

The Smalley-Curl Institute and the Kavli Foundation present

Sensing the Future: Workshop on Quantum Sensing

December 9 & 10, 2019

Rice University

Houston, TX







Program

The workshop will take place at the <u>Bioscience Research Collaborative</u> building (all talks will be in the Main Auditorium; lunch will be held in the Event Space)

Day 1 (Monday December 9)

| 8:00 AM | Breakfast and Check-in | Outside Main Auditorium | | |
|--|---|---|--|--|
| 8:45 AM | Welcome and Opening Remarks Alberto Pimpinelli, Executive Director, Smalley-Curl Institute and Bob Curl, Professor Emeritus, Chemistry, Rice University | | | |
| Session 1: Atoms as Sensors | | | | |
| Session Chair: Randall Hulet, Professor, Physics & Astronomy Rice University | | | | |
| 9:00 AM | Holger Müller, Associate Professor, University of California at Berkeley | "Using atom interferometry to probe fundamental physics" | | |
| 9:45 AM | Jim Shaffer , Senior Fellow, Quantum Valley Ideas Lab | "Rydberg Atom-based Electromagnetic Field Sensing and Detection" | | |
| 10:30 AM | Break | | | |
| 10:45 AM | Fredrik Fatemi , Branch Chief for Quantum Sciences, Army Research Laboratory | "Quantum Information and Sensing at the Army Research Laboratory" | | |
| 11:30 AM | Markus Oberthaler, Professor, University of Heidelberg (Germany) | "Quantum Atom Optics: Entanglement & the Ultimate Trace Analysis at the Single Atom Level" | | |
| 12:15 PM | Roundtable discussion | | | |

12:45 PM Lunch

Session 2: Materials, Color Centers

Session Chair: Gururaj Viveka Naik, Assistant Professor, Electrical & Computer Engineering Rice University

| 2:00 PM | Ron Walsworth , Professor, University of Maryland; Senior Physicist, Smithsonian Institution | "Quantum Diamond Sensors" |
|---------|---|---|
| 2:45 PM | Matt Trusheim, Postdoctoral Fellow, Massachusetts Institute of Technology | "The next generation of quantum sensors in diamond" |
| 3:30 PM | Break | |
| 3:45 PM | Jean-François Roch , ENS Paris- Saclay, Laboratoire Aimé Cotton (France) | "NV color centers in diamond as quantum sensors for extreme conditions" |
| 4:30 PM | Bob Hamers , Professor, University of Wisconsin-Madison | "NV Centers in Diamond as Reporters for Chemical Sensing" |
| 5:15 PM | Roundtable discussion | |

5:45 PM Reception and Poster Session

Program (continued)

Day 2 (Tuesday December 10)

| 8:00 AM | Breakfast | | | | |
|--|--|---|--|--|--|
| Session 3: More on Atoms, NV Centers, and Quantum Photonics | | | | | |
| Session Chair: Kaden Hazzard, Assistant Professor, Physics & Astronomy Rice University | | | | | |
| 9:00 AM | Frank Narducci, Associate Professor, Naval Postgraduate School | "A Dual Atom Beam Accelerometer Gyroscope and T ³ Scaling in Atom Interferometers" | | | |
| 9:45 AM | Friedemann Reinhard, Walter Schottky Institute, Technical University of Munich (Germany) | "What is Wrong with Ensemble Sensors" | | | |
| 10:30 AM | Break | | | | |
| 10:45 AM | Andrew Weiner, Professor, Pur- due University | "Frequency Domain Quantum Photonics" | | | |
| 11:30 AM | Randall Hulet, Professor, Rice University | "S and P Wave Fermions in One-Dimension" | | | |
| 12:15 PM | Roundtable discussion | | | | |
| 12:45 PM | Final remarks + Lunch | | | | |





The <u>Smalley-Curl Institute</u> and the <u>Kavli Foundation</u> present "<u>Sensing the Future: The Future</u> <u>of Sensing</u>" Workshop Series, a trio of visionary, cross-disciplinary meetings at Rice University that will focus on the future of sensing technology. These meetings bring together scientists and engineers from academia, government and industry to identify the grand challenges that could potentially be met by next-generation sensing technologies, and the fundamental scientific capabilities that will be needed to address those challenges. The third workshop in the series, "Quantum Sensing", brings together experts, users (actual and potential), government and private funding agencies, to discuss the most recent progress and technological advances in the field of quantum sensing.

