University of Notre Dame

PHYSICS GRADUATE STUDIES

ASTROPHYSICS

From the detection of exoplanets orbiting other stars, to unlocking the secrets of dark matter and dark energy, Notre Dame astrophysicists are working to answer some of the most fundamental questions about how the universe operates. Our faculty have been recognized for co-discovering the acceleration of the universe's expansion (dark energy), the oldest known star in the galaxy (HE 1523-0901), and the first Earth-like planet in a star's habitable zone (Kepler-62e). They make use of the Hubble Space Telescope, participate in the Sloan Digital Sky Survey, and are partners in the Large Binocular Telescope in Arizona, the largest and most advanced telescope in the world. Research at Notre Dame includes work on a wide variety of both theoretical and observational projects, including: studies of the big bang, extra dimensions, the origin of galaxies, stellar evolution, supernova explosions, black holes, neutron stars, brown dwarfs, circumstellar disks, and many other topics. We are a world leader in the field of nuclear astrophysics, studying the processes inside stars that produced the elements that we see around us. And we are fast becoming a leader in the new field of "galactic archaeology" in which astronomers use the oldest known stars to probe conditions soon after the Big Bang. Notre Dame has also recently developed an experimental astrophysics lab to build cutting-edge instruments for telescopes that operate at visible and near infrared wavelengths. These instruments will allow for unprecedented accuracy in detecting and studying Earth-like exoplanets.

ATOMIC PHYSICS

Atomic physics at Notre Dame focuses on the study of fundamental physical laws in atomic systems. Work involves precision atomic theory and measurements that are motivated by the study of parity non-conservation, fundamental symmetries, and the determination of fundamental constants. Experimental work provides tests of atomic structure calculations in many electron systems. Stabilized diode, Ti-sapphire, and dye lasers are used for making precision measurements of transition strengths, optical frequencies, and energy splittings. Precision spectroscopy is also applied to multiple areas of interdisciplinary research, such as quantum optics, nanoparticle analysis, and the detection of DNA and cancer. Atomic theory at Notre Dame centers on quantum electrodynamics, the modern theory of the interaction of charged relativistic particles with the electromagnetic field. Present research is investigating how this theory applies to quarks in the proton.

BIOPHYSICS

Our expanding research in biophysics involves experimental and theoretical effort geared toward understanding how biology works at the molecular level. The biophysics group comprises faculty from the Physics, Chemistry and Biochemistry, and Applied Mathematics departments. We study the geometry, electronic structure, and interactions of such biological systems as DNA, proteins, bacteria, viruses, and liposomes. In order to tackle these challenges our laboratories are equipped with state-of-the-art instrumentation for laser transmission spectroscopy, photoelectron spectroscopy, and nuclear magnetic resonance. In theoretical biophysics, mathematical and computational tools are applied to bio-complexity problems, including the development of new techniques for early detection of cancer and its treatment, in collaboration with the Harper Cancer Research Institute at Notre Dame.

COMPLEX SYSTEMS

Modern network science was born at Notre Dame with the invention of scale-free (or power-law) networks and the discovery that they were ubiquitous in both natural and man-made systems. Our group continues to work in complex networks, studying the many-body behavior of physical and biological systems in which disorder and strong interactions play an important role. Examples include disordered solids, social and biological networks, population genetics and evolution, inverse problems, reliability theory, swarms and active matter, and various foundational questions in quantum many-body theory. This research is driven by three fundamental questions: (1) Universality: To what extent do microscopic laws uniquely determine macroscopic behavior? (2) Statistics: How should microscopic laws be transformed to give macroscopic ones? (3) Inversion: Can microscopic laws be determined from macroscopic observations? The work is highly interdisciplinary, involving collaborations with applied mathematicians, biologists, engineers and computer scientists, and is funded by the NSF, NIH, and DARPA.

