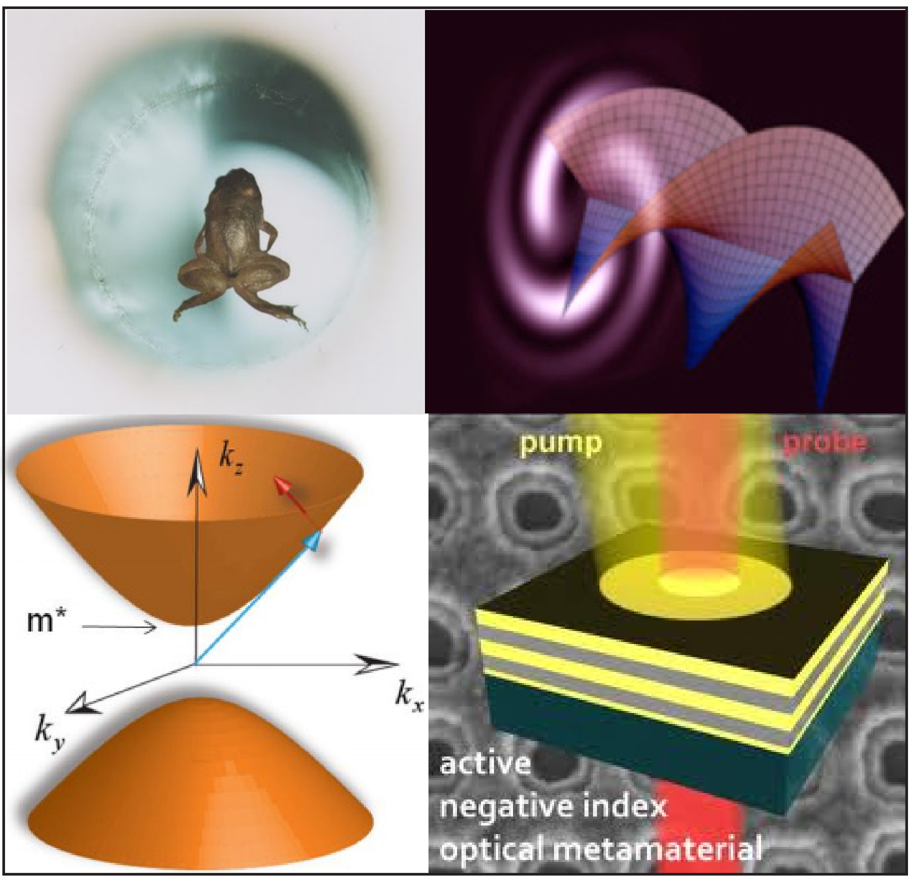
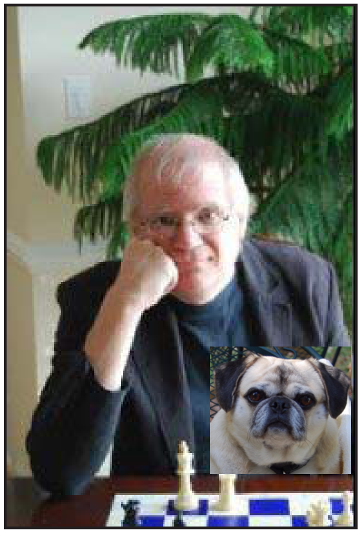
Workshop
Beyond the Imagination of Nature:
Spin, Quantum Optics, and Metamaterials



September 19-20, 2011 Buffalo, NY

RICHARD HAMMOND- US ARMY RESEARCH AND UNIVERSITY OF NORTH CAROLINA AT CHAPEL HILL



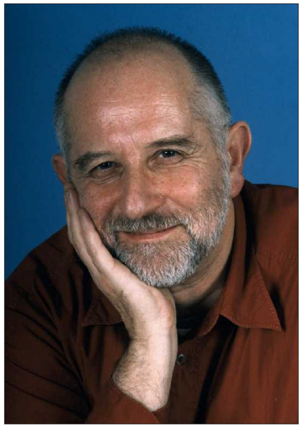
Richard Hammond is an Adjunct Professor at the University of North Carolina at Chapel Hill and the author of the book “The Unknown Universe: The Origin of the Universe, Quantum Gravity, Wormholes, and Other Things Science Still Can’t Explain”. He also works for the United States Army Research Office as a theoretical physicist. He has authored several academic papers on general relativity and quantum mechanics.

