduate Instructor Award was presented to Rebecca Flint by Devi Vijayan Ambika on behalf of the graduate student association.



### **MOST VALUABLE UNDERGRADUATE INSTRUCTOR AWARD**

The Most Valuable Undergraduate Instructor Award was presented to Peter Orth by Emily Pottebaum on behalf of the Physics and Astronomy Club.

## **DEAN'S LIST**

- Emmit Tyler Benitez
- Benjamin G. Burdick
- Daniel Patrick Buser
- Alexander Thomas Clarke
- Andrew Scott Clarke
- Dalton L. Hauschen
- Andrii Hopanchuk
- William B. Huynh
- John Steven Lawless
- Brent Mitchel Martin
- John Mobley
- Carsyn Lee Mueller
- George Shaker Nassif
- Matthew Elton Neller
- Wyatt S. Peterson
- Matthew T. Pham
- Emily G. Pottebaum
- Samuel Scott Roberts
- Till S. Schaeffeler
- John Louis Schmidt IV
- Patrick James Stanley
- Sadie G. Welter
- Ruifeng Zhang

## **New Physics Graduate Student Organization**

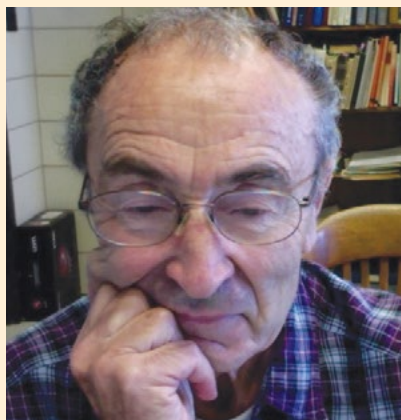
*by Miranda Elkins*

The Physics Graduate Student Organization (PGSO) is a new student-run organization in the Department of Physics and Astronomy. The group was recognized by the Student Activities Center (SAC) and Iowa State University in the fall of the 2020 school year. Several graduate students within the department wanted to create a space where others can gather to discuss ideas for how the qualification exam classes are taught, form study groups, and practice giving talks on their research. The hope is the group can be a place where students can voice their opinions and the elected officials can be a bridge for communication between faculty, staff, and students. In the future there is a possibility for the PGSO to host social events and invite speakers selected by the students themselves with funding provided by the university.

Due to the 2020–2021 school year being so abnormal, it has been difficult to hold regular meetings. The plan is for meetings to start in the fall of the 2021–2022 school year. The first meeting is expected to be during the first few weeks of the semester. This meeting will be dedicated to discussing what kind of activities the organization should attempt to host, drafting a budget, and filling open positions for the upcoming year. The current president of the PGSO is Miranda Elkins, and Jon Runchey is the vice president. Other filled positions include the treasurer and the GPSS representative, which are held by John Wilde and Elizabeth Krenkel, respectively. Many other positions are still open and several of the students listed will need to transfer their duties soon due to their graduation dates approaching. If anyone is interested in taking a role in the PGSO, please contact Miranda or Jon. More information about the PGSO can be found on the SAC organization database. We hope to see everyone at the first meeting next fall!

# Anisotropic Superconductors by Vladimir Kogan

Anisotropy of superconductors must be taken into account in particular considering their behavior in the magnetic field. Still, in the first decade after formulating the theory of superconductivity, most theorists focused on the isotropic case. The ice was broken by Lev Gor'kov, who developed the model of anisotropic superconductors near the critical temperature  $T_c$ , which unfortunately could not be used at low temperatures. By putting aside many important aspects of the theory, I turned to so-called London equations, which describe the basic Meissner effect at all temperatures and generalized them to anisotropic case.



Simplicity of the approach notwithstanding, it proved to become an important tool in studies of anisotropic superconductors in magnetic fields.

Superconductors differ from normal metals in their behavior in a magnetic field. Some (so-called type-I) expel the magnetic field from their interior (the Meissner effect), but the majority (called type-II) allow the field to penetrate in the form of "vortex lines" each one

containing the universal quantum of magnetic flux  $\phi_0 = \pi h e / c$  ( $h$  is the Plank constant,  $e$  is the electron charge, and  $c$  is the speed of light). The field inside such a vortex is directed along the line, say  $z$ , whereas the currents flow along concentric circles around the vortex center in the  $xy$  plane.

This picture holds for hypothetical isotropic materials and sufficed for understanding the behavior in the magnetic field of materials like cubic Nb. But as more and more superconducting compounds were discovered, it became clear that the isotropic theory is not enough. In 1964 Lev Gor'kov developed the theory of anisotropic superconductors near the critical temperature  $T_c$ , which unfortunately could not be used at low temperatures.