CONDENSED MATTER PHYSICS

In our experimental condensed matter program, students and faculty fabricate nanoscale materials (such as self-assembled quantum dots and nanowires) and study them using facilities on campus and at national laboratories. New materials investigated also include wide-bandgap hetero-structures and ferromagnetic semiconductors with possible spintronic applications. Graphene, topological insulators, and other low-dimensional systems are studied for fundamental electronic properties. Scanning tunneling microscope (STM) spectroscopy and small-angle neutron scattering are used to explore the structure and dynamics of magnetic vortices in superconductors. At even smaller length scales, researchers manipulate individual atoms on surfaces using an STM to study quasicrystals and organic superconductors. The resulting artificially engineered atomic structures are used to investigate fundamental properties of quantum electronic systems. Interdisciplinary research involves collaborations with chemists, biologists, and electrical, chemical, and environmental engineers. Theorists work on topics including the interaction of superconductors with magnetic materials, superconducting mesoscopic devices, and theoretical underpinnings of electrostatic behavior in molecular dynamics simulations.

HIGH ENERGY PHYSICS

Researchers in elementary particle physics at Notre Dame play major roles in the CMS experiment at the CERN Large Hadron Collider (LHC), leading major instrumentation, computing, and analysis efforts. The goal of the LHC program is the elucidation of the fundamental laws of nature, including electroweak symmetry breaking, the generation of particle mass, CP violation, and the hierarchy problem. In 2012, the Notre Dame team played a key role in the discovery of the Higgs boson at the LHC, and is now embarking on the measurement of the coupling between the Higgs boson and the top quark, as well as major detector upgrades. Notre Dame also participates in the DUNE neutrino oscillation experiment at Fermilab and the Sanford Underground Research Facility in South Dakota, hoping to elucidate the mass hierarchy among the neutrinos and their CP-violating phases. The theoretical efforts at Notre Dame focus on physics beyond the standard model, including how signals of novel particles or phenomena would manifest at the LHC, flavor physics and CP violation, dark matter, and cosmology.

NUCLEAR PHYSICS

The Nuclear Science Laboratory at Notre Dame is the longest continuously operating nuclear accelerator lab at any U.S. university, and its program is ranked among the strongest in the nation. Our research is built around a broad program in experimental and theoretical low energy nuclear physics, including nuclear astrophysics, nuclear structure, nuclear reactions with radioactive ion beams, and accelerator mass spectroscopy. The group emphasizes the participation of students in every aspect of the research program, while the laboratory, with its three accelerators and recently installed next-generation mass separator, provides an extensive and invaluable hands-on experience. Experiments are conducted at Notre Dame and at facilities worldwide, and are complemented by a theoretical program that includes modeling efforts in nuclear structure and nucleosynthesis and the use of supercomputing to explore the physics of light nuclei. Notre Dame is a founding member of the Joint Institute for Nuclear Astrophysics, one of only ten NSF-funded Physics Frontier Centers in the nation, and continually hosts visiting researchers from around the world who come to collaborate with our group and to use our facilities.

OUTREACH

Notre Dame's Physics Department has long emphasized the vital importance of public outreach as part of the mission of scientists, and graduate students are core contributors to the department's exceptional range of outreach programs. Members of the department run camps and workshops, lead physics activities in local and regional schools, and involve high school students and teachers in research. The QuarkNet program was founded at Notre Dame and Fermilab and now involves more than 50 universities across the country and nearly 600 high school teachers who are learning physics by participating in real world experiments. The Art2Science Camp integrates reading, writing, and a variety of art forms with math and the physical sciences. Other programs introduce participants to the fundamentals of atomic nuclei and offer professional development opportunities for K-12 teachers within the context of guided inquiry. Members of the physics department also share their love of physics with the local community through a Physics Demo team led by physics graduate students. The department hosts one of the nation's largest and longest-running Research Experiences for Undergraduates programs.

MESSAGE FROM THE CHAIR

Choosing the right graduate program is one of the most significant decisions faced by a young physicist. An ideal program blends world-class facilities, renowned faculty, a wide range of research specialties, thoughtful teaching and mentoring, and continual opportunities for professional development. At the University of Notre Dame, you will find all of these, as well as a large and growing faculty and a tight-knit community of graduate students working together to push forward the front lines of modern physics research.