Dr. Richard Hammond has published numerous scientific articles in a wide range of fields, from general relativity to quantum mechanics, and has pioneered a new theory of gravitation that has won international acclaim. He has won awards from NASA for his research and teaching, international awards for research on gravity, and was invited to Cal Tech’s Jet Propulsion Lab to study solar system tests of Einstein’s theory.

WORKSHOP OBJECTIVE

The objective of this workshop is to capture the state-of-the-art in three fascinating fields of modern optical physics, spin- and quantum-optics, and optical metamaterials. Hopefully we will generate new ideas and initiate new collaborations at the interface of these fields. Recent progress in the field of optical metamaterials has opened up an entirely new branch of modern optics that can be described as “refractive index engineering”. The unprecedented design flexibility provided by metamaterials has already given rise to new linear and nonlinear optical properties, magnetism at optical frequencies. The possibility of engineering space for light strongly suggests that these unique structures are likely to uncover a plethora of new fundamental optical phenomena as well as a number of civil and military applications based on spin-orbit interactions, enhanced linear and nonlinear magnetic effects, and singular optics (vortices).

SIR MICHAEL BERRY- UNIVERSITY OF BRISTOL, UK



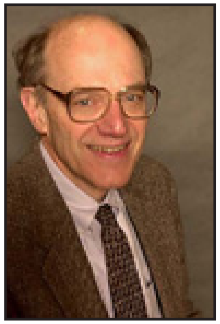
Michael Berry is a theoretical physicist at the University of Bristol, UK, where he has been for much longer than he has not. Currently he is the Melville Wills Professor Emeritus there. His interests are centred on the physics of waves, especially in quantum mechanics and optics, and more generally concern singularities and borderlands between physical theories at different levels of description. Examples are: caustics in geometrical optics, and the diffraction patterns that decorate them; phase singularities (a.k.a. optical vortices, nodal lines, or wave dislocations); quantum phases associated with states driven round cycles; mathematical asymptotics relevant to mathematical physics; and quantum physics of classically chaotic systems, especially the connection to prime numbers and the Riemann hypothesis.

He was elected a fellow of the Royal Society of London in 1982 and knighted in 1996. He has achieved numerous prizes and awards including Maxwell Medal and Prize, Institute of Physics, Fellow of the Royal Society of London, Fellow of the Royal Society of Arts, Fellow of the Royal Institution, Member of the European Academy, Dirac Medal and Prize, Institute of Physics, Lilienfeld Prize, American Physical Society, Royal Medal, Royal Society, Naylor Prize and Lectureship in Applied Mathematics, London Mathematical Society, US National Academy of Science, Dirac Medal, International Centre for Theoretical Physics, Kapitsa Medal, Russian Academy of Sciences, Wolf Prize for Physics, Wolf Foundation, Israel, Ig Nobel Prize for Physics, 2000 (shared with Andre Geim for "The Physics of Flying Frogs"), Onsager Medal, Norwegian Technical University, and others.

THE EXQUISITE SENSITIVITY OF POLARIZATION

Recent insights into the time-development of quantum states driven by nonhermitian matrices, and an exactly solvable model, can be applied to the evolution of optical polarization in a stratified nontransparent dielectric medium twisted cyclically along the propagation direction. The twist is chosen to encircle a degeneracy (branch-point) in the plane of parameters describing the medium. Polarization evolutions are determined analytically and illustrated as tracks on the Poincaré sphere and the stereographic plane. Even when the twist is slow, the exact evolutions differ sharply from those of the local eigenpolarizations and can display extreme sensitivity to initial conditions with the tracks exhibiting elaborate coilings and loopings that would be very interesting to explore experimentally. Underlying these dramatic violations of adiabatic intuition are the disparity of exponentials and the Stokes phenomenon of asymptotics.

JOSEPH H. EBERLY - UNIVERSITY OF ROCHESTER



Joseph H. Eberly earned his Ph.D. in Physics at Stanford University in 1962, and in 1979 joined The Institute of Optics faculty. A member of the UR physics faculty since 1967, he is the Andrew Carnegie Professor of Physics and Professor of Optics. A Fellow of OSA and APS, Professor Eberly is the recipient of the Townes Award and the Smoluchowski Medal, has been selected for a Senior Humboldt Award and elected a Foreign Member of the Academy of Sciences of Poland. In 1995, with funding from the National Science Foundation, he founded the Rochester Theory Center (RTC), a research group focused on optical and quantum optical science with faculty from several UR departments.

