EVENT PROGRAM

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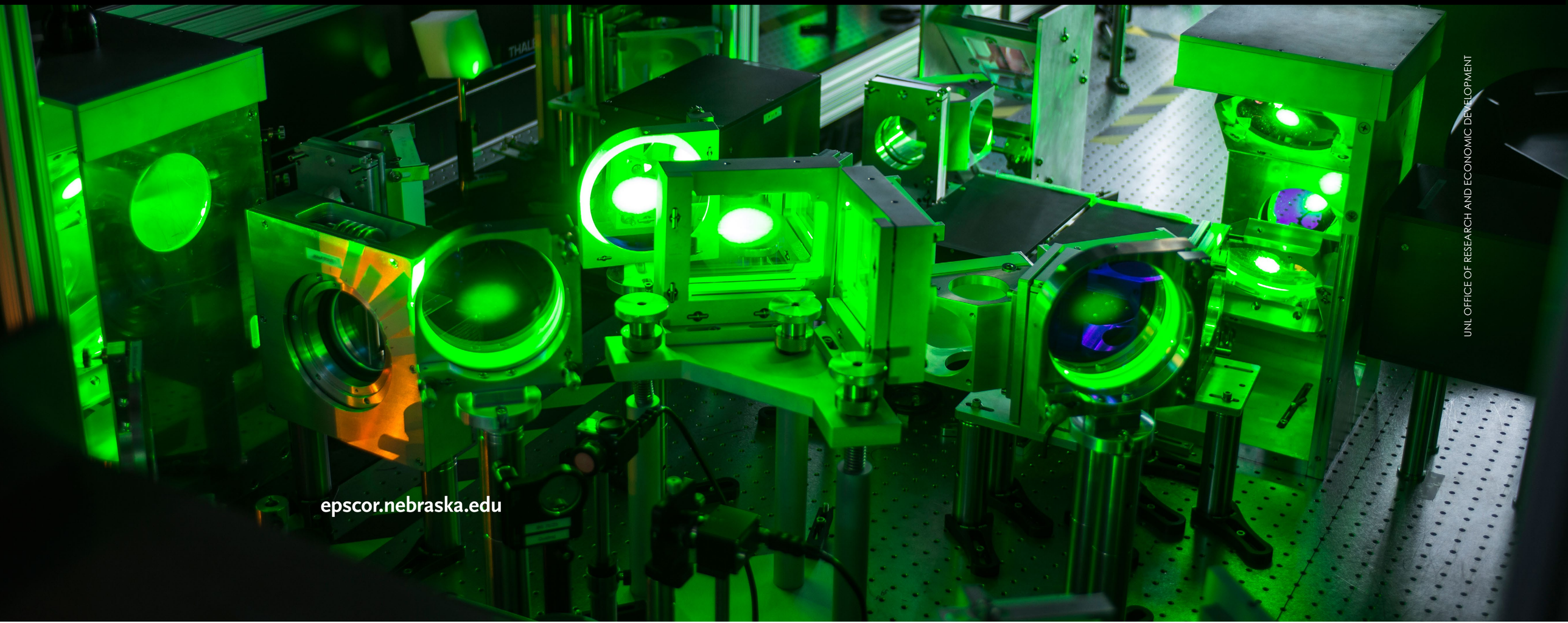
2015 Nebraska Research & Innovation Conference

SYMPOSIUM ON ULTRAFAST DYNAMICS OF ATOMS, MOLECULES & NANOSTRUCTURES

SEPTEMBER 29 | LINCOLN, NEBRASKA



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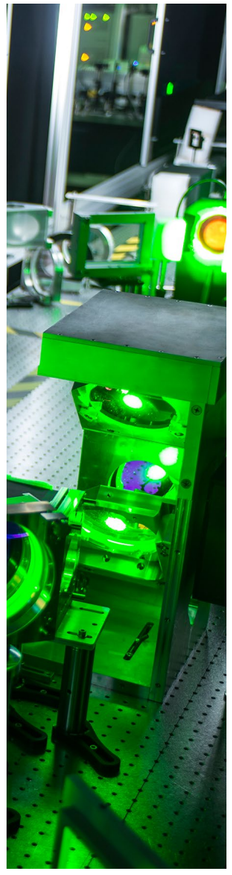

Message from the Nebraska EPSCoR Director

Dear Participants,

It is my pleasure to welcome you to the Symposium on Ultrafast Dynamics of Atoms, Molecules & Nanostructures, and I thank our speakers for sharing their time and expertise with us.

Today's event is a continuation of an annual series of conferences and symposia that Nebraska EPSCoR has been organizing in support of Nebraska researchers. This event is special because it is organized in support of collaborative research efforts of Nebraska and Kansas in AMO physics, funded by a three-year NSF EPSCoR grant.

Please enjoy today's knowledge transfer and networking opportunities, and make sure to visit the poster session to learn about exciting AMO research being conducted in Nebraska and Kansas.

Fred

F. Fred Choobineh, P.E., Ph.D.
Director, Nebraska EPSCoR
Blackman Distinguished Professor of Electrical Engineering, UNL

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Symposium Organizing Committee:

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Herman Batelaan, University of Nebraska-Lincoln
Itzik Ben-Itzhak, Kansas State University
Kristin Bowman-James, Kansas EPSCoR
Doug Byers, Kansas EPSCoR
Martin Centurion, University of Nebraska-Lincoln
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Fred Choobineh, Nebraska EPSCoR
Uwe Thumm, Kansas State University
Vinod Kumarappan, Kansas State University

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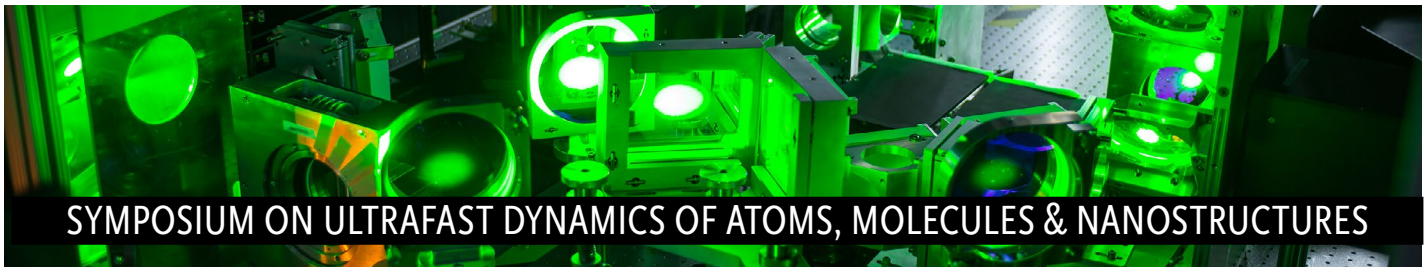


SYMPOSIUM ON ULTRAFAST DYNAMICS OF ATOMS, MOLECULES & NANOSTRUCTURES

TUESDAY, SEPTEMBER 29 | LINCOLN, NEBRASKA

7:30 am Registration and Continental Breakfast

8:30 am Opening Remarks
Dr. Prem Paul, University of Nebraska-Lincoln

8:45 am Metasurfaces: New Frontiers in Structured Light and Surface Waves
Dr. Federico Capasso, Harvard University

9:30 am Condensed Matter in Ultrafast and Superstrong Fields: Attosecond Phenomena
Dr. Mark I. Stockman, Georgia State University

