Optics and Photonics
Winter School and Workshop

University of Arizona College of Optical Sciences

Tucson, Arizona

January 4, 2017 – January 8, 2017

College of Optical Sciences
The University of Arizona

DeMund Foundation

Gretler Foundation

NSF

SPIE. Connecting minds. Advancing light.

OSA The Optical Society

TRIF

Alfred P. Sloan Foundation 1934

Optics and Photonics Winter School & Workshop 2017

Optical Sciences Organizing Committee

Poul Jessen
R. Jason Jones
Dae Wook Kim
John Koshel
Masud Mansuripur
Judith Su

External Advisory Committee

Jonathan Friedman, Universidad Metropolitana
Theresa Lynn, Harvey Mudd College
Jenny Magnes, Vassar College

Special Thanks to Our Sponsors:

Alfred P. Sloan Foundation
DeMund Foundation
Gretler Foundation
National Science Foundation
OSA
SPIE
TRIF

Schedule – Optics and Photonics Winter School 2017

Wednesday, Jan. 4, 2017

(All sessions at Optical Sciences 307)

8:50	**Welcome**	Dean Tom Koch
9:00	*Introduction to Optical Engineering*	Prof. Jim Schwiegerling
10:00	Break	
10:20	*Astronomical Optics*	Prof. Dae Wook Kim
10:50	Break	
11:00	*Optics and the Human Eye*	Prof. John Greivenkamp
11:30	**Lunch**	
1:00	**Lab Tours**	
3:00	*Introduction to Photonics*	Dean Tom Koch
4:00	Break	
4:20	*Nanophotonics*	Prof. Euan McLeod
4:50	Break	
5:00	*Optics, Photonics, and Solar Energy*	Prof. Roger Angel
5:30	**Lab Tours** (Including the Richard F. Caris Mirror Lab)	
7:00	**Dinner**	

Thursday, Jan. 5, 2017

(All sessions at Optical Sciences 307)

9:00	*Introduction to Imaging Science*	Prof. Lars Furenlid
10:00	Break	
10:20	*Polarization*	Prof. Russell Chipman
10:50	Break	
11:00	*Optics in Biology and Medicine*	Prof. Jennifer Barton
11:30	**Lunch**	
1:00	**Lab Tours**	
3:00	*Introduction to Optical Physics*	Prof. R. Jason Jones
4:00	Break	
4:20	*Quantum Optics*	Prof. Theresa Lynn
4:50	Break	
5:00	*Biosensing with Optical Resonators*	Dr. Judith Su
5:30	**Lab Tours/Free Time**	
6:00	**Dinner**	
7:00	**Poster Session and Workshop Welcome Reception**	

Schedule- Optics and Photonics Workshop 2017

FRIDAY, JAN. 6, 2017 (CAREER DAY)

Keynote Morning Session (ILC 130)

8:15 Tom Koch, University of Arizona
Welcome to the Optics and Photonics Workshop

8:30 David Reitze, Executive Director of LIGO, Caltech
The Final Ballet of Binary Black Holes: LIGO and the Dawn of Gravitational Wave Astronomy

9:45 **Break**

10:15 John Hayes, co-founder of 4D Technology (UA Optics Alumnus)
Light, Passion, and Getting a Life

11:00 Eugene Arthurs, SPIE
How Optics and Photonics Continues to Change Our World

11:45 **Lunch** (Optical Sciences)

(Afternoon sessions at Optical Sciences 307)

1:30 David Hagan, University of Central Florida, CREOL
Programs in Optics and Photonics at CREOL

2:00 Laura Coyle, Ball Aerospace (UA Optics alumnus)
Observations of an Early Career Optical Engineer

2:20 Souma Chaudhury, Intel (UA Optics alumnus)
What I did with my PhD in Optics

2:40 Panel Discussion on Careers in Optics

3:40 **Break**

4:00 Andrew Berger, University of Rochester, The Institute of Optics
Flipping the Electromagnetic Theory Classroom - Lessons Learned

4:30 Selim Unlu, Boston University
New Frontier in Diagnostics: Digital Protein Microarrays

5:00 Peter Smith, University of Arizona
The Joy of Space Exploration

5:30 **Lab Tours** (Including the Richard F. Caris Mirror Lab)

7:00 **Banquet** (Silver and Sage Room, UA campus)
Banquet Speaker: Michael Hart, University of Arizona

SATURDAY, JAN. 7, 2017

(All sessions at Optical Sciences 307)

8:30 **Keynote**: Elizabeth McCormack, Bryn Mawr College
The Creation and Deployment of Computational Learning Modules and Phys21: Preparing Physics Students for 21st Century Careers

9:15 James Clemens, Miami University
Optics at Miami University

9:45 Gary Bernstein, University of Notre Dame
A Modern Introduction to Electrical Engineering Laboratory Course at the University of Notre Dame

10:15 **Break**

10:45 Katharina Gillen, California Polytechnic State University, San Luis Obispo
Quantum Computing with Atoms and Light

11:15 Steven Olmschenk, Denison University
Ions and Photons for Quantum Information

11:45 Michaela Kleinert, Willamette University
Ultracold and Ultrafast. AMO Research at Willamette

12:15 **Lunch**

1:30 Charles Falco, University of Arizona
Optics & Art History

2:00 Ana Oprisan, College of Charleston
Optical Methods Used to Investigate Nanocolloids

2:30 Jenny Magnes, Vassar College
Women in the Sciences

Panel Discussion (Laura Coyle, Enrique Galvez, Theresa Lynn, Elizabeth McCormack, Will Williams)

3:30 **Break**

4:00 Nathan Lindquist, Bethel University
Plasmonic Nano-Imaging and Nano-Tweezing

4:30 Travis Gould, Bates College
Biological Imaging Beyond the Diffraction Limit Using STED Nanoscopy

5:00 Caroline Boudoux, Polytechnique Montreal
Dedicated Fiber Optics for Biomedical Imaging: Translation and Commercialization

5:30 **Lab Tours/Free Time**

7:00 **Dinner** (Reforma, next to Homewood Suites)

Sunday, JAN. 8, 2017

(Morning session at Optical Sciences 307)

8:30 **Keynote**: Gabriel Spalding, Illinois Wesleyan University
Just another day at the office: faster-than-light imaging and violations of local realism

9:15 Joe Shaw, Montana State University
Optics Education and Research in Montana

9:45 Enrique Galvez, Colgate University
Spatially Variable Polarization

10:15 **Break**

10:45 Will Williams, Smith College
Testing Quantum Electrodynamics with the Beryllium Atom

11:15 Gregory Ogin, Whitman College
Measuring the Thermo-Optic Properties of Dielectric Stack Mirror

11:45 Poul Jessen, University of Arizona
Quantum Control versus Chaos

12:15 Lunch

2:00 Trip to **Arizona-Sonora Desert Museum**

5:00 Dinner at the Arizona-Sonora Desert Museum

Abstracts – Workshop Oral Presentations

Friday, Jan. 6, 2017

8:30 Keynote: David Reitze, Executive Director of LIGO, Caltech
The Final Ballet of Binary Black Holes: LIGO and the Dawn of Gravitational Wave Astronomy
In late 2015, scientists observed the collision and fusion of two black holes by directly measuring the gravitational waves emitted during their collision. This detection, from the LIGO Scientific Collaboration and the Virgo Collaboration, comes 100 years after Einstein developed his revolutionary General Theory of Relativity that predicted the existence of gravitational waves, and 50 years after scientists began searching for them.

10:15 Eugene Arthurs, SPIE
How Optics and Photonics Continues to Change Our World

11:00 John Hayes, Co-founder of 4D Technology (UA Optics Alumnus)
Light, Passion, and Getting a Life

1:15 David Hagan, University of Central Florida, CREOL
Programs in Optics and Photonics at CREOL

2:00 Laura Coyle, Ball Aerospace (UA Optics alumnus)
Observations of an Early Career Optical Engineer

2:20 Souma Chaudhury, Intel (UA Optics alumnus)
What I did with my PhD in Optics

4:15 Andrew Berger, University of Rochester, The Institute of Optics
Flipping the Electromagnetic Theory Classroom - Lessons Learned

4:30 Selim Unlu, Boston University
New Frontier in Diagnostics: Digital Protein Microarrays

Detecting proteins and nanobioparticles using microarray technologies enables resolution and sensitivity beyond the reach of ensemble measurements.

5:00 Peter Smith, University of Arizona
The Joy of Space Exploration

Saturday, Jan. 7, 2017

8:30 Keynote: Elizabeth McCormack, Bryn Mawr College

The Creation and Deployment of Computational Learning Modules and Phys21: Preparing Physics Students for 21st Century Careers

Our computational instruction project is motivated by a desire to improve student learning of computer programming and algorithmic thinking. The approach is designed to minimize the impact on time-to-degree and faculty staffing demands. It purposely integrates skill building with content knowledge and emphasizes a culturally inclusive learning environment in an effort to improve the persistence and success of all students.

The computational instruction is designed around a sequence of learning modules that use a combination of online and classroom instruction. The modules incorporate computational techniques in the context of scientific applications. They include exercises to provide practice in applying these techniques and assessments for students to demonstrate mastery. In a flipped approach, the modules are made available online to be read before class, and in class students work together to complete the exercises. Questions can be immediately addressed and peer learning and collaboration takes place naturally. First developed and deployed in the context of a stand-alone course, these modules are now embedded in core physics courses throughout the major sequence. In this way students progressively learn and practice essential computational skills continually while earning their degree.

In this presentation I will share what has worked in using the learning modules with embedded exercises and assessment; our experience of using web-based computational notebooks on a dedicated server; what we've tried and learned from attempting to create a culturally inclusive learning environment, for example our use of hybrid journals, student generated scientist profiles, and student consultants for feedback; and we will report on the experiences of students using the modules.

I will also present the major findings of the report *Phys21: Preparing Physics Students for 21st Century Careers* commissioned by the APS and the AAPT and prepared by the Joint Task Force on Undergraduate Physics Programs (J-TUPP). The report addresses the following question: What skills and knowledge should the next generation of undergraduate physics majors possess to be well prepared for a diverse set of careers? We were particularly interested to understand better the needs of students who do not plan to pursue academic careers. In answering this question, we developed guidelines for revising the undergraduate curriculum, addressing the needs of an increasingly diverse population of students, providing professional skills development, and enhancing student engagement through high impact teaching practices.

9:15 James Clemens, Miami University

Optics at Miami University

I will attempt to give a broad overview of optics research going on in the physics department at Miami University. The physics department consists of fifteen full time faculty members of whom eleven are active in research. We have about 100 undergraduate majors and about 20 MS students.

9:45 Gary Bernstein and Kerry Meyers, University of Notre Dame

A Modern Introduction to Electrical Engineering Laboratory Course at the University of Notre Dame

A modern Introduction to Electrical Engineering Laboratory Course has been taught for the second time at the University of Notre Dame. The 80 students in the course come from the Departments of Electrical Engineering, Computer Engineering and Mechanical Engineering. This course incorporates several learning objectives for gaining knowledge and skills in the following areas: Topics of societal relevance in electrical engineering; a knowledge and skill set in the use of common electrical bench test equipment; a working knowledge of concepts that relate time domain and frequency domain; a basic knowledge in several areas that relate to their every-day experiences and that will prepare them for courses that appear later in their curriculum.

The course comprises nine written chapters covering various topics, eleven lectures including an overview of undergraduate research opportunities in Electrical Engineering at Notre Dame, and ten 3-hour laboratory sessions. The topics of the ten week's of labs are: 1) introduction to electronic components, in which students solder an AM radio kit to be used in a later lab; 2) introduction to basic bench equipment including function generator, power supply, digital multimeter and oscilloscope; 3) the power grid, power transmission, and house wiring; 4) concepts in time and frequency domains, frequency spectra, and filters; 5) radio transmission in which students broadcast music to their own AM radios on the lab bench and view the signal in both time and frequency domains; 6) semiconductors, including basic circuit bread-boarding and testing of various amplifier circuits (without analysis); 7) issues in energy conservation and renewable energy in which students test various types of light bulbs and determine their relative efficiency, and test solar cells on the lab bench; 8) demonstrations of analog-to-digital (ADC) and digital-to-analog (DAC) conversion, including aliasing, all in the time and frequency domains; 9) a second week of experimenting with sampling and 10) experiments with batteries and building power supplies.

Several custom electronic demonstrators were developed for these labs, including a low-voltage three-phase power supply, a custom light enclosure for simple light-bulb measurements, a custom ADC/DAC demonstrator board, and a fast timer for short-circuit battery testing.

In my talk I will provide details of each of the lab experiences, show the results of what students do in the labs, and provide results of a survey that gauged student learning and attitudes.

10:45 Katharina Gillen, California Polytechnic State University, San Luis Obispo

Quantum Computing with Atoms and Light

Quantum computers promise to be able to perform some tasks impossible on any supercomputer, including code breaking and simulations of large quantum systems, by exploiting the quantum mechanics phenomena of superposition and entanglement. One of the many approaches currently being explored, neutral atom quantum computing, uses atoms trapped and manipulated by light as its quantum bits (qubits). The remaining challenge of this approach is finding a light pattern that allows scaling up to many qubits without losing the ability to address individual qubits without disturbing their neighbors.

In our work at Cal Poly, we have shown computationally that the bright and dark spots in the diffraction pattern immediately behind a pinhole can serve as atom traps that can be moved together and apart to facilitate two-qubit gates. This approach can be scaled up by using a 2D array of pinholes. We will present computational results on the properties of these light patterns as well as our experimental progress towards realizing them in the lab, highlighting our undergraduate students' role in this work.

11:15 Steven Olmschenk, Denison University

Ions and Photons for Quantum Information

Trapped atomic ions are one of the leading candidates for applications in quantum information, due to their long trapping times, good coherence properties, and precise control of the atomic quantum states. Integrating this quantum memory with photons establishes a unique path to both long-distance quantum communication and scalable quantum computation.

The basic operations of reading, writing, and manipulating quantum information can be implemented in trapped atomic ions with laser and microwave radiation. We are currently working with barium ions (produced by laser ablation), which can be laser cooled using visible laser light (650 nm and 494 nm). Here, the red (650 nm) light used to prevent population trapping in the low-lying D-state is directly produced by a custom extended cavity diode laser (ECDL). The blue (494 nm) light for laser cooling is generated by frequency-doubling the light from an ECDL operated near 987 nm in a custom second-harmonic generation cavity. The odd isotopes of barium allow for a hyperfine-encoded quantum bit that may be initialized and measured using this laser light, while single-qubit operations may be implemented using resonant microwaves.

Laser excitation of an ion combined with polarization selection of an emitted photon may be used to entangle the ion and photon. When two such setups are combined with Hong-Ou-Mandel interference between the photons, it is possible to create entanglement between two distant atoms. By scaling this system to multiple nodes, it should be possible to establish an architecture for quantum communication over long distances.

While several challenges to scalability remain in this system, many may be alleviated by working with telecom-compatible wavelengths. To accomplish this, we proposed using doubly-ionized lanthanum as an atomic qubit, which has the advantage of transitions compatible with telecom fiber, but also presents a new set of challenges. We have made significant progress toward this goal, and aim to demonstrate laser cooling and trapping of doubly-ionized lanthanum in the future.

11:45 Michaela Kleinert, Willamette University

Ultracold and Ultrafast. AMO Research at Willamette

Willamette University is a liberal arts college located in Salem, OR. The physics department places a big emphasis on meaningful research experiences to prepare our majors for STEM careers after they graduate from Willamette. In this talk I will introduce you to my research projects on ultracold atoms and ultrafast lasers. The ultracold project focuses on the production of ultracold clouds of rubidium and calcium atoms with the goal of forming the polar molecule RbCa. So far, RbCa has only been formed on helium nanodroplets, but never from ultracold constituent atoms. Because RbCa has two permanent dipole moments, electric and magnetic, it can be manipulated in crossed electric and magnetic fields, leading to interesting dynamics. The ultrafast project focuses on laser ablation with nano-second and pico-second lasers, both by studying the crater that the laser pulse leaves behind on a metallic sample, as well as on the light that is emitted during and shortly after the ablation phase. We are currently focusing on brass, but have also begun looking into more exotic materials like metallic glasses.

1:30 Charles Falco, University of Arizona

Optics & Art History

In this talk I will show optical evidence for discoveries made with the artist David Hockney that convincingly demonstrate optical instruments were in use -- by artists, not scientists -- nearly 200 years earlier than commonly thought possible, and that account for the remarkable transformation in the reality of portraits that occurred early in the 15th century.

2:00 Ana Oprisan, College of Charleston

Optical Methods Used to Investigate Nanocolloids

Colloidal suspensions are ideal systems for investigating the spatio-temporal evolution of density fluctuations using optical methods since they have particle sizes larger than the characteristic size of atomic or molecular systems. We performed direct imaging experiments in order to investigate the non-equilibrium concentration-driven fluctuations using magnetic nanoparticles. The results from direct imaging are compared to those obtained from shadowgraphy in the same conditions. Our direct experimental setup involved a sample cell unit (SCU) filled with magnetic nanocolloidal suspension and water with the concentration gradient oriented against the gravitational field, a superluminescent diode (SLD) as the light source, and a collimator lens. For direct imaging, we added a microscope objective in front of the CCD camera whereas for the shadowgraph technique we only use an achromatic doublet between the SCU and the camera. A differential dynamic algorithm was used to extract the structure factor and eventually find power law exponents. Here we discuss the main differences between the two optical methods as well as the impact of an external magnetic field on non-equilibrium concentration fluctuations.

2:30 Jenny Magnes, Vassar College

Women in the Sciences

4:00 Nathan Lindquist, Bethel University

Plasmonic nano-imaging and nano-tweezing

The basic components of cells, viruses, and nano-devices are too small to individually probe, manipulate, and image with light due to diffraction. As one solution, the interdisciplinary field of metallic nano-plasmonics allows manipulating light with sub-wavelength precision: localized plasmons squeeze optical energy into ~10 nm hotspots while propagating plasmons only extend ~100 nm into their surrounding environment and have shorter wavelengths than free-space light. Because of these “near-field” effects, plasmons have been explored for many applications. In particular, plasmonic nano-imaging and nano-tweezing have generated immense interest to trap, probe, manipulate, and image nano-sized objects such as viruses, nanoparticles, and individual molecules. This talk will cover some of the background and current research at Bethel University in these areas. In particular, plasmon resonances in nano-structured silver films have shown promise as super-resolution imaging substrates. Since the localized fields are also very intense, surface enhanced chemical spectroscopy is performed at the same time, allowing super-resolution chemical imaging of biological structures, surfaces of cells, and other nano-structures. These intense fields are also capable of trapping and manipulating these nano-objects, giving researchers access to a wide range of novel experiments.

4:30 Travis Gould, Bates College

Biological Imaging Beyond the Diffraction Limit Using STED Nanoscopy

Fluorescence microscopy is no longer limited in spatial resolution by diffraction. A new class of microscopy techniques now provides diffraction-unlimited resolution in the far-field by exploiting the photophysical properties of fluorescent molecules. For example, in stimulated emission depletion (STED) microscopy, fluorescent molecules located near the periphery of the excitation volume are quenched through stimulated emission. Using this targeted switching approach to engineer sub-diffraction focal volumes, it has been possible to image biological structures with resolution on the order of a few tens of nanometers.

Here we review the principles of STED nanoscopy and present recent work on developing adaptive optics in STED for three-dimensional imaging of thick specimens and the application of STED to resolve the nanoscale organization of chromatin in HL-60/S4 (human myeloid leukemic) cells. We also highlight the involvement of undergraduate research assistants in developing an advanced fluorescence imaging laboratory at Bates College.

5:00 Caroline Boudoux, Polytechnique Montreal

Dedicated Fiber Optics for Biomedical Imaging: Translation and Commercialization

Sunday, Jan. 8, 2017

8:30 Keynote: Gabriel Spalding, Illinois Wesleyan University

Just another day at the office: faster-than-light imaging and violations of local realism

We are entering the '3rd Age' of high-speed imaging. The first age was limited by the inertial response of a mechanical shutter. The second age bypassed that limit via electronic shuttering (turning circuitry on and off). The new era is demarked by essentially *optical* shuttering techniques, which allows — surprisingly — for 'faster-than-light' (FTL) imaging. We have experimentally produced [1] a movie of something that is, in a basic sense, traveling backwards in time. While, there are clear physical limitations of such methods, we believe that the new age of photonic imaging promises to open entirely new worlds of possibilities for inquiry and explanation. — As time allows, we may introduce our ongoing experimental exploration of the Arrow of Time (and the emergence of the Second Law of Thermodynamics).

In a separate experiment, mostly using the same equipment, we demonstrate what Einstein termed 'spooky action at a distance.'[2] — Suppose that a *single* photon is found to deposit its energy within a particular, micrometer-scale pixel of a very sensitive, low-noise camera (which we accomplish by using the same advanced imaging and detection technologies that we've used for FTL imaging). We might then ask where that photon was *just before* that measurement was made. It seems, at first, a very simple question, but there are three possible kinds of answers:

a) The realist says that the particle was at, or very near, the location of that pixel.

b) The orthodox physicist says the particle wasn't really anywhere, because of wave-particle duality: a fundamental physical particle, such as a photon, can be said to deposit energy like a spatially localized particle, but propagates like a spatially extended wave. Thus, before detection, the particle *had no well-defined position*.

c) The agnostic says that asking such a question makes no sense, as the only way to determine the answer *seems* to be to perform the measurement, at which point you are no longer determining the state of things before the measurement was made!

In spite of the initial appeal of agnosticism, it turns out that this *is* an experimentally addressable issue.

...Day in, day out, we find ourselves extracting fundamental lessons from advanced imaging experiments.

Citations:

[1] "Observation of image pair creation and annihilation from superluminal scattering sources," M. Clerici, G. C. Spalding, R. Warburton, A. Lyons, C. Aniculaesei, J.M. Richards, J. Leach, R. Henderson, D. Faccio, *Science Advances* **2**, e1501691 (2016); arXiv:1512.02622

[2] "Video Recording true single-photon double-slit interference," R.S. Aspden, M.J. Padgett, G. C. Spalding, *American Journal of Physics* **84**, 671 (2016); http://scitation.aip.org/content/aapt/journal/ajp/84/9/10.1119/1.495517

[3] "Ghost Imaging," M. Padgett, R. Aspden, G. Gibson, M. Edgar and G. C. Spalding, *Optics & Photonics News* **27** (10) 38-45 (2016); http://www.osa-opn.org/home/articles/volume_27/october_2016/features/ghost_imaging/

9:15 Joe Shaw, Montana State University

Optics Education and Research in Montana

One of the highest per-capita concentrations of optics and photonics companies is in the small town of Bozeman, Montana, the home of more than thirty optics and photonics companies. Many of these companies are spin-offs from research at Montana State University, and many were founded by our graduates who chose to stay and create their own job rather than leave the area. We train optics students at all levels, from associate-degree technicians to Ph.D. researchers. This talk will summarize the current Montana optics activities in academia and industry and review the things we are doing to create and nurture this dynamic optics and photonics cluster.

9:45 Enrique Galvez, Colgate University

Spatially Variable Polarization

10:45 Will Williams, Smith College

Testing Quantum Electrodynamics with the Beryllium Atom

The fundamental goal of atomic physics is to understand the complex interactions and inner workings of the atom. Our knowledge of atomic systems is driven by both experimental and theoretical results. Theoretical calculations generally become more difficult as the neutron, proton, and electron number increases. During the last 80 years, research on the helium and lithium atoms have served to calibrate various quantum mechanical methods. For helium, numerical methods have more than 40 digits accuracy and are more precise than the best experiments. For lithium, the accuracy achieved is up to 14-15 digits.

The beryllium atom is theoretically difficult because we have to consider the interactions of four electrons simultaneously. Four-electron integrals are difficult to solve and computationally expensive. While the theoretical precision for beryllium still lags behind the other light elements, recent improvements in theoretical methods has resulted in more accurate theoretical predictions (9 digits) than current experimental results for several energy levels.

The most precise measurements of beryllium occurred over 50 years ago for most of the energy levels with a precision of 6-7 digits. For comparison, experimental energy levels for the lighter elements are known up to 15 digits.

The Smith College atomic physics lab has begun performing high precision spectroscopy on the singlet states for the stable isotope beryllium-9, which will significantly improve the uncertainty over previous measurements by factors of 500 - 1800. In this talk, I will tell you about our current experimental setup and the progress we have made in improving the experimental accuracy on the lowest singlet state in beryllium.

11:15 Gregory Ogin, Whitman College

Measuring the Thermo-Optic Properties of Dielectric Stack Mirror

Thermo-optic noise (apparent motion of the surface of a dielectric stack mirror due to optical effects generated by random temperature fluctuations) was predicted to be within a factor of 10 of Advanced LIGO's noise floor. Since there was significant uncertainty in the values of the coefficient of expansion and dn/dT (change in index of refraction with temperature) for the thin-film materials used to make the mirrors, we set up an experiment to measure them in-situ, and verify technical details of the thermo-optic effect. In this talk I will describe the experiment, results, and continued work.

11:45 Poul Jessen, University of Arizona

Quantum Control versus Chaos

Quantum mechanics has been the "theory of everything" for about a century, accounting for the behavior of light and matter at all scales from the microscopic to the macroscopic. Modern physics is now increasingly focused on a new challenge: how do we make quantum systems behave the way we want, rather than having them do what comes naturally to them? This is opening up an entirely new field of "quantum engineering", in which quantum mechanics itself becomes the foundation for new technology.

This presentation touches on three main themes of importance for the budding quantum engineer. The first is the idea of "Control" as a scientific discipline, a way of developing a generic toolbox for control of classical and/or quantum systems. The second is the idea of "Chaos", a phenomenon that occurs in most complex systems and which manifests itself as hypersensitivity to the tiniest perturbations (the "butterfly effect"). And the third is the idea of "Simulation", in which a "well controlled" quantum system is used to simulate another, an idea that is now widely pursued as a means to model and understand quantum solids. The discussion will be illustrated throughout with results from experiments that use individual Cesium atoms as a test bed for quantum control and quantum simulation.

Poster Session

7:00 pm. Thursday, Jan. 5, 2017

Poster 1 – Linda Gong, University of Notre Dame

Digitally-Controlled Frequency Generation Using Variable Length Ring Oscillators

A simple variable-length ring oscillator (VLRO) in which a selectable number of inverters is shunted using bypass transistors is introduced. A range of frequencies can be selected by activating or de-activating the bypass circuitry. LTspice simulations demonstrating the performance are presented. BSIM4 transistor models using 50 nm gate lengths are used in the design of the inverters and bypass transistors. The fundamental frequency generated by each VLRO is determined via Fourier transforms of the output square wave. The data show that the VLRO can effectively generate a wide range of frequencies in a large number of steps based on the selection of bypass transistors that are activated. The prototypical circuit presented here uses 45 CMOS inverters to generate a range of frequencies between about 0.56 GHz and 1.4 GHz. Four different VLROs that demonstrate the ability to synthesize frequencies based on external inputs are presented. Based on the chosen VLRO design, anywhere from 6 to 16 unique frequencies can be selected over the frequency range.

Poster 2- Anthony Young, Miami University

Quantitative assessment of reactive hyperemia using laser speckle contrast imaging at multiple wavelengths

Reactive hyperemia refers to an increase of blood flow in tissue post release of an occlusion in the local vasculature. Measuring the temporal response of reactive hyperemia, post-occlusion in patients has the potential to shed information about microvascular diseases such as systemic sclerosis and diabetes. Laser speckle contrast imaging (LSCI) is an imaging technique capable of sensing superficial blood flow in tissue which can be used to quantitatively assess reactive hyperemia. Here, we employ LSCI using coherent sources in the blue, green and red wavelengths to evaluate reactive hyperemia in healthy human volunteers. Blood flow in the forearms of subjects were measured using LSCI to assess the time-course of reactive hyperemia that was triggered by a pressure cuff applied to the biceps of the subjects. Raw speckle images were acquired and processed to yield blood-flow parameters from a region of interest before, during and after application of occlusion. Reactive hyperemia was quantified via two measures - (1) by calculating the difference between the peak LSCI flow during the hyperemia and baseline flow, and (2) by measuring the amount of time that elapsed between the release of the occlusion and peak flow. These measurements were acquired in three healthy human participants, under the three laser wavelengths employed. The studies shed light on the utility of *in vivo* LSCI-based flow sensing for non-invasive assessment of reactive hyperemia responses and how they varied with the choice source wavelength influences the measured parameters.

Poster 3- Warren Foster, Montana State University

Characterization of shape control of a Boston Micromachines Corp. deformable mirror

Adaptive optics attempts to improve imaging systems by correcting aberrations of incoming wavefronts towards diffraction-limited performance. This enables the imaging of notoriously difficult objects, including light passing through atmospheric turbulence and scattering tissue. Our team is investigating the performance of an adaptive optics-contrived deformable mirror by Boston Micromachines Corp. to evaluate the prospect of use in a real-time in-vivo two photon scanning system. The mirror's aberration correction in this system can only be optimized by measuring the brightness or sharpness of the output image. As a result, closed loop control techniques like wavefront measurement are not available. Characterization has shown that output image training does not produce mirror shapes as accurately as wavefront measurement, but that it can still be used to achieve diffraction-limited performance. Thorough understanding of industry-leading mirrors is requisite to effective real-time adaptive optics that may lead to useful medical imaging instruments.

Poster 4- Toan Le, Illinois Wesleyan University

Imaging through Scattering Environments

Light scattering is a primary obstacle to imaging in many different scenarios. On small scales in biomedical microscopy and diffuse tomography scenarios static scattering is caused by tissue. On larger scales, dynamic scattering from dust and fog provide challenges to vision systems for self-driving cars and remote-imaging systems. We are developing models for scattering environments and investigation methods for improved imaging by exploiting both spatial and temporal information of photons that travel through those environments.
With the emergence of Single Photon Avalanche Diode detectors and fast semiconductor lasers, illumination and capture on picosecond timescales are becoming possible in inexpensive, compact, and robust devices. This opens up opportunities for new computational imaging techniques that make use of photon time of flight.

Time of flight or range information is used in remote imaging scenarios in gated viewing and in biomedical imaging in time-resolved diffuse tomography. In addition spatial filtering is popular in biomedical scenarios with structured illumination or structured detection. We are presenting a combination analytical, computational, and experimental models that allow us develop and test imaging methods across scattering scenarios and scales. This framework will be used for proof of concept through experiments with fog as well as tissue phantoms to evaluate new computational imaging methods.

Poster 5- Preston Huft, Bethel University

Plasmonic Tweezing with Silver Nano-Pillars.

We demonstrate plasmonic nano-tweezing on isolated silver nano-pillars with a 660 nm laser. Due to the strong optical resonances of the nano-pillars, efficient trapping was shown on 200 nm fluorescent polystyrene beads, overcoming Brownian motion for these sub-wavelength particles. We fabricated the nano-pillars using a homemade electron beam lithography system, thermal deposition of silver, and lift-off.

Poster 6- Dylan Palo, Miami University

NADH Conformation Assessed Using Spectral Phasor Analysis: Illustrating Concepts From Molecular Folding To Metabolic Monitoring

The wide applicability of spectroscopy makes fluorescence measurements on biomolecules an attractive modality for introducing biophysical topics into undergraduate physics laboratory courses. Here we show how the spectroscopic assessment of reduced nicotinamide adenine dinucleotide (NADH) conformation is useful for conveying concepts spanning multiple size scales. While advanced sources of optical contrast for NADH conformation include fluorescence excitation transfer efficiency, excited--state lifetime, and anisotropy decay rate, our recently published studies have shown how the quantification of autofluorescence spectrum shape using spectral phasor analysis is useful for monitoring NADH conformations during metabolic transitions. Here we present the pedagogical use of spectral phasor approaches to assess NADH conformation, with educational modules illustrating concepts ranging from molecular folding to protein binding, in addition to cellular metabolic monitoring.

Poster 7- Max Trostel and Arjendu Pattanayak, Carleton College

Chaos in the transition from classical to quantum systems

The damped driven double-well Duffing oscillator models the chaotic behavior of various simple mechanical devices. The question of how this system's behavior changes as quantum effects increase is of fundamental interest and has important practical implications for building microscale devices in the laboratory. We vary the effective Planck constant β (a normalized value defining the quantumness of the system) and three other system parameters, driving strength, driving frequency, and damping, and quantify the level of chaos for each simulation using Lyapunov exponents. We find that increasing the level of quantumness from the classical limit $\beta \to 0$ causes some classically periodic regions in parameter space to become chaotic semiclassically. Increasing β further into the quantum regime, however, reverses this trend, so that trajectories are periodic across all parameters near the fully quantum system $\beta \to 1$.

Poster 8- Joseph Greene, Boston University

Rapid Bacterial Mutation Identification using Interferometric Reflectance

Peptide Nucleic Acid, or PNA, has often been used as a method of identifying DNA for PNA's chemical structure allows it to strongly bond with a unique DNA sequence. