RESEARCH FOCUS:

QUANTUM SCIENCE AND ENGINEERING

DIVISION FOR RESEARCH
UNIVERSITY AT ALBANY
State University of New York

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A MESSAGE FROM THE DIVISION OF RESEARCH

The University at Albany (UAlbany) is a comprehensive Research 1 (R1) institution under the Carnegie Classification and one of four research-focused "University Centers" in the State University of New York system. UAlbany is well-known across the country and the world for its cutting-edge research programs. We offer a wide range of student-centered academic and research experiences as well as opportunities for research collaborations and industry partnerships. Our students, faculty and staff have a long history of service to New York's Capital Region and, as such, the University was recently recognized by the Carnegie Foundation's Community Engagement Classification.

This publication offers a glimpse of UAlbany's substantial expertise in Quantum Science and Engineering. Quantum theory describes the nature and behavior of very small systems. The emergent quantum computing and communication paradigm, based on the principles of quantum science, promises phenomenally fast and secure computational tools for scientific research, industry and financial applications, and national defense. Our quantum strengths reside in the departments of physics, mathematics, chemistry, engineering, and atmospheric and environmental sciences. Research projects in this field are supported by grants from the National Science Foundation, the Department of Energy, and private foundations. We hope that you will be inspired by the many opportunities available to our students and research partners.

JAMES A. DIAS, PH.D.
VICE PRESIDENT FOR RESEARCH

SATYENDRA KUMAR, PH.D.
ASSOCIATE VICE PRESIDENT
FOR RESEARCH

Professor Ariel Caticha is looking at the connection between physics, information and applications of quantum theory. His research group is developing a framework for entropic inference that can address questions about the nature of information and how it is processed. That includes exploring how the laws of physics might reflect the rules for processing information about nature.

ARIEL CATICHA

PROFESSOR
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EXPERTISE

Information and entropic physics, foundations of physics: quantum mechanics, statistical mechanics, general relativity

ACHIEVEMENTS

The entropic dynamics approach to deriving and/or reconstructing quantum theory from entropic and informational principles has been successfully applied to: the quantum measurement problem, momentum and uncertainty relations, the Bohmian limit, the classical limit, extensions to curved spaces, relativistic fields in curved space-time, and the spin of single and entangled particles.

PUBLICATIONS

- *Quantum measurement and weak values in entropic quantum dynamics*, K. Vanslette and A. Caticha, in Bayesian Inference and Maximum Entropy Methods in Science and Engineering, edited by G. Verdoolaege, AIP Conf. Proc. **1853**, 090003 (2017).
- *Entropic Dynamics: Reconstructing Quantum Field Theory in Curved Spacetime*, S. Ipek, M. Abedi and A. Caticha, Class. Quantum Grav. **36**, 205013 (2019).
- *The Entropic Dynamics approach to Quantum Mechanics*, A. Caticha, Entropy **21**, 943 (2019).

Human activity generates harmful atmospheric nanoparticles with serious implications for health and morbidity. Quantum chemistry provides an opportunity to understand the physiochemical mechanisms that underlie nanoparticle formation. That knowledge, says Professor Fangqun Yu, can help scientists develop new technologies to reduce nanoparticle emissions and improve climate change projections.

FANGQUN YU

SENIOR RESEARCH ASSOCIATE
ATMOSPHERIC SCIENCES
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EXPERTISE

Quantum chemistry, density functional theory, multicomponent molecular clusters, clustering thermochemistry

ACHIEVEMENTS

- Obtained new thermochemical data for hundreds of binary and ternary clusters (both neutral and charged) through quantum-chemistry studies
- Achieved novel molecular-scale understanding of nanoparticle formation in the atmosphere
- Developed robust new nucleation theories constrained by quantum-chemistry data

PUBLICATIONS

- *H_2SO_4-H_2O-NH_3 ternary ion-mediated nucleation (TIMN): Kinetic-based model and comparison with CLOUD measurements*, Fangqun Yu, Alexey B. Nadykto, Jason Herb, Gan Luo, Kirill M. Nazarenko and Lyudmila A. Uvarova, Atmos. Chem. Phys. **18** 17451 (2018).
- *Clustering of sulfuric acid, bisulfate ion and organonitrate $C_{10}H_{15}O_{10}N$: Thermodynamics and atmospheric implications*, Jason Herb, Alexey B. Nadykto, Kirill M. Nazarenko, Nikolai A. Korobov and Fangqun Yu, Computational and Theoretical Chemistry **1133** 40 (2018).
- *Towards understanding the sign preference in binary atmospheric nucleation*, Alexey B. Nadykto, Fangqun Yu and Jason Herb, Physical Chemistry Chemical Physics **10** 7073 (2008).

Harnessing the fundamental properties of matter and their interaction with light is essential for future technological advances. Professor Herbert Fotso's research uses a combination of theoretical and computational methods to study the physics of this question as it relates to novel materials and quantum information science.