Within the microscopic theory, the superconducting phase is described by a complex order parameter that turns zero at the transition to the normal state and is suppressed by the magnetic field. This parameter, the quantum-mechanical psi-function of the superconducting current carriers (Cooper pairs),

is described by a complicated microscopic theory that takes into account coexistence of superconducting and normal phases. Within such a theory, the description of the vortex core (at the center of which the order parameter turns zero, whereas the magnetic field decays with distance from the vortex axis) is forbiddingly complex.

Out of the core, the order parameter modulus is constant, magnetic field decays exponentially, and a simpler theory can be used to describe the behavior of superconductors in an applied field. This is so-called London theory, which operates with magnetic field distributions and contains the only material parameter, the London penetration depth  $\lambda$ , related to the density of Cooper pairs. The London equations are linear, express the basic Meissner effect, and can be easily generalized to anisotropic materials. That is what I have done in a Brief Report to Physical Review in 1981. Nobody payed attention to this report till 1987 when strongly anisotropic high- $T_c$  superconductors were discovered. The anisotropic London equations turned out to describe a number of effects in these materials. In particular, they were used to understand mechanical torques acting on anisotropic samples in an applied field. Since then they have been widely used to characterize anisotropic superconductors.

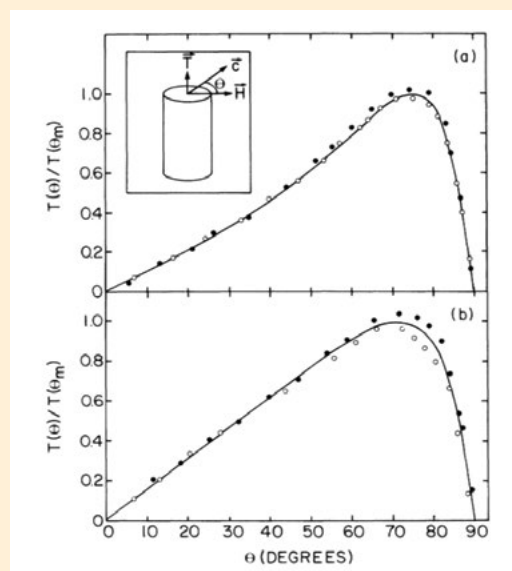


Figure 1: Normalized torque as a function of angle (defined in the inset) for sample I at  $T=84.5$  K with (a)  $H=6$  T and (b)  $H=1$  T. Open circles represent data taken with the angle increasing and closed circles with angle decreasing. Figure from "Experimental Evidence for a Transverse Magnetization of the Abrikosov Lattice in Anisotropic Superconductors," Phys. Rev. Lett, **61** (1988) 2805.

# Daniel Zaffarano Lectureship

The next Daniel Zaffarano Lectureship will be held at Iowa State University in 2022. 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 the 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/zaffarano-lectures>.

## 2022 ZAFFARANO LECTURE

Wendy L. Freedman

**TBD** (*see department website for details*)

The next Zaffarano Lecture will be given by Professor Wendy L. Freedman. She is the John & Marion Sullivan University Professor of Astronomy and Astrophysics at The University of Chicago, and she will be giving the next Zaffarano Lecture on the subject of observational cosmology. Professor Freedman is well known for her work on the Hubble constant and her tenure as director of the Carnegie Observatories in Pasadena and the Las Campanas in Chile. She is a member of the National Academy of Sciences, she received the Dannie Heineman Prize for Astrophysics, and she is a corecipient of the Gruber Cosmology Prize. Her work and leadership has resulted in great improvements to the accuracy of the cosmic distance scale, essential for constraining fundamental cosmological parameters.

## WENDY LAUREL FREEDMAN


Wendy Laurel Freedman (born July 17, 1957) is a Canadian-American astronomer, best known for her measurement of the Hubble constant and as director of the Carnegie Observatories in Pasadena, California, and Las Campanas, Chile.

She is also the John & Marion Sullivan University Professor of Astronomy and Astrophysics at The University of Chicago.

Her principal research interests are in observational cosmology, focusing on measuring both the current and past expansion rates of the universe and on characterizing the nature of dark energy.

Freedman has been elected a member of the U.S. National Academy of Sciences and the American Philosophical Society, a Fellow of the American Academy of Arts and Sciences, and a Fellow of the American Physical Society. In 2009 Freedman was one of three corecipients of the Gruber Cosmology Prize. She received the 2016 Dannie Heineman Prize for Astrophysics, awarded jointly by the American Institute of Physics and the American Astronomical Society, “for her outstanding contributions and leadership role in using optical and infrared space- and ground-based observations of Cepheid stars, together with innovative analysis techniques, to greatly improve the accuracy of the cosmic distance scale and thereby constrain fundamental cosmological parameters.”





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