Our department consists of 44 tenured and tenure-track faculty, 17 research professors and more than 100 graduate students working towards their Ph.D. Our faculty includes 15 fellows of the American Physical Society and 7 American Association for the Advancement of Science (AAAS) fellows, two winners of major American Physical Society (APS) prize fellowships and a co-awardee of the 2015 Breakthrough Prize in fundamental physics. As a student at Notre Dame, you would be participating in top research programs while gaining a truly global perspective. It is no accident that U.S. News and World Report recently ranked us as the 4th strongest physics department in the world in terms of commitment to international collaboration.

One of the best reasons to consider Notre Dame is the quality of our research. Our nuclear physics program is ranked among the top in the nation, and our Nuclear Science Laboratory, with its three research accelerators, involves graduate students in every phase of the experimental process, from conception and construction to accelerator operation and data analysis. Our high-energy physics group is active in the CMS experiment on the LHC and the DUNE experiment at Fermilab, and was deeply involved in the recent discovery of the Higgs boson. Our astrophysics group has built a strong international reputation over the last two decades, making strong use of the Hubble Space Telescope, being active in the Sloan Digital Sky Survey, and being a partner in the Large Binocular Telescope. Our condensed matter, biophysics, and atomic physics groups play major roles in pushing forward our understanding of superconductivity, topological insulators, the effects of radiation on living matter, and how to make atomic clocks even more accurate. Notre Dame was also one of the founding institutions in the new field of network science, and maintains a strong reputation in that field to this day. Finally, theorists make up one third of our faculty and provide students with the opportunity to study any of these fields from a more mathematical and computational perspective.

Our Physics Department strives to be a friendly environment for all. Seven of our tenured or tenure-track faculty are women, as is 30% of our graduate population. We welcome students from all nations, all creeds, and all backgrounds, regardless of sexual orientation, gender status, or disability. I encourage you to learn more about our programs through this brochure, via our website, or by calling us at (574) 631-6386. Good luck in making this difficult decision. We hope you'll consider taking your place in our thriving research community.

Christopher Kolda

GRADUATE PROGRAM AT A GLANCE

Graduate students are an indispensable part of the Notre Dame Department of Physics, contributing to and energizing research in experimental and theoretical physics from a wide range of areas. During a typical year, approximately 100 graduate students collaborate with the 60 faculty members, and 25 post-doctoral researchers who make up the department.

All admitted students receive full tuition support and a stipend. Beginning doctoral students typically work as teaching assistants (about 15 hours per week) during the academic year. During the summer most students hold research assistantships. The majority of advanced students work as research assistants funded by external research grants. Applicants with strong academic records are automatically considered for fellowships.

The APS cites the Notre Dame Department of Physics as a female-friendly physics department with approximately 30% female graduate students.

Notre Dame offers the research opportunities of a large university coupled with the environment of a smaller, private university. The Notre Dame Department of Physics prides itself on its collaborative and supportive environment.

Tan Ahn, *Assistant Professor,* Experimental Nuclear Physics (Ph.D., Stony Brook University, 2008).

Mark Alber, *Concurrent Professor,* Mathematical and computational biophysics (Ph.D., University of Pennsylvania, 1990).

Ani Aprahamian, *Freimann Professor,* Experimental Nuclear Physics (Ph.D., Clark University, 1986).

Dinshaw Balsara, *Associate Professor,* Theoretical Astrophysics (Computational) (Ph.D., University of Illinois Urbana-Champaign, 1990).

Dan Bardayan, *Associate Professor,* Experimental Nuclear Physics (Ph.D., Yale University, 1999).

Mary Beard, *Research Assistant Professor,* Theoretical Nuclear Physics (Ph.D., University of Notre Dame, 2010).

Timothy Beers, *Notre Dame Chair in Astrophysics,* Astrophysics (Ph.D., Harvard University, 1983).

David Bennett, *Research Professor,* Observational Astrophysics (Ph.D., Stanford University, 1986).