Professor Eberly's research interests focus on: cavity QED; quantum information and control of non-classical entanglement; response of atoms to high-intensity optical pulses; coherent control theory of optical interactions, including soliton and adiabaton propagation.

Professor Eberly and his research group predicted spontaneous revival effects in the wave function of a single atom in a cavity, and first identified the efficient counter-intuitive excitation method. These and related quantum phenomena are the subjects of theoretical and experimental study in Rochester and elsewhere.

BEYOND STOKES: A TALE OF TWO VECTOR SPACES

There is an overlooked element of optics and optical imaging that has been largely bypassed by advances in the generation, propagation, transmission, and storage of light. This is optical spin, i.e., polarization. Developments arising from fundamental advances during the past 5 decades in coherent, quantum, nonlinear and statistical optics have been noteworthy, even spectacular. In stark contrast, the understanding of polarization is still grounded in the insights of Sir George Stokes from 150 years ago. But this is beginning to change. Both theoretical and practical considerations are pointing to the need for new breakaway treatments of polarization. The next decade will almost certainly see a revolution in polarization optics as the constraints inherent in gaussian beam physics are discarded. Here we will focus on a reformulation of the technical parameter called the degree of polarization, which is no longer appropriate in several ways, for example to high numerical aperture imaging. This will illustrate some of the changes that will be coming.

VLADIMIR M. SHALAEV, PURDUE UNIVERSITY

Vladimir M. Shalaev, the Robert and Anne Burnett Professor of Electrical and Computer Engineering and Professor of Biomedical Engineering at Purdue University, specializes in metamaterials, transformation optics, nanophotonics and plasmonics. He made pioneering contributions to the optics of fractal and percolation composites, their applications for Surface Enhanced Raman Spectroscopy (SERS), and to the field of optical metamaterials, including first experimental observation (collectively with his research team at Purdue University) of negative refractive index in the optical range (This work was ranked in the top 50 innovations in nanotechnology in 2006 by Nanotech Briefs) and magnetism across the entire visible range.

Prof. V. Shalaev received several awards for his research in the field of nanophotonics and metamaterials. He is a Fellow of the American Physical Society (APS), of The International Society for Optical Engineering (SPIE), and of the Optical Society of America (OSA). Prof. Shalaev is a Co-/Editor for five books in the area of nano-optics and an Editorial Board Member for a number of research journals. He co-/authored two books, twenty invited book contributions, and about 300 research publications. One of the books, Electrodynamics of Metamaterials, is authoritative in the field of plasmonic nanostructure research. He is also on the editorial board of the peer reviewed journal Metamaterials, along with a number of other notable board members who have significantly contributed to metamaterial research.

ACTIVE AND QUANTUM METAMATERIALS

Metamaterials, i.e. artificial materials with rationally designed geometry, composition, and arrangement of nanostructured building blocks called meta -"atoms," are expected to open a gateway to unprecedented electromagnetic properties and functionalities that are unattainable with naturally occurring materials. We review this exciting and emerging field and discuss the recent, significant progress in developing metamaterials for the optical part of the electromagnetic spectrum. Specifically, unique properties of active and quantum metamaterials will be discussed in this talk.

MILES PADGETT, UNIVERSITY OF GLASGOW

Miles Padgett holds the Kelvin Chair of Natural Philosophy in the School of Physics and Astronomy at the University of Glasgow. He heads a 15-person team covering a wide spectrum from blue-sky research to applied instrument development.

In 2001 he was elected to Fellowship of the Royal Society of Edinburgh. In 2007/8 he was a Leverhulme Trust Royal Society Senior Research Fellow. In 2008 Padgett was awarded the Institute of Physics Optics and Photonics Division Prize and in 2009 the Young Medal and Prize for "pioneering work on optical angular momentum". Since 2009 he is supported by a Royal Society–Wolfson Merit Award.