HERBERT FOTSO

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EXPERTISE

Theoretical and computational studies of nonequilibrium quantum systems, quantum information processing platforms, quantum optics, quantum control, strongly correlated systems, ultracold atomic gases, quantum metrology

ACHIEVEMENTS

- Control protocols for photon-mediated quantum information processing operations
- Characterization of field-driven correlated quantum systems
- Numerical solutions of the Hubbard model in 2D using 2-particle level diagrammatic methods

PUBLICATIONS

- *Pulse-Enhanced Two-Photon Interference with Solid State Quantum Emitters*, Herbert F Fotso, Phys. Rev. B **100**, 094309 (2019).
- *Controlling the Emission and Absorption Spectrum of a Quantum Emitter in a Dynamic Environment*, Herbert F Fotso, J. Phys. B **52**, 2 (2019).
- *Suppressing Spectral Diffusion of the Emitted Photons with Optical Pulses*, Herbert F Fotso, A. E. Feiguin, D. D. Awschalom and V. V. Dobrovitski, Phys. Rev. Lett. **116**, 033603 (2016).

Combinatorics is a field of mathematics that studies discrete structures arising as arrangements of objects according to specified rules. Professor Cristian Lenart was drawn to combinatorial problems as a young student and appreciated the ingenuity they required. Combinatorial objects are used to encode complex structures in geometry, algebra, physics and computer science. He has been using them in the representation theory of quantum groups and statistical physics.

CRISTIAN LENART

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EXPERTISE

Quantum groups, representation theory, combinatorics, crystals, vertex models, energy function, alcove model, SAGE computer algebra system

ACHIEVEMENTS

Professor Lenart and his collaborators have developed a combinatorial model for representations of quantum groups, called the alcove model. This has applications to efficient computations, such as the energy function in the vertex models of statistical physics. The alcove model was implemented in the open-source computer algebra system SAGE, and it has been used by several researchers.

PUBLICATIONS

- *A uniform realization of the combinatorial R-matrix for column shape Kirillov-Reshetikhin crystals*, C. Lenart and A. Lubovsky, Adv. Math. **334** 151 (2018).
- *A uniform model for Kirillov-Reshetikhin crystals II: Alcove model, path model, and P = X*, C. Lenart, S. Naito, D. Sagaki, A. Schilling, and M. Shimozono, Int. Math. Res. Not. **14** 4259 (2017).
- *A combinatorial model for crystals of Kac-Moody algebras*, C. Lenart and A. Postnikov, Trans. Amer. Math. Soc. **360** 4349 (2008).

One of Professor Daniel Robbins' research goal is to understand the "space of consistent quantum theories." By studying the structures that arise in quantum field theory and string theory, he hopes to find connections among them and to other areas of physics and mathematics. Identification of structures that lead to inconsistencies may reveal why the laws of physics take the form they do.

DANIEL ROBBINS

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EXPERTISE

Quantum field theory, supersymmetry, quantum gravity

ACHIEVEMENTS

- With his graduate student, Thomas Vandermeulen, Professor Robbin constructed a procedure to extract correlation functions from a large class of quantum field theories (orbifold conformal field theories)
- With collaborators at Texas A&M University, he wrote the first description of the simplest supergravity theory for which the supersymmetry is manifest even for off-shell quantities
- Studied the interplay between topological defects in two-dimensional field theories and global symmetries and their anomalies

PUBLICATIONS

- *Eleven-dimensional supergravity in 4D, N=1 superspace*, K. Becker, M. Becker, D. Butter, S. Guha, W. Linch and D. Robbins, JHEP **1711** 199 (2017).
- *Conformal interfaces between free boson orbifold theories*, M. Becker, Y. Cabrera and D. Robbins, JHEP **1709** 148 (2017).
- *A landscape of field theories*, T. Maxfield, D. Robbins and S. Sethi, JHEP **1611** 162 (2016).

According to Professor Kevin Knuth, quantum mechanics isn't mysterious; it's a specific application of inference to quantum systems. Critical aspects of quantum mechanics, relativity, and particle properties appear to be derivable by considering an embedded agent that consistently quantifies observations and makes consistent inferences about them.

KEVIN H. KNUTH

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EXPERTISE

Quantum foundations, quantum information, quantum walks, relativistic quantum mechanics

ACHIEVEMENTS

- Derivation of the Feynman rules from fundamental symmetries
- Derivations of quantum mechanics and probability theory, highlighting their mutual relationship
- Developed influence theory, which results in both a theory of 1+1 spacetime and the relativistic quantum mechanics (Dirac equation)
- Developed a statistical mechanical description of quantum Zitterbewegung

PUBLICATIONS

- *An introduction to influence theory: Kinematics and dynamics*, K.H. Knuth and J.L. Walsh, Annalen der Physik **531** 1700370 (2018).
- *The symmetrical foundation of measure, probability and quantum theories*, J. Skilling and K.H. Knuth, Annalen der Physik **531** 1800057 (2018).
- *Understanding the electron*, K.H. Knuth, in: Information and Interaction: Eddington, Wheeler, and the Limits of Knowledge, edited by I. T. Durham and D. Rickles. Springer Frontiers Collection, Springer-Verlag, Heidelberg, pp. 181-207 (2017).

Molecular orbital theory describes the electronic structure of molecules using quantum mechanics. Professor Lawrence Snyder works on finding molecular orbital states at the Fermi level of graphene, believed to be the thinnest and strongest material on earth. Graphene exhibits quantum properties and has a wide range of proposed applications in electronics, energy, medicine and industrial processes.

LAWRENCE SNYDER

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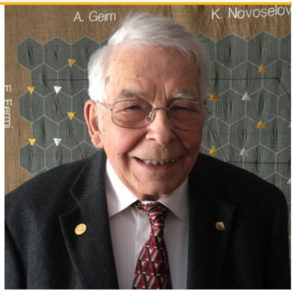

EXPERTISE

Theoretical chemistry, molecular orbital theory applied to solid state systems (e.g., graphene, boron nitride)

ACHIEVEMENTS

- Elucidation of molecular orbital states at the Fermi level of graphene, boron nitride and multilayer systems of these compounds, as executed in doctoral thesis of Christopher Wells
- Studies of the electronic structure of molecules
- Determination of molecular geometry from nuclear magnetic resonance spectra in nematic solvents

PUBLICATIONS

- *Band Gap Estimation Method for Commensurate Graphene/Hexagonal Boron Nitride Multilayered Systems*, Lawrence C. Snyder and Christopher Wells, New York Section of the American Physical Society, Albany, New York (April 8, 2011).
- *Graphene K and K' States at the Dirac Point*, Lawrence C. Snyder and Christopher Wells, American Physical Society, Dallas, Texas (March 21, 2011).
- *Graphene Quilt*, Lawrence C. Snyder, Christopher Wells and Shirley Livingston, Mid-Atlantic Quilt Festival XXII, Hampton, Virginia (February 24, 2011).

Professor Oleg Lunin explores connections between gravity, quantum field theory and string theory. He is especially interested in quantum properties of black holes and in dynamics of strongly coupled gauge theories and integrable string theories. Black holes serve as great laboratories for exploring quantum gravity, while integrable models improve our analytical understanding of the strong interaction.

OLEG LUNIN

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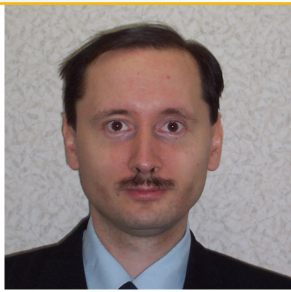

EXPERTISE

String theory, quantum field theory, supergravity

ACHIEVEMENTS

Professor Lunin's group made major contributions to several areas of research:

- Quantum theory of black holes and their excitations
- Gauge/gravity duality
- Quantum field theory at strong coupling
- Integrability in classical and quantum systems

PUBLICATIONS

- *Excitations of the Myers-Perry Black Holes*, O. Lunin, JHEP **1910** 030 (2019).
- *Scalar fields on λ-deformed cosets*, O. Lunin and W. Tian, Nucl. Phys. **B938** 671 (2019).
- *Maxwell's equations in the Myers-Perry geometry*, O. Lunin, JHEP **1712** 138 (2017).

Spinors describe the “spin” of subatomic particles, which produce observable fields. One of Professor Akira Inomata’s early collaborations looked at spinor fields in general relativity. His spinor model proposed a solution to the non-linear Heisenberg equation. The so-called Inomata-McKinley spinors have recently been applied to quantum field theory research.

AKIRA INOMATA

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EXPERTISE

Path integral, supersymmetric quantum mechanics, quantum dots, qubits

ACHIEVEMENTS

- Using Feynman's disentanglement method, calculated the spin-flip probabilities in a quantum dot and proposed a scheme to provide qubits to quantum computation
- Developed various techniques for improving Feynman's path and clarified close relations of path integration to dynamical groups and Lie algebras
- For supersymmetric quantum mechanics, derived a semiclassical formula for the case of broken supersymmetry
- Formulated a geometric theory of neutrinos within the Rainich-Misner-Wheeler scheme

PUBLICATIONS

- *Path integral and spectral representations for supersymmetric Dirac-Hamiltonians*, G. Junker and A. Inomata, J. Math. Phys. **59**, 052301 (2018).
- *Geometric spin manipulation in semiconductor quantum dots*, S. Prabhakar, R. Melnik and A. Inomata Appl. Phys. Lett. **104**, 142411 (2014).
- *Path integration in the field of a topological defect: the case of dispiration*, A. Inomata, G. Junker and J. Raynolds, J. Phys. A **45**, 075301 (2012).

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