Presenter information (in alphabetical order by presenter last name):



Fredrik Fatemi, Branch Chief for Quantum Sciences, Army Research Laboratory

"Quantum information and Sensing at the Army Research Laboratory"

Abstract – This talk will provide an overview of research in quantum information science and sensing at the Army Research Laboratory in Adelphi, MD. Our research focuses on optical cavities and nanophotonics as optical interfaces to cold atoms and materials for quantum memories and repeaters. I will also describe recent sensing efforts using Rydberg atoms for communications.

Dr. Fredrik Fatemi is the Branch Chief for Quantum Sciences at the Army Research Laboratory in Adelphi, MD, and oversees a portfolio of research in quantum sensing and networks. He received his PhD from the University of Virginia in molecular cluster physics, and then did an NRC postdoctoral

fellowship at NIST-Gaithersburg on ultracold atomic collisions. Dr. Fatemi joined ARL after working at the Naval Research Laboratory for 15 years, where he conducted research in atomic, molecular, laser, and optical physics. He continues active research programs in nanophotonics, strong light-matter interactions, and atomic physics.



Robert Hamers, Professor, University of Wisconsin-Madison

"NV Centers in Diamond as Reporters for Chemical Sensing"

Abstract - Nv centers in diamond have emerged as highly sensitive detectors of magnetic and electric fields. We are interested in using the quantum properties of Nv centers and other quantum-based color centers to develop and implement new approaches to chemical sensing and imaging. One application is the use of Nv centers to selectively identify diamond nanoparticles within complex matrices such as biological samples, where autofluorescence and scattering make it otherwise difficult to identify the spatial location of the nanoparticles. We have explored the use of differential imaging techniques to isolate the Nv center

fluorescence and remove background autofluorescence and scattering. Measurement of contrast using optically detected magnetic resonance (ODMR) and using static magnetic field imaging show that both can achieve quantum-based contrast, but the static magnetic field imaging achieves higher contrast under conditions relevant for microscopy studies in environmental and biological matrices. Measurements as a function of the magnetic field and laser intensity on nanodiamonds of different sizes demonstrate contrast exceeding 20% in nanodiamond samples of 40 nm diameter. Using differential imaging of images acquired in the absence and presence of the magnetic field from an inexpensive electromagnet then allows selective imaging of the nanodiamond without interference from autofluorescence or scattered light. As a proof of concept, we demonstrate selective imaging of diamond nanoparticles ingested by C. elegans, a model system for understanding environmental fate and transport of nanoparticles in the environment. Magnetic-field modulated different imaging is attractive in part because it can be replicated in nearly any laboratory at minimal cost. A second effort is using shallow Nv centers implanted into single-crystal diamond to probe for the presence of nearby paramagnetic sensors. The goal of this work is to use paramagnetic centers such as TEMPO that can be covalently linked to probe molecules, coupled with the use of molecular recognition to alter the distance of the paramagnetic centers from the diamond surface and the implanted Nv centers. The binding or cleavage of the probe molecules from a surface can then in principle be detected via the spin-spin interactions and measurements of changes in fluorescence intensity, T1, or T2. I will also present our progress in this direction and discuss some of the challenges and opportunities for quantum-based sensing for chemical applications.

Dr. Robert Hamers is the Steenbock Professor of Physical Science at the University of Wisconsin-Madison and is the Director of the Center for Sustainable Nanotechnology, an NSF-supported Center for Chemical Innovation linking 12 universities to understand the transformations and biological impact of nanomaterials in the environment. His research interests include surface chemistry of diamond and other semiconductor materials, environmental fate and transport of nanomaterials, development and application of novel in situ analytical techniques, and electronic and optical properties of semiconductors in both bulk and nanoparticle form.

Randall Hulet, Professor, Rice University

"S and P Wave Fermions in One-Dimension"

Abstract – I will discuss experiments with ultracold 1D fermions of ⁶Li atoms. We have measured the speed of sound (charge mode) in a strongly interacting spin-1/2 Fermi gas, and are preparing to measure the spin mode. This will be the first quantitative measurements of spin-charge separation with tunable interactions. We are also exploring the possibility of p-wave pairing in a spin-polarized gas as a way to create Majorana fermions for fault-tolerant quantum computation.