SESSION CHAIR
DR. ANTHONY STARACE
UNIVERSITY OF NEBRASKA-LINCOLN

10:15 a.m. Break

10:45 am QASER: From Radio Frequencies to Optical Domain
Dr. Anatoly Svidzinsky, Texas A&M University

11:30 am Ultrafast Electron Motion in Atoms and Molecules
Dr. Philip H. Bucksbaum, Stanford University

SESSION CHAIR
DR. HERMAN BATELAAN
UNIVERSITY OF NEBRASKA-LINCOLN

12:15 p.m. Lunch

1:30pm Attosecond Dynamics: From Atoms to Semiconductor Solids
Dr. Stephen Leone, University of California, Berkeley

2:15 pm Understanding and Modeling Ultrafast Molecular Dynamics from First Principles
Dr. Todd Martinez, Stanford University

SESSION CHAIR
DR. MATTHIAS FUCHS
UNIVERSITY OF NEBRASKA-LINCOLN

3:00 p.m. Break

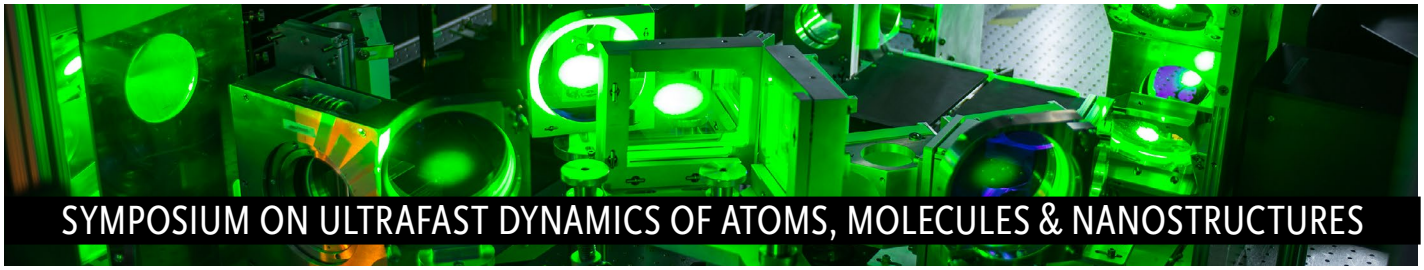
3:30 pm Angle-Resolved Measurements Using Rotational Wavepackets in Asymmetric Top Molecules
Dr. Vinod Kumarappan, Kansas State University

3:55 pm Ultrafast Electron Transport In and Between Single Atomic Layers
Dr. Hui Zhao, University of Kansas

4:20 pm Diffractive Imaging of Isolated Molecules with Femtosecond Electron Pulses
Dr. Martin Centurion, University of Nebraska-Lincoln

SESSION CHAIR
DR. UWE THUMM
KANSAS STATE UNIVERSITY

4:45 p.m. Poster session and reception (ends at 6:30 p.m.)



SYMPOSIUM ON ULTRAFAST DYNAMICS OF ATOMS, MOLECULES & NANOSTRUCTURES

Metasurfaces: New Frontiers in Structured Light and Surface Waves

FEDERICO CAPASSO
Robert Wallace Professor of Applied Physics
and Vinton Hayes Senior Research Fellow in Electrical Engineering
School of Engineering and Applied Sciences, Harvard University

8:45– 9:30 A.M.

ABSTRACT: Patterning surfaces with subwavelength spaced metallo-dielectric features (metasurfaces) allows local control of the amplitude, phase and polarization of scattered light, and generation of complex wavefronts such as optical vortices of different topological charge and dislocated wavefronts. Recent results on achromatic metasurfaces will be presented including lenses and collimators. Metasurfaces have also become a powerful tool to shape surface plasmon polaritons (SPPs) and, more generally, surface waves. I will present new experiments on imaging SPPs that have revealed the formation of Cherenkov SPP wakes and demonstrated polarization sensitive light couplers that control the directionality of SPPs and lenses which demultiplex focused SPP beams depending on their wavelength and polarization.

BIO: Dr. Federico Capasso is the Robert Wallace Professor of Applied Physics at Harvard University, which he joined in 2003 after 27 years at Bell Labs where he was Member of Technical Staff, Department Head and Vice President for Physical Research. He pioneered band-structure engineering of semiconductor nanostructures and quantum devices, including the invention and realization of the quantum cascade laser, and reported the first measurement of the repulsive Casimir force. In the past decade he has focused on wavefront control using plasmonics and on a new approach to diffractive optics based on metasurfaces, known as flat optics. Key results of this research include the formulation and demonstration of the generalized laws of refraction and reflection and aberration free flat lenses. He is a member of the National Academy of Sciences and the National Academy of Engineering, a fellow of the American Academy of Arts and Sciences, and a foreign member of the Accademia dei Lincei. His awards include the IEEE Sarnoff Award, the Materials Research Society Medal, the Franklin Institute Wetherill Medal, the Rank Prize in Optoelectronics, the Optical Society Wood Prize, the IEEE Edison Medal, the American Physical Society Arthur Schawlow Prize in Laser Science, the King Faisal Prize, the Berthold Leibinger Zukunft Prize, the Julius Springer Prize in Applied Physics, the Institute of Physics Duddell Medal, the Jan Czochralski Award for lifetime achievements in Materials Science, the European Physical Society Quantum Electronics Prize, the SPIE Gold Medal and the Gold Medal of the President of Italy for meritorious achievement in science. He holds honorary doctorates from Lund University, Diderot University and the Universities of Bologna and Roma II (Tor Vergata).

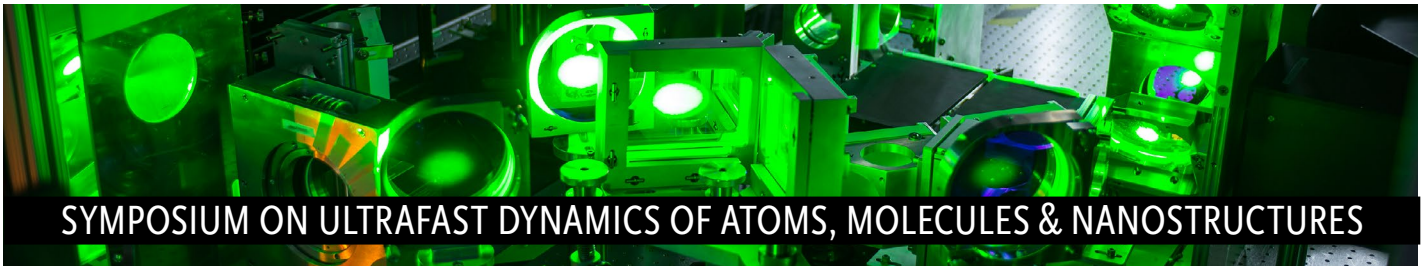
Condensed Matter in Ultrafast and Superstrong Fields: Attosecond Phenomena

MARK I. STOCKMAN
Professor of Physics and Director of the Center for Nanooptics (CeNO)
Georgia State University

9:30 - 10:15 A.M.

ABSTRACT: We discuss a new class of phenomena in condensed matter optics when a strong optical field ~1-3 V/Å reversibly changes a solid within an optical cycle. Such a pulse drives ampere-scale currents in dielectrics and controls their properties, including optical absorption and reflection, extreme UV absorption, and generation of high harmonics in a non-perturbative manner on a 100-as temporal scale. Applied to a metal, such a pulse causes an instantaneous and reversible loss of the metallic properties. We will also discuss our latest theoretical results on graphene that in a strong ultrashort pulse exhibits unique behavior. New phenomena are predicted for buckled two-dimensional solids, silicene and germanine. These are fastest phenomena in optics unfolding within a half period of light. They offer the potential for petahertz-bandwidth signal processing, generation of high harmonics on a nanometer spatial scale, etc.