Georg Berg, *Research Professor,* Experimental Nuclear Physics (Ph.D., University of Cologne, 1974).

Ikaros Bigi, *Professor,* Theoretical Particle Physics (Ph.D., University of Munich, 1976).

Maxime Brodeur, *Assistant Professor,* Experimental Nuclear Physics (Ph.D., University of British Columbia, 2010).

Bruce Bunker, *Professor,* Experimental Condensed Matter Physics (Ph.D., University of Washington, 1980).

Mark Caprio, *Associate Professor,* Theoretical Nuclear Physics (Ph.D., Yale University, 2003).

Daniela Corollo, *Research Assistant Professor,* Astrophysics (Ph.D., Australian National University, 2011).

Philippe Collon, *Associate Professor,* Experimental Nuclear Physics (Ph.D., Universität Wien, 1999).

Manoel Couder, *Assistant Professor,* Experimental Nuclear Physics (Ph.D., Université Catholique de Louvain, 2004).

Gregory Crawford, *Vice President and Associate Provost,* Experimental Condensed Matter Physics (Ph.D., Kent State University, 1991).

Justin R. Crepp, *Freimann Assistant Professor,* Observational Astrophysics Instrumentation (Ph.D., University of Florida, 2008).

Antonio Delgado, *Associate Professor,* Theoretical Particle Physics (Ph.D., Universidad Autonoma de Madrid, 2001).

Malgorzata Dobrowolska, *Professor,* Experimental Condensed Matter Physics (Ph.D., Polish Academy of Science, 1980).

Morten Eskildsen, *Professor,* Experimental Condensed Matter Physics (Ph.D., University of Copenhagen, 1998).

Stefan Frauendorf, *Professor,* Theoretical Nuclear Physics (Ph.D., Technical University of Dresden, 1971).

Jacek Furdyna, *Marquez Professor,* Experimental Condensed Matter Physics (Ph.D., Northwestern University, 1960).

Umesh Garg, *Professor,* Experimental Nuclear Physics (Ph.D., Stony Brook University, 1978).

Peter Garnavich, *Professor,* Observational Astrophysics/Cosmology (Ph.D., University of Washington, 1991).

Kenjiro K. Gomes, *Freimann Assistant Professor,* Experimental Condensed Matter Physics (Ph.D., University of Illinois Urbana-Champaign, 2008).

Joachim Görres, *Research Professor,* Experimental Nuclear Physics (Ph.D., University of Munster, 1983).

Michael Hildreth, *Professor,* Experimental Particle Physics (Ph.D., Stanford University, 1995).

J. Christopher Howk, *Associate Professor,* Observational Astrophysics (Ph.D., University of Wisconsin, 1999).

Anthony Hyder, *Professor,* Experimental Nuclear Physics (Ph.D., Air Force Institute Technology, 1971).

Boldizsár Jankó, *Professor,* Theoretical Condensed Matter Physics (Ph.D., Cornell University, 1996).

Colin Jessop, *Professor,* Experimental Particle Physics (Ph.D., Harvard University, 1993).

Dan Karmgard, *Research Assistant Professor,* Experimental Particle Physics (Ph.D., Florida State University, 1999).

Christopher Kolda, *Department Chair, Professor,* Theoretical Particle Physics (Ph.D., University of Michigan, 1995).

Kevin Lannon, *Associate Professor,* Experimental Particle Physics (Ph.D., University of Illinois Urbana-Champaign, 2003).

Nicolas Lehner, *Research Associate Professor,* Observational Astrophysics (Ph.D., Queens University of Belfast, 2000).

Xinyu Liu, *Research Associate Professor,* Experimental Condensed Matter Physics (Ph.D., University of Notre Dame, 2003).

John LoSecco, *Professor,* Experimental Particle Physics (Ph.D., Harvard University, 1976).

Nancy Marinelli, *Research Associate Professor,* Experimental Particle Physics (Ph.D., University of Bari, 1997).

Adam Martin, *Assistant Professor,* Theoretical Particle Physics (Ph.D., Boston University, 2007).

Grant Mathews, *Professor,* Theoretical Astrophysics / Cosmology (Ph.D., University of Maryland, 1977).

Kathie Newman, *Professor,* Theoretical Condensed Matter Physics (Ph.D., University of Washington, 1981).

Jeffrey Peng, *Concurrent Associate Professor,* Experimental Biophysics (Ph.D., University of Michigan, 1993).

Lara Arielle Phillips, *Research Assistant Professor,* Theoretical Astrophysics/Cosmology (Ph.D., Princeton University, 2003).

Vinicius Placco, *Research Assistant Professor,* Astrophysics, (Ph.D., University of Sao Paulo, 2010).

Sylwia Ptasinska, *Marquez Assistant Professor,* Experimental Biophysics/Chemical Physics (Ph.D., University of Innsbruck, 2004).

Terrence Rettig, *Professor,* Observational Astrophysics (Ph.D., Indiana University, 1976).

Daniel Robertson, *Research Assistant Professor,* Experimental Nuclear Physics (Ph.D., University of Notre Dame, 2010).

Randal Ruchti, *Professor,* Experimental Particle Physics (Ph.D., Michigan State University, 1973).

Jonathan Sapirstein, *Professor,* Theoretical Atomic Physics (Ph.D., Stanford University, 1979).

Anna Simon, *Assistant Professor,* Experimental Nuclear Physics (Ph.D., Jagellonian University, 2010).

In-Saeng Suh, *Concurrent Research Associate Professor,* Theoretical Astrophysics (Computational) (Ph.D., Hanyang University, 1997).

Rebecca Surman, *Associate Professor,* Theoretical Nuclear Physics (Ph.D., University of North Carolina at Chapel Hill, 1998).

Wanpeng Tan, *Research Associate Professor,* Experimental Nuclear Physics (Ph.D., Michigan State University, 2002).

Carol Tanner, *Professor,* Experimental Atomic Physics (Ph.D., University of California Berkeley, 1985).

Zoltán Toroczkai, *Professor,* Theoretical Condensed Matter Physics (Ph.D., Virginia Polytechnic Institute, 1997).

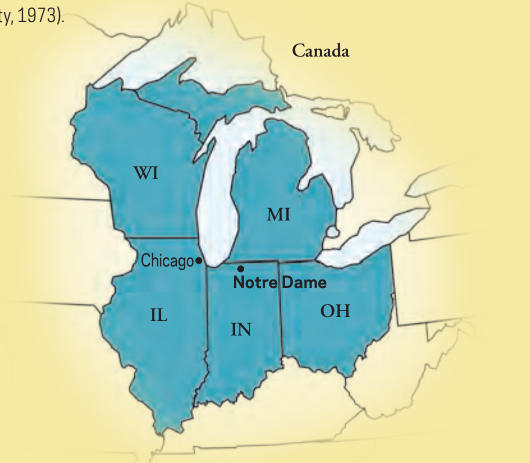
Dervis Can Vural, *Assistant Professor,* Theoretical Condensed Matter Physics (Ph.D., University of Illinois Urbana-Champaign, 2011).

Mitchell Wayne, *Professor,* Experimental Particle Physics (Ph.D., University of California, Los Angeles, 1985).

Michael Wiescher, *Freimann Professor,* Experimental Nuclear Physics (Ph.D., University of Munster, 1980).

ABOUT THE UNIVERSITY OF NOTRE DAME

The University of Notre Dame is located in northern Indiana, adjacent to the city of South Bend and approximately 90 miles east of downtown Chicago. The university has 1000 faculty members, 8400 undergraduate students, 1900 graduate students and 1500 professional students (Law, M.Div., Business, M.Ed.). Notre Dame is an independent, coeducational Catholic research university, founded in 1842. It is rated among the nation's top 25 institutions of higher learning in surveys conducted by U.S. News and World Report, Princeton Review, Time, Kiplinger's, Kaplan/Newsweek, and others.



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