Randall Hulet is the Fayez Sarofim Professor of Physics and Astronomy at Rice University. He has received many awards, including the I.I. Rabi Prize of the American Physical Society, the National Science Foundation Presidential Young Investigators Award, a NASA Medal for Exceptional Scientific Achievement, the Willis E. Lamb Medal for Laser Science and Quantum Optics, the Davisson-Germer Prize of the American Physical Society (APS), and the Herbert Walther

Award from the Optical Society of America and the German Physical Society. He is a Fellow of the APS and the American Association for the Advancement of Science, and he is a member of the American Academy of Arts and Sciences.

Hulet is known for his many important contributions to atomic physics. He played a leading role in the development of laser cooling and trapping of atoms. His most important achievements are the first realization of Bose-Einstein condensation in an atomic gas with attractive interactions, the creation of a degenerate Fermi gas and the exploration of the BEC-BCS crossover, and the observation of antiferromagnetic order in the Fermi-Hubbard model using ultracold atoms.



Holger Müller, Associate Professor, University of California at Berkeley

"Atom Interferometers for Fundamental Physics"

Abstract: We ave used interferometry with laser-cooled cesium atoms to make the most precise measurement yet of the fine-structure constant, at 0.20 ppb precision. Our new "Project Alpha" will reduce the experimental error further by roughly 1 order of magnitude. The current measured value differs by 2.5 σ from the value obtained from measurements of the electron's magnetic moment, mirroring the well-known 3.7 σ difference observed in the muon magnetic moment. Analogous to the remeasurement of the muon

magnetic moment, the higher-precision measurement of α by project Alpha could reveal signs of new physics. Project Alpha will also advance the methods of quantum metrology and atomic interferometry, key techniques for discoveries in beyond-standard model physics.

Holger Müller successfully applied for his first patent when he was 14. Later, he did his undergraduate thesis with Jürgen Mlynek at the University of Konstanz, Germany. He graduated from Humboldt-University, Berlin, with Achim Peters as advisor. Müller received a fellowship of the Alexander von Humboldt foundation and joined the group of Steven Chu in Stanford as a postdoc. In July 2008, he joined the physics faculty at U.C. Berkeley.

Presenter information (continued):



Francesco Narducci, Associate Professor, Naval Postgraduate School

"Novel atom interferometers"

Abstract – In this talk, I will highlight two novel interferometers currently being developed at the Naval Postgraduate School. The first interferometer utilizes a magnetic field gradient to break the symmetry between the two atomic paths, which leads to a higher scaling in the time T between the atom optic pulses. I will briefly describe details of the theory, including a novel method of understanding interference in atom sensors [1] before discussing the status of our experiments. A typical Ramsey fringe is depicted in figure 1 (left). The second interferometer uses continuous opposing beams of slow atoms originating from a 2-dimensional magneto -optical trap (2D-MOT) and continuous Raman fields for the atom optics. I will discuss the impact of gravity on this interferometer when operated as a gyroscope. I

will discuss some novel effects such as the asymmetry notable in the figure depicted in figure 1 (right), as well as the physics of the optimal single photon detuning for the Raman beams in our system.



Figure 1: (Left) A Ramsey fringe from the T-cubed experiment. (Right) Ramsey interference fringes from a continuous slow atom beam.

[1] M. Zimmermann, M. A. Efremov, W. Zeller, W. P. Schleich, J. P. Davis und F. A. Narducci, "Representation-free description of atom interferometers in time-dependent linear potentials," New Journal of Physics, p. 073031, 2019.

Funding – The work described in this talk was funded by a grant from the Office of the Secretary of Defense (qSEP program) and the Office of the Secretary of Defense (LUCI program).

Prof. Narducci graduated with top honors in both physics and math from Drexel University in Philadelphia, Pa in 1989. He then went to the University of Rochester to earn a Masters of Arts in 1991 and a Ph.D. in 1996. The late Prof. Leonard Mandel supervised his Ph.D. dissertation, entitled *Photon correlations in single and multi-atoms systems*. Upon completion of his degree, he joined the Naval Air Systems Command as a staff physicist establishing his own research team to investigate effects in various atomic systems, including cold atom and warm cells. He served as a program manager for the Office of Naval Research from 2000-2003. He was elected a NavAir Associate Fellow in 2006 and a full NavAir Fellow in 2012. He won the Dolores Etter Award for Top Navy Scientist (Individual) in 2013 and become the Senior Science and Technology Manager: Position, Navigation and TimeKeeping. He joined the faculty of the Naval Postgraduate School in July 2017. He continues his research while teaching. Also, "on the side", he has served as Associate Editor for *Physical Review A* (currently the longest serving editor) and Associate Editor for Physical *Review Letters*. He has also guest edited a special issue of the Journal of Modern Optics for the last 10 or so years devoted to the Proceedings of the Conference of The Physics of Quantum Electronics.