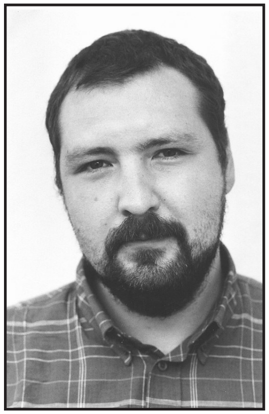
The group's work has led to the fundamental understanding of light's momentum, including conversion of optical tweezers to optical spanners, observing the topology of vortex lines in optical speckle, and demonstrating an angular form of the EPR paradox.

LIGHT IN A TWIST: OPTICAL ORBITAL ANGULAR MOMENTUM

A feature of wave superposition is that one plus one does not necessarily equal two. The interference of two equivalent waves can result in a zero intensity – e.g. Young's double slits. However, the waves fill 3D space not just a 2D screen and Young's dark fringes map out planes. But two waves are a special case. In general, when three or more waves interfere, complete destructive interference forms dark lines (phase singularities) around which the phase advances or retards by 2π. This azimuthal phase gradient means that the Poynting vector, and associated energy flow, circulates too – hence the dark lines are also called "optical vortices". Despite their appearance in all natural light fields, it was not until the early 1990s that it was recognized by Allen et al that light beams containing a single line phase singularity carried an angular momentum, completely independent of the photon spin.

This orbital angular momentum can be created using simple lens systems, or holograms - made from 35mm film or encoded onto liquid crystal displays. Both whole beams, and single photons can carry this information, or transfer it to particles to create an optical spanner. In this talk I hope to introduce the underlying physical properties and discuss a number of manifestations of orbital angular momentum, which highlight how optics still contains surprises and opportunities for both the classical and quantum worlds.

KONSTANTIN BLIOKH - UNIVERSITY OF IRELAND



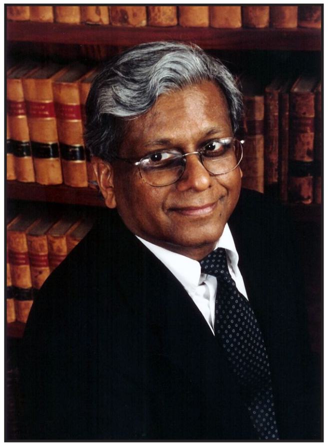
Dr. Konstantin Bliokh received a Ph.D. degree in physics from the Kharkov National University, Ukraine, in 2001. His post-doctoral experience includes 2.5 years at the Bar-Ilan University, Israel, 1 year at the Australian National University, and numerous scientific visits throughout the world. Currently, he is a Marie Curie Research Fellow at the Applied Optics Group of the National University of Ireland, Galway. His research interests include wave propagation and scattering in inhomogeneous media, semiclassical dynamics of quantum particles, geometric phases, singular optics, spin and orbital angular momenta, localization of waves, and plasmonics. His results have been published in more than 50 full-length papers.

HYPERBOLIC RADIATION-ABSORBING METAMATERIALS

I will give an overview of the fine spin-orbit phenomena which appear in evolution of polarized light and optical vortex beams at subwavelength scale. These are spin and orbital Hall effects, spin-to-orbit angular momentum conversion, etc. Interference of partial waves gaining geometric-phase gradients underlies these phenomena and provides their “wave” description. At the same time, conservation and dynamics of the angular-momentum degrees of freedom of light provides a “particle” picture of the spin-orbit interactions. The spin-orbit effects appear in most of the basic optical processes (such as interference, diffraction, scattering, focusing, reflection, etc), and are of a great importance for modern nano-optics.

I will also discuss vortex-beams and angular-momentum states for free electrons. Recently, such novel electron states were predicted and observed experimentally in the scalar paraxial regime. Evolution of photons and electrons carrying angular momentum has much in common and offers an exciting exchange of ideas between optics and quantum physics.

GOVIND P. AGRAWAL



Govind P. Agrawal received the B.S. degree from the University of Lucknow in 1969 and the M.S. and Ph.D. degrees from the Indian Institute of Technology, New Delhi in 1971 and 1974 respectively. After holding positions at the Ecole Polytechnique, France, the City University of New York, New York, and AT&T Bell Laboratories, Murray Hill, NJ, Dr. Agrawal joined in 1989 the faculty of the Institute of Optics at the University of Rochester, where he is a Professor of Optics. His recent research focuses on optical communications, nonlinear optics, and silicon photonics. He is an author or coauthor of more than 380 research papers and eight books including Fiber-Optic Communication Systems (4th ed., Wiley 2010); Nonlinear Fiber Optics (4th ed., Academic Press 2007); Applications of Nonlinear Fiber Optics (2nd ed., Academic Press 2008); and Light Propagation in Gain Media: Optical Amplifiers (with M. Premaratne, Cambridge University Press, 2011). He has been involved multiple times in organizing technical conferences sponsored by IEEE and OSA and was the General Co-Chair in 2001 for the Quantum Electronics and Laser Science (QELS) Conference. From 2008 to 2010 Dr. Agrawal was a member of the OSA Board of Directors and chaired the OSA Publication Council. Dr. Agrawal is a Fellow of both the Optical society of America (OSA) and the Institute of Electrical and Electronics Engineers (IEEE). He is also a Life Fellow of the Optical Society of India.

NEGATIVE REFRACTION IN MULTILAYER METAMATERIALS

A general theory of light propagation in periodic stratified heterostructures is developed to show that such devices exhibit a negative refractive index over a range of incident wavelengths . The periodic structure is allowed to contain an arbitrary number of homogeneous, isotropic, nonmagnetic layers in each unit cell. Employing a novel 4x4 matrix technique, we derive analytic expressions for the normal modes of such a heterostructure slab, introduce the average refraction angles of the energy flow and wave vector for the TE- and TM-polarized plane waves falling obliquely on the slab, and derive expressions for the reflectivity and transmissivity of the whole slab. Using the example of a semiconductor heterostructure slab with two layers in a unit cell, we demonstrate that ultrathin layers are preferable for metamaterial applications because they enable higher transmissivity within the frequency band of negative refraction. Our theory can be used to study the optical properties of any stratified metamaterial, irrespective of whether semiconductors or metals are employed because it includes absorption within each layer.

With I. D. Rukhlenko and M. Premaratne, Monash University, Australia

EKATERINA POUTRINA - DUKE UNIVERSITY

Dr. Ekaterina Poutrina received the MS degree in Physics from Moscow State University in 1991 and MS and PhD degrees from the Institute of Optics, University of Rochester in 2003 and 2005, respectively. She is currently a Research Assistant Professor at the Center for Metamaterials and Integrated Plasmonics at Duke University.

Her research interests include active and nonlinear metamaterials, nonlinear plasmonics, and the manifestation of quantum effects in composite media, with the focus on tailoring optical nonlinearities and quantum properties of the composite medium through the mechanisms of field enhancement, controlled dispersion and anisotropy, and tailored photonic density of states.

ENHANCEMENT OF FOUR WAVE MIXING PROCESSES BY NANOWIRE ARRAYS COUPLED TO A GOLD FILM

We consider the process of four-wave mixing (FWM) in a system of an array of gold nanowires strongly coupled to a gold film. Using full-wave simulations, we perform a quantitative comparison of the FWM efficiency associated with the thin film geometry with and without the nanowire arrays. When the nanowire array is present, both the delocalized surface plasmon of the film as well as the localized surface plasmon resonances of the nanowires contribute to the local field enhancement, yielding an overall FWM efficiency enhancement of several orders of magnitude over a wide range of excitation angles.

With David R. Smith, Duke University

PARAS N. PRASAD - UNIVERSITY AT BUFFALO

Dr. Paras N. Prasad is a SUNY Distinguished Professor of Chemistry, Physics, Medicine and Electrical Engineering, the highest rank in the New York State university system. He has the highly unusual distinction of being a faculty member in three different UB schools: College of Arts and Sciences, School of Engineering and Applied Sciences, and the School of Medicine and Biomedical Sciences. He also holds the Samuel P. Capen Chair at the University at Buffalo. He is the Executive Director of the multidisciplinary Institute for Lasers, Photonics and Biophotonics. He has published over 646 scientific papers, co-edited six books, written three monographs, and holds over 20 patents

His current areas of research are (i) Hybrid Nanomaterials (ii) Nanophotonics (iii) Biophotonics and (iv) Nanomedicine. The application targeted are to Solar Energy, Nanobiotechnology, Environment and Information Technology. Dr. Prasad has received much recognition for his pioneering contributions. He is a Fellow of the American Physical Society, a Fellow of the Optical Society of America, a Fellow of the SPIE, and a recipient of the prestigious Sloan and Guggenheim fellowships. Dr. Prasad has received the Schoellkopf Award, "Excellence in Pursuit of Knowledge" award, and is a recipient of the Morley Prize. He was chosen Scientific American's Top 50 Scientists (2005), and awarded a State of New York Legislative Resolution Honoring Dr. Prasad (2006).

CHIRAL METAMATERIALS: A BOTTOM-UP APPROACH

The unique electromagnetic behavior of metamaterials stems from the structure and properties of their subwavelength constituent nanostructures. In order to realize metamaterials at optical frequencies, top-down techniques such electron-beam lithography or focused ion beam milling are typically used to tailor the features of carefully chosen constituent materials with nanoscale resolution. Though providing adequate resolution, these techniques tend to be limited to the fabrication of planar materials and associated with high-cost and low-throughput. In this presentation we present a bottom-up chemical approach to metamaterials that holds promise for the low-cost and high-throughput fabrication of polymeric metamaterials for use in the IR and visible range. This approach seeks to leverage chirality, a material property that can be tuned to render negative refractivity with low loss for circularly polarized light. In our research, we exploit chirality at multiple length scales. At the smallest scale, chirality is realized at the molecular level via the synthesis of novel chiral polymers. Metallic particles are dispersed within a film of these molecules to achieve further plasmonic enhancement of the molecular chiral response. The film is then patterned into arrays of chiral elements using two-photon lithography. This patterning couples the intrinsic enhanced molecular chirality of the film with the larger scale geometric chirality. In this presentation we provide an overview of the chiral approach to metametrials and present theoretical and experimental results for materials and structures produced to date.

ILDAR R. GABITOV - UNIVERSITY OF ARIZONA

Ildar R. Gabitov received his Ph.D. in Theoretical and Mathematical Physics from Landau Institute for Theoretical Physics in 1984. Professor Gabitov joined the faculty of the Department of Mathematics, University of Arizona in 2002. He is currently on leave from University of Arizona and is Betty Clements Chair of Applied Mathematics at the Southern Methodist University. Previously, he held a position of an Associate Senior Researcher at the Landau Institute for Theoretical Physics, Moscow, a Visiting Professor at Aston University, UK, and a Staff Member at the Theoretical Division of Los Alamos National Laboratory. Prof. Gabitov's research interests and experience include: mathematical and theoretical physics, nonlinear optics, optical fiber communications, nonlinear metamaterials. Prof. Gabitov is a recipient of Theoretical Division Award of the Los Alamos National Laboratory in 2002 and Galileo Fellow Award in 2004.

OPTICAL PULSE DYNAMICS IN AN ACTIVE NEGATIVE INDEX METAMATERIALS

Optical pulse dynamics in an active optical metamaterials is considered for the cases of two level and Λ-configuration atoms. A new model generalizing the Maxwell-Lorenz system is derived to describe and analyze electromagnetic field interaction with hybrid nanostructured materials. Active metamaterial considered in this case consist of magnetically active metallic structures with embedded two level atoms. Electrodynamics of metamaterials composed with a host dielectric with embedded Λ-configuration atoms containing magnetically active structures is also considered. Coherent loss compensation for short optical pulses was considered in the first case. Polarization dynamics of optical pulses was analyzed in the second case

GROVER A. SWARTZLANDER, JR. - ROCHESTER INSTITUTE OF TECHNOLOGY

Dr. Swartzlander received a B.S. in physics from Drexel University, and an M.S.E.E. degree in physics and electrical engineering from Purdue University. He completed his Ph.D. work at the Johns Hopkins University in the field of nonlinear optics. He is credited with the experimental discovery of the optical vortex soliton, which is the optical analog of vortices in Bose-Einstein condensates. More recently, he is a co-inventor of the optical vortex coronagraph, which will be used by astronomers to discover exoplanets and detect signs of life in planetary spectra. Additionally, he is currently exploring novel three-dimensional imaging techniques. An exciting new branch of his research involves the ability to make specially shaped objects fly with light. Dr. Swartzlander is a fellow of the Optical Society of America, and serves on both the Fellows Board and the Publications Board of the OSA.

SUPER-RESOLVED FEATURES USING AN OPTICAL VORTEX CORONAGRAPH

Resolution criteria in an imaging system arise because high spatial frequency information is lost in the glare of the dominant zero spatial frequency component. A means of extinguishing this latter component using an optical vortex coronagraph will be discussed. This scheme opens the possibility of using a small aperture lens to achieve super-resolved features, thereby obviating the need for complex adaptive optics systems.

MICHAEL SCALORA - U.S. ARMY AVIATION AND MISSILE COMMAND, CHARLES M. BOWDEN RESEARCH FACILITY

Dr. Michael Scalora earned his MS (1988) and PhD (1990) in Physics from Rensselaer Polytechnic Institute. Scalora is currently a Research Physicist with the U.S. Army, Aviation and Missile Command at the Research, Development and Engineering Center. He has written 180 peer-reviewed publications and contributed to over 300 international conferences/workshops. Scalora has 15 US patents and has been a member of the Optical Society of America (OSA) since 1988 and was an elected fellow of the OSA in 2006.

CLASSICAL AND QUANTUM OPTICS IN METAL-BASED NANO-STRUCTURES AND EPSILON-NEAR-ZERO MATERIALS: STIMULATED SCATTERING AT VISIBLE AND UV WAVELENGTHS

Stimulated Raman scattering consists of the inelastic scattering of photons, and as such it is a ubiquitous process. A red-shifted signal called the Stokes field and/or a blue-shifted component, referred to as the anti-Stokes field, are generated, co-propagate and mutually interact. I will present a study of the nonlinear response of Raman-active media embedded near and inside the apertures that form a metal grating in the enhanced transmission regime, and compare to the nonlinear response in uniform so-called epsilon-near-zero materials.

JOSEPH W. HAUS - UNIVERSITY OF DAYTON

Joseph W. Haus received a Ph.D. in Physics in 1975 from Catholic University of America. Since 1999 he has been at the University of Dayton, where serves as the Director of the Electro-Optics Program and from 2006 he is the founding Director of the Air Force funded LADAR and Optical Communications Institute (LOCI). He is a fellow of the Optical Society of America (OSA), the SPIE and the American Physical Society (APS).

He published more than 200 papers and has organized several conferences, including the OSA sponsored International Conference on Nanophotonics, where he served as the Conference Chair. His recent research is largely devoted to linear and nonlinear optical properties of heterogeneous materials, including photonic crystals and metamaterials. He has 5 patents or patent disclosures

CYLINDRICAL POLARIZATION OF COHERENT LIGHT FOR SENSING AND INFORMATION TRANSFER

Cylindrical polarization states of the electromagnetic field have provided a new paradigm enabling higher performance optical systems and new functionality of photonic devices. In this talk I report our research on fiber sources emitting cylindrical polarized light, and nonlinear optical and linear atmospheric propagation effects using these states. The development of fiber sensors is proposed and is a nascent application we envision using these states.

NATALIA M. LITCHINITSER- UNIVERSITY AT BUFFALO

Natalia M. Litchinitser earned her Ph.D. degree in Electrical Engineering in 1997 from the Illinois Institute of Technology and a Master's degree in Physics in 1993 from Moscow State University in Russia. Prof. Litchinitser joined the faculty of the department of Electrical Engineering at the State University of New York at Buffalo as Assistant Professor in 2008. She was promoted to Associate Professor position in 2011 (effective August 2011).

Prior to coming to the State University of New York at Buffalo, she conducted research at the University of Michigan, Ann Arbor. Natalia Litchinitser previously held a position of a Member of Technical Staff at Bell Laboratories, Lucent Technologies and of a Senior Member of Technical Staff at Tyco Submarine Systems. Natalia Litchinitser's research interests include linear and nonlinear optics in metamaterials, photonic devices, and optical communications. She authored 5 invited book chapters, over 70 journal and conference research papers, and over 20 invited conference talks. Natalia M. Litchinitser is a Fellow of the Optical Society of America.

METAMATERIALS AS A POTENTIAL NEW PLATFORM FOR SPIN-OPTICS

Recent developments in the field of metamaterials and transformation optics enable unprecedented control over light propagation and a possibility of "designing" space for light propagation; opening a new paradigm in spin-optics - a fascinating emerging area of modern optics that considers spin and angular momentum properties of light and therefore, brings a new dimension to the science of light. In this talk, we review our recent theoretical and experimental studies of light-matter interactions in such "engineered" nanostructures, including inhomogeneous, nonlinear and magnetic metamaterials. We discuss the phenomena of bistability, anomalous field enhancement, resonant absorption, and strong polarization sensitive light propagation phenomena.