BIO: Mark I. Stockman received his PhD and DSc degrees from institutes of the Russian Academy of Sciences. He is a Professor of Physics and the Director of the Center for Nanooptics (CeNO) at Georgia State University, Atlanta, GA, USA. He is a Fellow of the American Physical Society, Optical Society of America, and SPIE – The International Society for Optoelectronic Engineering. He has served as a Distinguished Visiting Professor at Ecole Normale Supérieure de Cachan (France) and as a Visiting Professor at Ecole Supérieure de Physique and de Chimie Industrielle (Paris, France), and also as a Guest Professor at University of Stuttgart (Germany), Max Plank Institute for Quantum Optics (Garching, Germany), and Ludwig Maximilian University (Munich, Germany). A major direction of his research is theoretical nanoplasmonics and strong-field ultrafast optics. He is a co-inventor of the spaser (nanoplasmonic laser). He is an author of over 190 major research papers and has presented numerous plenary, keynote, and invited talks at major international conferences. He gave lectures and taught courses on nanoplasmonics and ultrafast optics at many major international meetings and scientific institutions in the US, Canada, Europe, Asia, and Australia.



SYMPOSIUM ON ULTRAFAST DYNAMICS OF ATOMS, MOLECULES & NANOSTRUCTURES

QASER: From Radio Frequencies to Optical Domain

ANATOLY SVIDZINSKY
Research Associate Professor, Department of Physics & Astronomy
Texas A&M University

10:45 – 11:30 A.M.

ABSTRACT: Collective interaction of light with atomic ensembles occurring on fast superradiant time scales can yield light amplification at high frequencies by the process of difference combination resonance. A device that generates high frequency coherent radiation by driving an atomic ensemble with a much smaller frequency is called the QASER. Amplification mechanism of the QASER is governed by the difference combination parametric resonance which occurs when the driving field frequency matches the frequency difference between two normal modes of the coupled light atom system. I will review the concept of the QASER making a connection with the combination resonance in a system of asymmetrically coupled parametric oscillators and inverted pendulum. I will demonstrate the QASER amplification mechanism at radio frequencies in coupled RLC circuits and microwave cavities. I will also discuss possible realization of the QASER at optical frequencies in gases and nonlinear media with negative refractive index or materials with strong anomalous dispersion.

BIO: Anatoly Svidzinsky is a research associate professor with the Department of Physics & Astronomy at Texas A&M University. He received two Ph.D. degrees, from Moscow Institute of Physics and Technology in 1997 and Stanford University in 2001. His research interests in theoretical physics include quantum optics, Bose-Einstein condensation, superconductivity, chemical physics and astrophysics. He is best known for his work on collective, nonlocal and virtual effects in emission of atomic ensembles; development of novel coherent sources of radiation; pioneering work on dynamics of superfluid vortices; Bose-Einstein condensate statistics; prediction of novel magnetic, thermal and transport properties of high temperature superconductors; development of description of the chemical bond based on dimensional scaling analysis; prediction of a new mechanism of neutron star radiation produced by superfluid core and invention of an alternative vector theory of gravity. He is an author of about 100 research papers.

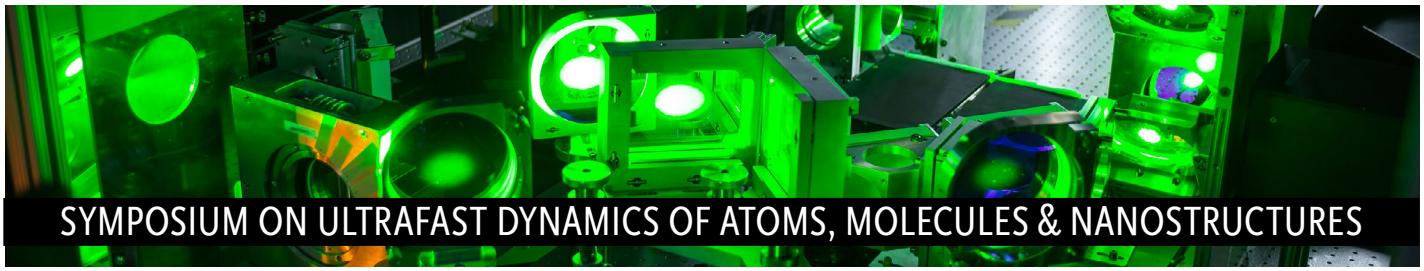
Ultrafast Electron Motion in Atoms and Molecules

PHILIP H. BUCKSBAUM
Marguerite Blake Wilbur Professor in Natural Science
Stanford University

11:30 A.M. – 12:15 P.M.

ABSTRACT: The timescale for internal motion in atoms and small molecules is determined by their Angstrom sizes and Rydberg binding energies to be femtoseconds or shorter. The binding fields for the outermost electrons are tens of volts per Angstrom, while inner electrons can be bound by kilovolts or more. I will describe recent experiments designed to study the internal motion of electrons and nuclei in molecules utilizing laser fields on these scales of time, photon energy and field strength. Two kinds of laser sources are employed: strong focused infrared lasers, and X-ray free electron lasers.

BIO: Philip H. Bucksbaum is the Marguerite Blake Wilbur Professor in Natural Science at Stanford University, in the Physics, Applied Physics, and Photon Science departments. He directs the PULSE Institute at Stanford and SLAC. Bucksbaum graduated from Harvard College (A.B. 1975) and the University of California at Berkeley (M.A. 1978; Ph.D. 1980). He was previously on the University of Michigan faculty and the Technical Staff at Bell Laboratories. He has been elected to the National Academy of Sciences and the American Academy of Arts and Sciences, and is a Fellow of the American Physical Society and the Optical Society.



SYMPOSIUM ON ULTRAFAST DYNAMICS OF ATOMS, MOLECULES & NANOSTRUCTURES

LUNCH 12:15 - 1:30 p.m.

Please enjoy lunch with colleagues in the Regents Ballroom C.

We look forward to your participation at the poster session in Regents Ballroom C following today's sessions!

Attosecond Dynamics: From Atoms to Semiconductor Solids

STEPHEN LEONE

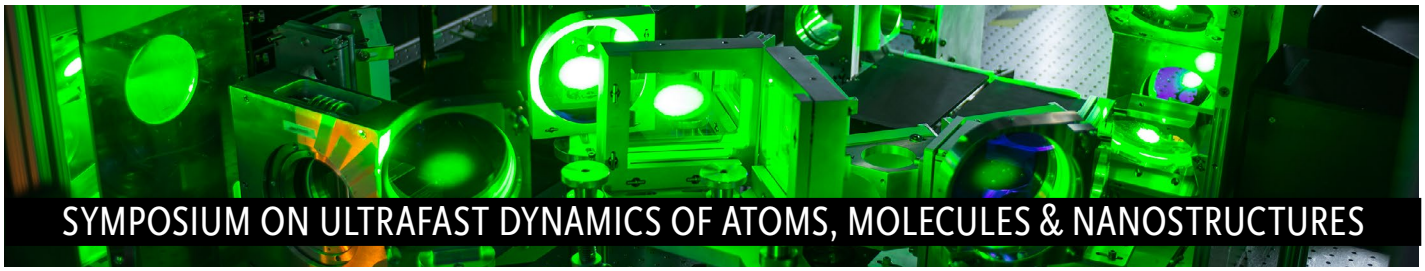
John R. Thomas Endowed Chair in Physical Chemistry, Professor of Chemistry and Physics

University of California, Berkeley

1:30 - 2:15 P.M.

ABSTRACT: Intriguing physics and chemistry problems abound in the pursuit of attosecond science, as such measurements push the boundaries of fundamental electron dynamics timescales. The x-ray transitions accessed by attosecond pulses are responsive to charge, chemical oxidation state, and electronic environment, and they exhibit sensitive shifts even with vibrational excitation. An introduction to attosecond measurements is presented, with a basic goal to reveal new dynamical timescales. Investigations involve the development of methods to explore coherent electronic superpositions and timescales for autoionization, strong-field ionization, and in the solid-state to determine how fast a band gap or strongly correlated material responds upon carrier excitation.

BIO: Stephen Leone is the John R. Thomas Endowed Chair in Physical Chemistry, Professor of Chemistry and Physics at the University of California, Berkeley, and faculty investigator, Lawrence Berkeley National Laboratory. His research interests are ultrafast and attosecond laser investigations of atomic, molecular, and solid state dynamics. His honors include the American Chemical Society Award in Pure Chemistry, the Herbert P. Broida Prize of the American Physical Society, the Bourke Medal of the Faraday Division of the Royal Society of Chemistry, the American Chemical Society Peter Debye Award, the Polanyi Medal of the Gas Kinetics Division of the Royal Society of Chemistry, and the Irving Langmuir Prize in Chemical Physics of the American Physical Society. He is a member of National Academy of Sciences and Fellow of the American Academy of Arts and Sciences.



SYMPOSIUM ON ULTRAFAST DYNAMICS OF ATOMS, MOLECULES & NANOSTRUCTURES

Understanding and Modeling Ultrafast Molecular Dynamics from First Principles

TODD MARTINEZ
Ehrsam and Franklin Professor of Chemistry
Stanford University

2:15 – 3:00 P.M.

ABSTRACT: The Born-Oppenheimer approximation (BOA), arising from the mass disparity between electrons and nuclei, is a cornerstone of theoretical chemistry. Within this approximation, the electronic state of a molecule is well-defined and independent of nuclear motion. However, the BOA must break down when multiple electronic states are involved, and this must be the case when a molecule is promoted to an excited electronic state (for example by light absorption). In order to describe such phenomena, we must introduce quantum mechanical descriptions for both the electrons and nuclei. In this talk, I will give an overview of our current understanding of ultrafast molecular dynamics beginning on excited electronic states and the breakdown of the BOA. By solving both the electronic and nuclear Schroedinger equations simultaneously, we can calculate this dynamics for molecular systems ranging from smaller paradigmatic cases to larger practically relevant ones. We illustrate these ideas with photoinduced cis-trans isomerization and excited state proton transfer (using molecules in isolation, solution and protein environments as examples).

BIO: Todd Martínez received his B.S. in Chemistry from Calvin College in 1989 and his Ph.D. in Chemistry from the University of California at Los Angeles in 1994. From 1994 to 1996, he was a Fulbright Junior Postdoctoral Researcher at Hebrew University in Jerusalem and a University of California President's Postdoctoral Fellow at UCLA. In 1996, he joined the faculty in the Department of Chemistry at the University of Illinois. He rose through the ranks to become the Gutgsell Chair in Chemistry. In 2009, he was recruited to join the faculty at Stanford University and the SLAC National Accelerator Laboratory, where he is currently David Mulvane Ehrsam and Edward Curtis Franklin Professor.

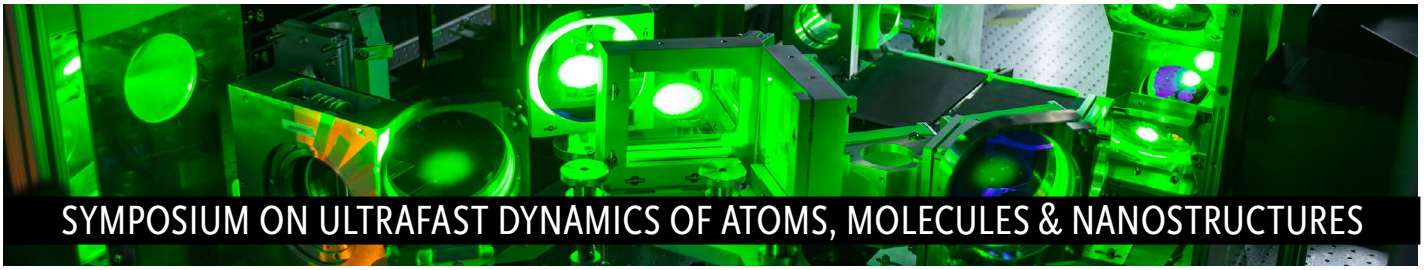
Angle-Resolved Measurements Using Rotational Wavepackets in Asymmetric Top Molecules

VINOD KUMARAPPAN
Associate Professor of Physics
Kansas State University

3:30 – 3:55 P.M.

ABSTRACT: Conventional methods of making molecular frame measurements do not work well for asymmetric top molecules due to the difficulties in aligning the molecules and in determining their orientation by momentum imaging of fragments. Rotational wavepacket dynamics offers a new route to molecular frame measurements in such molecules, enabling simultaneous characterization of the orientation dependence of ultrafast processes and the rotational wavepacket itself. This variation of rotational coherence spectroscopy will be discussed using strong field ionization and fragmentation of ethylene as examples.

BIO: Vinod Kumarappan received his Ph.D. from Tata Institute of Fundamental Research, Mumbai, for research on laser-generated plasmas in rare-gas clusters. After postdoctoral work first at University of Maryland at College Park and then at Aarhus University, he joined Kansas State University in 2007 as an assistant professor in the department of physics. His current research interests include measurements in the molecular frame, photoelectron spectroscopy and ultrafast electron diffraction.



SYMPOSIUM ON ULTRAFAST DYNAMICS OF ATOMS, MOLECULES & NANOSTRUCTURES

Ultrafast Electron Transport In and Between Single Atomic Layers

HUI ZHAO
Associate Professor of Physics
University of Kansas

3:55 - 4:20 P.M.

ABSTRACT: This presentation will convey the Nebraska-Kansas Consortium's progress on understanding, controlling, and detecting ultrafast electron transport in and between materials composed of single atomic layers. In these ultimately thin solids, electron transport is truly two dimensional. Using ultrafast laser techniques, we studied ballistic, diffusive, and spin/valley-polarized transport of electrons in two-dimensional materials such as phosphorene, tungsten disulfide, and rhenium disulfide. The group has also investigated ultrafast electron transport across van der Waals interfaces between two monolayers, such as graphene - tungsten disulfide, molybdenum disulfide – molybdenum diselenide, and tungsten disulfide – phosphorene. These studies revealed fundamental aspects of electron transport on ultimately small scales in solids.

BIO: Hui Zhao obtained his PhD in 2000 from Beijing Jiaotong University. After postdoc trainings at Karlsruhe Institute of Technology (Germany) and University of Iowa, he joined University of Kansas in 2007 as an Assistant Professor in Physics, and was promoted to Associate Professor in 2012. At KU, he developed an ultrafast laser program to study novel transport phenomena in semiconductors. His current research interests are optical and electronic properties of two-dimensional materials and the heterostructures.

Diffractive Imaging of Isolated Molecules with Femtosecond Electron Pulses

MARTIN CENTURION
Associate Professor, Department of Physics and Astronomy
University of Nebraska-Lincoln

4:20 – 4:45 P.M.

ABSTRACT: Photo-induced molecular reactions often involve short-lived intermediate states whose structure is unknown. Imaging the nuclear geometry in transient excited states remains a challenge due to the extreme requirements for spatial and temporal resolution. Ultrafast electron diffraction can in principle simultaneously provide sufficient temporal and spatial resolution. We use femtosecond laser pulses to align molecules, and show that the full 3-D structure of the molecules can be retrieved from the diffraction patterns. Recent developments have allowed us to capture structures with femtosecond resolution, which brings us within reach of fully mapping the evolution of transient states during a chemical reaction..

BIO: Martin Centurion is an Associate Professor in the Department of Physics and Astronomy at the University of Nebraska-Lincoln. He received his Ph.D. in Physics from Caltech in 2005, where he studied ultrafast holography and nonlinear optics. After a one-year postdoc at Caltech, he received a Humboldt postdoctoral fellowship to join the Max Planck Institute of Quantum Optics in Garching, Germany. In 2009 he joined the University of Nebraska as an Assistant Professor. His current research involves imaging of isolated molecules and ultrafast molecular dynamics, and the interaction of atoms and molecules with intense laser fields.

POSTER SESSION BEGINS AT 4:45 P.M.

Applications of Elliptically-Polarized, Few-Cycle Attosecond Pulses **1611**

Jean Marcel Ngoko Djiokap, S.X. Hu, L.B. Madsen, N.L. Manakov, A.V. Meremianin, Anthony F. Starace

A new nonlinear dichroic effect is predicted as a first application of our ability to solve the six-dimensional two-electron, time-dependent Schroedinger equation for He interacting with an elliptically-polarized XUV pulse. Specifically, we demonstrate control of double ionization of He by means of the polarization and carrier-envelope-phase (CEP) of an intense, few-cycle attosecond XUV pulse. Another application of circularly-polarized attosecond pulses is the production of vortices in photoelectron momentum distributions.

Attosecond time-resolved streaked photoemission from Mg-covered W(110) surfaces **1612**

Uwe Thumm, Q. Liao

We formulate a quantum-mechanical model for infrared-streaked photoelectron emission by an ultrashort extreme ultraviolet pulse from adsorbate-covered metal surfaces. Applying this numerical model to ultrathin Mg adsorbates on W(110) substrates, we analyze streaked photoelectron spectra and attosecond streaking time delays for photoemission from the Mg/W(110) conduction band and Mg(2p) and W(4f) core levels. Based on this analysis, we propose the use of attosecond streaking spectroscopy on adsorbate-covered surfaces with variable adsorbate thickness as a method for investigating (a) electron transport in condensed-matter systems and (b) metal-adsorbate interfacial properties at subatomic length and time scales. Our calculated streaked photoemission spectra and time delays agree with recently obtained experimental data.

Attosecond plasmonic streaking from gold nanospheres **1613**

Uwe Thumm, Jianxiong Li

To study time--resolved photoemission from gold nanospheres, we developed a semi--analytical quantum--mechanical approach. We use Mie theory to analytically calculate plasmonically enhanced fields near 10 to 200 nm gold nanospheres, driven by intense incident near--infrared (NIR) or visible light pulses. We model the gold conduction band in based on spherical square well potentials. Our first numerical results for streaked photoelectron spectra from gold nanospheres show a 3 times increased streaking spectrum amplitude for incident 800 nm streaking pulses and 10 nm diameter gold nanospheres, as compared with calculations in which the plasmonic near-field enhancement is switched off. Supported by the NSF-EPSCOR program.

An Atomic Photoionization Experiment by Harmonic Generation Spectroscopy **1614**

Jan Tross, M. V. Frolov, T. S. Sarantseva, N. L. Manakov, K. D. Fulfer, B. P. Wilson, X. Ren, E. D. Poliakoff, A. A. Silaev, N. V. Vvedenskii, Anthony F. Starace, C. A. Trallero-Herrero

Measurements of the high-order harmonic generation (HHG) yield of the argon (Ar) atom driven by a strong elliptically-polarized laser field are shown to completely determine the field-free differential photoionization cross section of Ar, i.e., the energy dependence of both the angle-integrated photoionization cross section and the angular distribution asymmetry parameter.

Investigation into the differences between incoherent and pulsed white light absorption by nanoparticles in solution **1615**

Brandin Davis, J. Powell, S. Zigo, Y. Qin, C. Sorensen, C. Trallero-Herrero

We investigate the difference between absorption spectroscopy done on nanoparticles in solution with incoherent white light and ultrafast pulses of white light. An 800nm, 25 fs, Ti:Saph laser is focused on a CaF2 crystal to produce a coherent white light pulse. The nanoparticle absorption spectrum is subsequently measured.

Anomalous Nonlinear X-ray Compton Scattering **1616**

Matthias Fuchs, M. Trigo, J. Chen, S. Ghimire, S. Shwartz, M. Kozina, M. Jiang, T. Henighan, C. Bray, G. Ndabashimiye, P. H. Bucksbaum, Y. Feng, S. Herrmann, G. Carini, J. Pines, P. Hart, C. Kenney, S. Guillet, S. Boutet, G. J. Williams, M. Messerschmidt, M. M. Seibert, S. Moeller, J. B. Hastings, D. A. Reis

X-ray scattering is typically used as a weak linear atomic-scale probe of matter. At high intensities, such as produced at free-electrons lasers (FELs), nonlinearities can become important, and the probe may no longer be considered weak. Here we report the observation of one of the most fundamental nonlinear X-ray–matter interactions: the concerted nonlinear Compton scattering of two identical hard X-ray photons producing a single higher-energy photon. The X-ray intensity reached 4x1020 Watt/cm2 corresponding to an electric field well above the atomic-unit of strength and within almost four orders of magnitude of the quantum-electrodynamic critical field. We measure a signal from solid beryllium that scales quadratically in intensity, consistent with simultaneous non-resonant two-photon scattering from nearly-free electrons. The high-energy photons show an anomalously large redshift that is incompatible with a free-electron approximation for the ground-state electron distribution, suggesting an enhanced nonlinearity for scattering at large momentum transfer.

Manipulation of Beams of Ultra-relativistic Electrons to Create Femtosecond X-ray Pulses **1617**

Jordan ONeal, Austin Schulte, Matthias Fuchs

We develop a compact, laser-driven next-generation X-ray lightsource. To this end, we will use a novel approach that has the potential to shrink the size of high-power X-ray sources from a typical footprint of more than a dozen football fields to roughly that of a dining room table. The source is expected to generate femtosecond pulses with ~10^9 photons at a photon energy tunable from ~100eV through the water window into the hard X-ray range. We investigate a novel X-ray focusing technique based on the manipulation of the electron beam during the radiation emission.

3-D Molecular Imaging and Dynamics Studied by Ultrafast Electron Diffraction **1618**

Jie Yang, Joshua Beck, Cornelis J. Uiterwaal, Martin Centurion

Ultrafast electron diffraction (UED) is a powerful method to study molecular structure and dynamics. For molecules in the gas phase, aligning the molecules break the spherical symmetry of the angular distribution and making the 3-D imaging possible. In this poster we demonstrate that by combining UED and laser alignment, we were able to achieve 3-D molecular images with atomic resolution. We have also used UED to capture the structure of a transient excited state where we have observed alignment, bond lengthening and dissociation of carbon disulfide molecules after interacting with an intense laser pulse.

Favorable target positions for intense laser acceleration of electrons in hydrogen-like, highly-charged ions **1619**

Liang-Wen Pi, S. X. Hu, Anthony F. Starace

Classical relativistic Monte Carlo simulations of petawatt laser acceleration of electrons bound initially in hydrogen-like, highly-charged ions show that both the angles and energies of the laser accelerated electrons depend on the initial ion positions with respect to the laser focus. Electrons bound in ions located after the laser focus generally acquire higher (~GeV) energies and are ejected at smaller angles with respect to the laser beam. Our simulations assume a tightly-focused linearly-polarized laser pulse with intensity approaching 10^{22}W/cm^2. Up to fifth order corrections to the paraxial approximation of the laser field in the focal region are taken into account. In addition to the laser intensity, the Rayleigh length in the focal region is shown to play a significant role in maximizing the final energy of the accelerated electrons. Results are presented for both Ne^{9+} and Ar^{17+} target ions.

Electron Steering With a Low Power Optical Laser **1620**

Peter Beierle, Wayne Huang, Roger Bach, Maria Becker, Derek Ruffner, Herman Batelaan

As a beam of 4keV electrons passes by a metallic wall which is illuminated by a laser beam, the electrons experience a force that deflects the beam's direction by 550microrad when the electrons are approx. 10 microns from the surface, and as far as 200 microns. This "electron switch" has a response time of approximately 6 microseconds. This switching mechanism is shown to be robust, as it is demonstrated for various optical wavelengths and surfaces. This type of electronic-free electron manipulation has potential use in electron beam microscopy (EBM) and electron beam lithography (EBL). In addition, while diffracting a 10keV electron beam through a nanofabricated electron grating, we observe the effects of illuminating the grating with a laser beam, with inconclusive results which seem to depend on the wavelength of the laser and relative angles between the grating and the laser beam electron beam.

Compression of Electron pulses for Ultrafast Diffraction Experiments **1623**

Omid Zandi, Kyle Wilkin, Alice DeSimone, Jie Yang, Martin Centurion

Non-relativistic highly charged electron pulses are compressed by the time-varying longitudinal electric field of an RF cavity to ultrashort durations for time-resolved electron diffraction experiments. The compression is done by the synchronization of the cavity's field to the pulses so that it pushes the front and back sides of each pulse toward each other. The cavity performance is then evaluated by a streak camera that measures the pulse duration in situ. It consists of a capacitor in parallel to a GaAs photo switch. The capacitor is initially charged to a high voltage. At the moment the compressed pulse is traversing the capacitor plates, a laser pulse activates the switch resulting in a GHz range underdamped oscillation of the capacitor electric field. Hence the front and back halves of each pulse see opposite electric fields. This will streak the pulse on the detector with a length proportional to the pulse duration.

Mega-Electronvolt Ultrafast Electron Diffraction at SLAC and UNL **1624**

Matthew Robinson, Jie Yang, Markus Guehr, Theodore Vecchione, Renkai Li, Nick Hartmann, Xiaozhe Shen, Ryan Coffee, Jeff Corbett, Alan Fry, Kelly Gaffney, Tais Gorkhover, Carsten Hast, Keith Jobe, Igor Makasyuk, Alexander Reid, J. S. Robinson, Sharon Vetter, Fenglin Wang, Stephen Weathersby, Charles Yoneda, Xijie Wang, Alexandra Hotchkiss, Serge Y. Kalmykov, Bradley Shadwick, Matthias Fuchs, Martin Centurion

Ultrafast electron diffraction (UED) is a rapidly advancing technique, allowing one to study structural changes in molecules during dynamic processes. Yet due technological limitations, experiments generally struggle to observe dynamics with sub-500 femtosecond time-resolution and sub-Angstrom spatial resolution; the parameters necessary to resolve individual atomic motions within a molecule during a dynamic process. However, here we present two experiments: one is the fastest UED experiment carried out to date, with 100 fs RMS time resolution and sub-Angstrom spatial resolution; the other is a newly established plasma accelerated electron source, which will produce high-energy high-charge pulsed electron beams for UED experiments.

Probing vibrating SF6 with inner-shell photoelectron diffraction **1625**

Ngoc Ty Nguyen, Anh Thu Le, Chii-Dong Lin

We present theoretical calculation for photoelectron angular distribution (PAD) from S(2p) in SF6 at low photoelectron energy region below 100 eV. Inner-shell photoelectron is known to carry information about molecular structure, as it experiences during this half-collision process. We show that it is possible to image very small structural changes during molecular vibration with PAD near the shape resonance at 13 eV. This is achieved in a pump-probe scheme, in which SF6 is first Raman excited dominantly to symmetric stretch mode by a relatively short laser pulse and then later probed at different time delays by a soft X-ray pulse of a duration of a few femtoseconds and photon energy near 200 eV.

Single-shot energy- and angular- characteristics of all-laser inverse-Compton x-ray source measured using single-photon spectroscopy 1626

Grigory Golovin, S. Banerjee, K. Brown, S. Chen, D. Haden, C. Liu, J. Mills, C. Petersen, J. Zhang, P. Zhang, B. Zhao, D. Umstadter, M. Veale, M. Wilson

We present spectral and spatial characterization of an all-optical tunable x-ray source based on inverse-Compton scattering. A unique CdTe single-photon-counting camera was used to measure angular-resolved spectra. The data obtained allowed us to precisely measure central energy, energy spread, and divergence of the scattering electron beam. A sensitive detection system enabled us to perform the measurements for single laser shots. For the experimental conditions relevant to this work, the source's quasi-monoenergetic spectrum was tuned in the energy range 50-110 keV. The source size was measured to be 4Â±1 um using the knife-edge technique. The source characteristics and our measurements demonstrate that it is possible to use the inverse-Compton x-ray source to perform single-photon imaging based on k-edge absorption, x-ray fluorescence, and x-ray diffraction.

Cavity-enhanced optical Hall effect in two-dimensional free charge carrier gases detected at terahertz frequencies 1627

S. Knight, S. Schöche, V. Darakchieva, P. Kühne, C.M. Herzinger, J.A. Woollam, M. Schubert, T. Hofmann

The effect of a tunable, externally coupled Fabry-Pérot cavity to resonantly enhance the optical Hall effect signatures at terahertz frequencies produced by a two-dimensional electron gases is shown and discussed. Tuning the externally coupled Fabry-Pérot cavity strongly modifies the optical Hall effect signatures, which provides a new degree of freedom for optical Hall effect experiments in addition to frequency, angle of incidence, and magnetic field direction and strength. We use epitaxial graphene grown by Si-sublimation on SiC and AlInN/GaN-based high-electron mobility transistor structures on a sapphire substrate as model systems for this experiment.

Electron Dynamics in Nanoparticles Under Intense Laser Fields 1628

Jeffrey Powell, S.J. Robatjazi, A. Vajdu, V. Makhija, X. Li, M.F. Kling, C. Sorensen, A. Rudenko

Nanoparticles bridge the gap between atomic/molecular and bulk matter and, thus, offer unique opportunities to study dynamics of complex systems. Ultrashort laser pulses provide tools to visualize and, potentially, to control electronic motion in nanoscale objects, nurturing the vision for developing ultrafast, light-driven optoelectronics. In particular, photoelectron emission from isolated nanosystems pulses can bring insights into their electronic response, local field enhancement and collective excitations (plasmons).

A Cylindrically Symmetric 'Micro-Mott' Electron Polarimeter 1629

Nathan Clayburn, E. Brunkow, G. H. Rutherford, S. J. Burtwistle, T. J. Gay

A small, novel, cylindrically-symmetric Mott electron polarimeter is described. The effective Sherman function, or analyzing power, and the device's maximum efficiency have been determined. The new polarimeter's performance is compared to published results for similar compact retarding-field Mott polarimeters. SIMION electron trajectory simulations incorporating calculations of Sherman function are presented to explain the differences in performance between this new Mott polarimeter and previous designs. This polarimeter will be used to measure the polarization of a new, potentially fast source of electrons. Funded by NSF PHY-1206067 and EPSCoR IIA-1430519

Development of flexible electron time of flight for ultrafast pulse characterization 1630

Pratap Timilsina, P. Mundine, C.Trallero-Herrero

We develop an electron time of flight (eTOF) to characterize ultrafast (femtosecond, sub-femtosecond & attosecond) electric field pulses ranging from the far IR to the XUV. By measuring the photoelectrons in the presence of two electric fields and their quantum interference we will be able to extract the amplitude and phase of the electric field. For XUV pulses these are the well-known streaking and RABITT (Reconstruction of Attosecond Beating by Interference of Two-Photon Transition) methods. The eTOF is based on a set of tunable electrostatic lenses and is capable of measuring 0-150 eV electrons. In addition we can selectively increase the photoelectron yield in different energies of the spectrum. The precise tuning of electrostatic lens system is done with a Genetic Algorithm with an intensity fluctuation discriminator in the fitness.

State-selective photoexcitation and molecular dissociation using XUV pump – Near-infrared probe 1631

Kanaka Raju Pandiri, Y. Malakar, W. L. Pearson, B. Kaderiya, Xiang Li, D. Trabert, F. Wilhelm, Wei Cao, I. Ben-Itzhak, A. Rudenko

Attosecond light sources based on high-harmonics generation are employed to study time-resolved dynamics. These broadband light sources populate superposition of states in the system. In contrast, we used narrow bandwidth XUV pulses to achieve state-selective excitation. The experiment is performed with 11th harmonic pump (100 fs, â^¼417.3 eV, 200 meV bandwidth) and 800-nm probe pulse sequence to induce the dissociative ionization of O2, which was characterized by energy- and angle-resolved photoion and photoelectron detection. The observed data can be understood in terms of the (net) absorption of one and two 800-nm photons by the XUV-excited ionic state.

This project is supported by the Chemical Science, Geosciences, and Bio-Science Division, Office of Basic Energy Science, Office of Science, U.S. Department of Energy. K.R.P. supported by National Science Foundation Award No. IIA-1430493.

Spin Transfer of Quantum Information between Majorana Modes and a Resonator **1632**

Alexey Kovalev

This work shows that resonant coupling and entanglement between a mechanical resonator and Majorana bound states can be achieved via spin currents in a 1D quantum wire with strong spin-orbit interactions. The bound states induced by vibrating and stationary magnets can hybridize, thus resulting in spin-current induced 4Ï€-periodic torques, as a function of the relative field angle, acting on the resonator. We study the feasibility of detecting and manipulating Majorana bound states with the use of magnetic resonance force microscopy techniques.

Progress towards a femtosecond, spin-polarized electron source **1633**

Maria Becker, Herman Batelaan, Eric Jones, Tim Gay, Evan Brunkow, Nathan Clayburn, Susan Enders, Omid Zandi

Previous and ongoing experiments involving the interaction of femtosecond laser pulses with GaAs crystals are aimed at developing an ultrafast source of spin-polarized electrons. Experimental studies, including a heuristic model for the unexpected result of subadditivity in pump-probe measurements, will be presented that indicate electron emission from GaAs occurs at a sub-picosecond time scale. When realized, the ultrafast, spin-polarized electron source will be used for fundamental physics studies, including electron-electron dynamics in two-particle quantum interference effects such as the Hanbury-Brown Twiss effect. Progress towards this study has included production of double tips for coherent electron emission.

Nanoantennas and metasurfaces to enhance light-matter interactions at nanoscale **1634**

Christos Argyropoulos

Nanoantennas and metasurfaces can manipulate the electromagnetic radiation in unprecedented ways and at nanoscale regions. Metals or high index dielectrics can be used to build these nanophotonic systems. The large field enhancement in the vicinity of these systems due to localized or collective resonances ensures a significant boosting of optical nonlinear effects, spontaneous emission rates, and other quantum effects. In addition, two dimensional materials, such as MoS2 and graphene, can be integrated in these resonating systems. Several future integrated nanophotonic systems are envisioned with the proposed hybrid nanostructures, such as tunable optical sensors and efficient electro-optical modulators with compact footprint.

Multiphoton dissociative ionization of CS^+ **1635**

Jyoti Rajput, Bethany Jochim, M. Zohrabi, K. J. Betsch, U. Ablikim, Ben Berry, T. Severt, Peyman Feizollah, A. M. Summers, Kanaka Raju P., G. S. J. Armstrong, B. D. Esry, K. D. Carnes, I. Ben-Itzhak

We have studied the dissociative ionization of a CS+ molecular-ion beam in the strong-field regime using ~790 nm, ~30 fs laser pulses. A coincidence three-dimensional momentum imaging method was used to measure all ions and neutrals formed during this multiphoton process. Two prominent channels were observed: charge-symmetric dissociation, yielding C^+ + S^+, and charge asymmetric dissociation, yielding C + S^(2+). The unusual angular distribution for the charge-symmetric dissociation channel will be discussed in light of the population of metastable states in the transient CS^(2+) molecular ion.

Velocity-map imaging and streaked photoelectron emission from metallic nanostructures **1636**

Erfan Saydanzad, Saydanzad, Erfan, Uwe Thumm

Attosecond time-resolved XUV-pump–IR probe spectroscopy has been shown to be a powerful method for investigating the electron dynamics in atom, and this technique is now being transferred to the investigation of electronic excitations, electron propagation, and collective electronic (plasmonic) effects in solids[1,2]. Based on classical trajectory calculations, we simulated (i) the final photoelectron velocity distribution in order to provide observable velocity-map images for gold nanospheres of 10 and 100 nm diameter and (ii) streaked photoemission spectra. By analyzing our numerical results, we illustrate how spatio-temporal information about the sub-IR-cycle plasmonic and electronic dynamics is encoded in velocity-map images and streaked spectra. *Supported by the NE/KS NSF-EPSCOR program.

[i] Attosecond physics: attosecond streaking spectroscopy of atoms and solids, U. Thumm, Q. Liao, E. M. Bothschafter, F. Süßmann, M. F. Kling, and R. Kienberger, p. 387, Handbook of Photonics, Volume 1, (Wiley, 2015).

[ii] Attosecond time-resolved streaked photoemission from Mg-covered W(110) surfaces, Q. Liao and U. Thumm, Phys. Rev. A 92, 031401(R) (2015).

Progress Towards Large Flux High-Order Harmonic Generation Driven by Two-Color Laser Fields **1637**

Travis Severt, J. Tross, P. Timilsina, S. Buczek, C. Trallero-Herrero, I. Ben-Itzhak

In the past decade, there has been a push to create bright tabletop XUV sources to study ultrafast dynamics in atoms and molecules. One of the more promising techniques is high-harmonic generation (HHG) driven by two-color laser fields. Our first step towards this goal is to investigate HHG from argon in an 800/400-nm laser field. In preliminary data, we observe two orders of magnitude increase for most harmonics created by the two-color field, and almost a three orders of magnitude enhancement of the ninth harmonic, when compared to the single-color (800-nm) field.

Strong-field dissociation dynamics of molecular dications **1638**

Bethany Jochim, T. Severt, M. Zohrabi, U. Ablikim, Ben Berry, B. Gaire, K. J. Betsch, F. Anis, K. D. Carnes, B. D. Esry, I. Ben-Itzhak

We study the dissociation dynamics of metastable molecular dications, NO_2^+, CS_2^+, and CO_2^+ (several-keV beam targets), driven by intense ultrafast laser pulses. In NO_2^+, time-dependent Schrodinger equation calculations and measured angular distributions demonstrate the importance of multiphoton permanent dipole transitions. Similar permanent dipole transitions are experimentally observed in CS_2^+ dissociation. In CS_2^+, we also find dissociation involving no energy gain (or loss) from the field due to a pump-dump-like process driven by a single laser pulse. This phenomenon is also observed in CO_2^+, whose ground electronic state has structure similar to that of CS_2^+.

Carrier-envelope phase control over fragmentation of H_2^+ and D_2 **1639**

Bethany Jochim, M. Zohrabi, B. Berry, Nora G. Kling, Bethany Jochim, T. Severt, U. Ablikim, K. J. Betsch, S. Zeng, F. Anis, Z. Wang, M. F. Kling, K. D. Carnes, B. D. Esry, I. Ben-Itzhak

We examined carrier-envelope phase (CEP) dependences in H_2^+ dissociation and Rydberg D* formation from D_2. D* formation exhibits strong CEP dependences in the total yield, and both molecules show CEP-dependent asymmetries in the fragment emission direction with respect to the laser polarization. These observations result from interfering pathways involving different numbers of photons and are consistent with the general CEP theory [1]. Moreover, D* spatial asymmetry and yield exhibit higher-order oscillations related to a higher difference in the number of photons involved in the interfering pathways.

[1] V. Roudnev and B. D. Esry, Phys. Rev. Lett. 99, 220406 (2007)

A 600 MW light source at 7 micrometer center wavelength as a path to strong field science in the far infrared **1640**

Derrek Wilson, Carlos Trallero-Herrero

We demonstrate a far infrared source (7 micrometer) with pulse duration of ~ 130 fs and pulse energies of 80 mJ. This source was generated by performing difference frequency generation on the Signal and Idler pulses from an Optical Parametric Amplifier. We show a clear path to achieving 1 GW peak power and applications of this light source to strong field science in both atoms and solid systems.

Study of Nuclear Wave Packet Dynamics in Strong-Field Ionized Iodomethane and Diiodomethane **1641**

Yubaraj Malakar, Balram Kaderiya, Wright Lee Pearson, Kanaka Raju Pandiri, Mohammad Zohrabi, Farzaneh Ziaee, Itzik Ben-Itzhak, Daniel Rolles, Artem Rudenko

As a prototypical polyatomic system with well-studied photodissociation dynamics, the iodomethane molecule (CH_3I) has recently been used to test novel quantum control schemes and to investigate charge transfer processes after X-ray absorption. Here we present the results of Infra-Red pump-probe experiment that maps bound and dissociating nuclear wave-packets in singly and doubly charged CH_3I ionic states. Measuring dependence of energies and yields of ionic fragments on time-delay between two 25fs, 800nm pulses, we track the propagation of different dissociation pathways and vibrational motion of the molecule. We employ the same experimental technique to study nuclear wave-packet dynamics in diiodomethane (CH_2I_2).

Pump-probe Sub-additivity in Photoelectron Emission from GaAs **1642**

Evan Brunkow, Nathan B. Clayburn, Maria Becker, Eric Jones, Herman Batelaan, T.J. Gay

Using a 75 ns pulsed laser (800 nm center wavelength; 10 nJ/pulse), we have shown that photoemission from GaAs induced by coherent pump and probe pulses is more than additive for delays < 200 fs. This implies that the emission is slower than 200 fs or that other dynamics that affect the photoemission are operative [1]. For delays between 0.5 and 16 ps, the electron emission is sub-additive. This appears to be the result of the reflectance changing due to the first pulse, which reduces the absorption of the second pulse. The results of experiments studying this sub-additivity are presented.

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[1] E. Brunkow et al., Bull. Am. Phys. Soc. 59 (2014).

Progress report on laser control of electrons in nanostructures **1643**

Eric Jones, Gobind Basnet, Maria Becker, Evan Brunkow, Nate Clayburn, Peter Beierle, Bret Flanders, Tim Gay, Herman Batelaan

Laser-induced field emission tips are the standard for ultrafast electron microscopy and diffraction, capable of delivering single-electron pulses of femtosecond duration with picometer resolution. We investigate the electron emission from two modified tip sources: a gold (Au) nanowire, and a GaAs tip. Electron emission from the Au nanowire may give insight into the internal electron dynamics in and on the wire. Controlling those dynamics could allow for single- or multi-electron pulses on demand. The GaAs tip may be a novel ultrafast source of spin-polarized electrons. Other nanostructures under investigation include nanofabricated gratings and plasmonic antenna arrays for free-electron control.

Field-Enhanced Chemical Reactions: Photochromic Switching in the Plasmonic Field of Gold Nano-Structures **1644**

Christopher Otolski, Ryan Hamelin, Christopher G. Elles

The photochromic ring-opening and ring-closing reactions of a diarylethene derivative in the solid phase proceed readily following resonant excitation of the molecule. Molecules deposited onto an array of gold nanorods undergo the same reaction through non-resonant excitation due to the interaction of the molecules with the plasmonic field of the nanostructured array. Plasmonic field enhancement allows non-resonant switching with very low intensity irradiation at wavelengths that are not resonant with the absorption bands of the molecule. Only a fraction of the molecules convert back to the open form under these conditions due to the limited range of the plasmonic field.

Bond rearrangement and hydrogen migrations in small hydrocarbons through strong-field induced interactions **1645**

Wright Lee Pearson, Yubraj Malakar, Artem Rudenko

Imaging and control schemes for photo-induced structural rearrangement dynamics are of particular interest to ultrafast photochemistry. Here we report on a series of experiments that study bond dissociation and rearrangement of small hydrocarbons (CH_4, C_2H_2, C_2H_4) irradiated by intense 800nm laser pulses. Different fragmentation pathways, isomerization and proton migration channels are measured by coincident ion momentum patterns for two- or three-body breakup channels. Among these studies we observe C_2H_2 and C_2H_4 isomerization where the evolution of kinetic energy release spectra with increasing laser pulse duration differentiates active isomerization pathways within or after the pulse.

Intense-Field Photoionization of Molecules using Ultrashort Radiation Pulses: Carbondisulfide and Substituted Monoaromatic Hydrocarbons **1646**

Joshua Beck, Timothy Scarborough, Cornelis J. Uiterwaal

We experimentally investigate the intense-field photodynamics of molecules using 50-fs, 800-nm pulses with in-tensities of 1012 to 1014 W/cm2. Target molecules include carbondioxide (CO_2), carbondisulfide (CS_2), and substi-tuted monoaromatics, such as aniline (C_6H_5-NH_2) and nitrobenzene (C_6H_5-NO_2). We use mass spec-trometry to detect ions, and avoid focal intensity averaging. For CS_2, the onset of ionization is dominated by parent ions (1+, 2+). We show that ionization is insignificant for intensities that maximize alignment of CS_2, which validates ultrafast electron diffraction experiments from aligned CS_2. For the substituted monoaromatics we discuss the role of the substituent.