Markus Oberthaler, Professor, University of Heidelberg (Germany)

"Quantum Atom Optics: Entanglement & the Ultimate Trace Analysis at the Single Atom Level"

Abstract - The manipulation and control of atoms has been brought to unprecedented precision extending our capabilities of sensing beyond classical limits as well as addressing very different questions in physics. I will present two very distinct topics. I will give a short overview of the achievements of the generation and use of highly entangled states with ultracold gases [1]. While these results are of fundamental interest an applications is not in direct reach now, a true application of quantum atom optics is the

detection of atoms one by one. With that we have recently realized the detection of argon 39 a very rare radioactive isotope which is ideally suited for dating water [2] and ice [3] leading to new insight in environmental physics. This approach opens the general avenue for trace analysis at the ultimate single atom level.

[1] Quantum metrology with nonclassical states of atomic ensembles, Rev. Mod. Phys. 90, 035005 (2018).

[2] Ar-39 dating with small samples provides new key constraints on ocean ventilation, Nature Comm. 9, 5046 (2018).

[3] Dating glacier ice of the last millennium by quantum technology, PNAS 116, 8781 (2019).

Prof. Dr. Markus Oberthaler is Professor of Physics and Chair of Experimental Physics, Kirchhoff-Institute for Physics, at the University of Heidelberg (Germany).



Friedemann Reinhard, Walter Schottky Institute, Technical University of Munich (Germany)

"What is wrong with ensemble sensors?"

Abstract – A decade ago, diamond quantum sensors attracted the attention of the scientific world [1]. Two main visions were put forward at the time: single NV centers could become atomically small sensors, opening an unprecedented access to nanoscale magnetism. Large ensembles of NV centers - densely doped red fluorescent diamonds - could trade spatial resolution for sensitivity and measure magnetic fields on the femto-Tesla level, rivaling superconducting SQUIDs. While the first vision has become reality, progress with ensemble sensors has been considerably slower. The best published laboratory experiment has only reached pico-Tesla-level sensitivity [2], and the first generation of chip-scale integrated devices is limited to even lower performance on the nano-Tesla level [3,4]. This is a roadblock, because ensemble sensors are one of the most promising paths to large -scale applications like brain-machine interfaces [5,6] or inertial navigation [7,8]. I will speculate on the reasons for this development, which are in my opinion largely

connected to problems with spin readout in large ensembles. I will survey different approaches to mitigate these problems and present recent results of our groups on this issue.

[1] J. Taylor, P. Cappellaro et al., Nature Physics 4, 810 (2008)

- [3] D. Kim et al., Nature Electronics 2, 284 (2019)
- [5] J. Barry et al., PNAS 113, 14133 (2016)
- [7] A. Ajoy and P. Cappellaro, PRA 86, 062104 (2012)
- [2] T. Wolf et al., Phys. Rev. X 5, 041001 (2015)
- [4] F. Stürner et al., Diam. Rel. Mat. 93, 59 (2019)
- [6] M.W. Dale and G.W. Morley, arxiv:1705.01994v1
- [8] M.P. Ledbetter et al., Phys. Rev. A 86, 052116 (2012)

Dr. Friedemann Reinhard is heading an independent Emmy Noether research group at the Technical University of Munich (Germany). He received a diploma degree in Physics from the University of Göttingen, and a PhD degree from Université Paris VI (Pierre et Marie Curie) for work on atomic clocks. He subsequently shifted his research to NV centers in diamond and their application as quantum sensors, joining the laboratory of Jörg Wrachtrup at the University of Stuttgart. Since 2014 he has been heading an independent laboratory at the Technical University of Munich. The focus of his group is nanoscale magnetic resonance imaging, using NV centers in diamond as detectors for small ensembles of electron and nuclear spins. The group has also pione ered several improved readout schemes for NV centers.

Presenter information (continued):



Jean-François Roch, ENS Paris-Saclay, Laboratoire Aimé Cotton (France)

"NV color centers in diamond as quantum sensors for extreme conditions"

Abstract - The nitrogen-vacancy (NV) color center is a point defect of diamond that behaves as an artificial atom with a discrete spectrum of quantum states. Due to this remarkable property, the NV center can be used as a solid-state quantum sensor down to the atomic scale. I will describe how techniques for magnetic field sensing can be implemented inside a diamond anvil cell in order to investigate the magnetic and superconducting properties materials under extreme high pressure conditions.

The diamond anvil cell is a table-top system that implements in laboratory conditions pressures above the megabar range, leading to the onset of specific quantum states of matter. However, confining the sample in the tiny dimension of the diamond anvil cell makes the implementation of any non-optical sensing technique highly challenging. I will describe the results obtained on a model phase transition induced by applying a pressure between 10 and 40 GPa inside a diamond

anvil cell. This NV-based high-pressure sensing method is compatible with a synchrotron-based characterization of the crystalline structure. The implementation of these complementary techniques in a single set-up will open a broad range of applications, for instance for the discovery of novel superconductors with record critical temperatures.

Jean-François Roch is the co-author of 135 publications with a current h-index of 44 in Web of Science. He is professor "classe exceptionnelle" at Ecole normale supérieure (ENS) Paris-Saclay (formely ENS Cachan) which is the highest grade in French universities. Aside from his academic work in quantum optics and quantum sensing, he served as the vice-rector of ENS Cachan (2009-2010) where he was in charge of all research and innovation activities (fundamental science, engineering, and humanities), and then as the director of Laboratoire Aimé Cotton (2012-2017). In 2016, he started a joint laboratory with Thales to foster developements on quantum technologies. His experiments are now settled in the Thales research center in Palaiseau (France). He supervised more than 10 PhD students, with 2 theses ongoing. He is responsible for the "Technological and Scientific Resources" axis of the network SIRTEQ that federates research and innovation on quantum technologies in the region of Île-de-France. In addition, he is a member of the scientific committee of the annual Diamond Hasselt meeting; referee for high-level scientific journals: Phys. Rev. Lett., Nature, Science, etc. (typically 10 per year); and adjunct professor at East China Normal University (Shanghai).

James Shaffer, Senior Fellow, Quantum Valley Ideas Lab

"Rydberg Atom-based Electromagnetic Field Sensing"

Abstract – Highly excited Rydberg atoms have exaggerated properties that can be controlled through state selection, since these properties can scale strongly with principal quantum number, n. Rydberg state properties such as large transition dipole moments and polarizability can be used for quantum technologies, where the unique features of quantum phenomena are exploited for applications in areas like sensing, communications and computing. In this talk, we describe how Rydberg states can be used for electromagnetic field sensing in a frequency range spanning almost six orders of magnitude, including the GHz to THz regime. In particular, we have shown that Rydberg atoms can be used for high-sensitivity, absolute, self-calibrated sensing of high frequency electric fields. We have achieved high sensitivity using several different read-out strategies. These methods demonstrated read-out laser shot-noise limited performance. Fundamen-

tal limits to the sensitivity of the Rydberg atom-based RF electric field sensing have been addressed. We will present recent work on improving the accuracy of the method and achieving higher sensitivities. Results involving a 3-photon read-out scheme which enables the Autler-Townes regime of Rydberg atom-based electrometry to be extended to lower electric field strengths will be presented. We show that the residual Doppler shifts can be practically eliminated and signal strengths increased using the approach. We will also address implementing this strategy in small, subwavelength vapor cells, including an introduction to the effect of the vapor cell on the measurements.

James Shaffer is a Senior Technical Fellow at Quantum Valley Ideas Lab in Waterloo, Ontario. He joined Ideas Lab in 2017 as the first research group leader and served as Acting Director of Ideas Lab in 2018. Before moving to Ideas Lab, he was the Homer L. Dodge Professor of Atomic, Molecular and Optical Physics at the University of Oklahoma. Jim received his B.S. in physics from the University of Illinois Urbana-Champaign. After earning his B.S., he spent a year at Argonne National Laboratory. He received his Ph.D. in optics from the University of Rochester. After earning his Ph.D., he was a visiting fellow at the Steacie Institute for Molecular Sciences at the National Research Council in Ottawa, Ontario. During his time at The University of Oklahoma, Jim spent a year as a Visiting Professor at the University of Stuttgart in Germany. His research has spanned many areas including ultracold collisions, Rydberg atom physics, ultrafast spectroscopy, and quantum sensing, always involving lasers. Amongst other efforts, he currently serves as the Section Editor for Quantum Technologies for the Journal of Physics B.



Matt Trusheim, Postdoctoral Fellow, Massachusetts Institute of Technology

"The next generation of quantum sensors in diamond"

Abstract - Quantum sensors, including atomic-vapor magnetometers and superconducting quantum interference devices, now set the state of the art in numerous applications. Solid-state devices based on nitrogen-vacancy (NV) centers are among the most sensitive vector magnetometers, with added ambientcondition operation. As powerful as they are, these sensors do not fully realize their *quantum* advantage: they reach only the standard quantum limit (SQL) as an ensemble of uncorrelated sensors, rather than achieving the Heisenberg scaling enabled through non-classical correlations i.e. entanglement. In this talk, I will

discuss a path towards the next generation of sensors in diamond, through ab-initio material discovery and modeling, nanophotonic engineering, and scalable integration in a coherent quantum network architecture.

Matt Trusheim received his B.S. in Applied Physics from Yale University in 2010, his M.S. from Columbia University in 2011, and completed his PhD at MIT with a 2018 thesis entitled 'Nanoscale Engineering of Spin-Based Quantum Devices in Diamond'. His work focuses on quantum sensing at the nanoscale employing color centers in diamond, both as optically-addressable room-temperature spin systems and as qubits in a larger quantum information processing architecture. During his time as a IC Postdoctoral Fellow at MIT, Matt investigated a new class of quantum emitters, the Group-IV emitters in diamond, demonstrating their optical and spin coherence and indicating their potential as future quantum nodes in a distributed sensor network. Matt is now a Postdoctoral Fellow at Harvard, working with the group of Prineha Narang to computationally model quantum emitters from first principles, beginning with the discovery of new emitter complexes through to the development of noise-resilient quantum sensing algorithms.

Presenter information (continued):



Ronald Walsworth, Professor, University of Maryland; Senior Physicist, Smithsonian Institution

"Quantum Diamond Sensors"

Abstract – The nitrogen–vacancy (NV) quantum defect in diamond is a leading modality for magnetic, electrical, temperature, and force sensing with high spatial resolution (nanometers to millimeters) under ambient conditions. This technology has wide-ranging application across the physical and life sciences — from probing magnetic materials to biomedical diagnostics. I will provide an overview of quantum diamond sensors and their diverse applications

Ronald Walsworth leads an interdisciplinary research group with a focus on developing precision measurement tools and then applying them to problems in both the physical and life sciences. He is the Minta Martin Professor of Physics and of Electrical and Computer Engineering at the

University of Maryland (UMD), Founding Director of the UMD Quantum Technology Center, and a Senior Physicist at the Harvard-Smithsonian Center for Astrophysics.



Andrew Weiner, Professor, Purdue University

"Broadband Photonic Signal Processing for Time-Frequency Quantum Optics – and Imaging?"

Abstract – Entanglement is a key resource for quantum information processing. Photons have proven to be an indispensable tool for investigation of entanglement and its applications; they also have a long history in (classical) imaging. Over the last several years, my group has worked with broadband photons that are entangled in discrete frequency bins or in continuous timefrequency degrees of freedom. In this talk I will review our progress in adapting tools from the fields of classical ultrafast optics and high-speed photonics (pulse shapers, phase modulators, dispersion) to expand our ability to manipulate broadband photon entanglement.

I will also discuss the relevance of this work to timing measurements at speeds faster than the resolution of single photon detectors and comment on possible

connections to imaging.

Andrew Weiner, the Scifres Family Distinguished Professor of Electrical and Computer Engineering at Purdue University, is best known for pioneering work on programmable femtosecond pulse shaping and ultrafast signal processing. His recent work concerns optical frequency combs as well as multi-frequency and time-frequency quantum optics, including integrated photonics quantum sources. Weiner is a member of the National Academy of Engineering and National Academy of Inventors, was selected as a Department of Defense National Security Science and Engineering Faculty Fellow, and has received the OSA Wood Prize and the IEEE Photonics Society Quantum Electronics Award, among others. He is author of the textbook Ultrafast Optics and recently concluded a six year term as Editor-in-Chief of Optics Express.



Organizing Committee Members

Kaden Hazzard, Rice University Randy Hulet, Rice University Tom Killian, Rice University Junichiro Kono, Rice University Gururaj Viveka Naik, Rice University Francesco Narducci, Naval Postgraduate School Doug Natelson, Rice University Alberto Pimpinelli, Rice University Daniel Stark, Halliburton Augustine Urbas, Air Force Research Laboratory









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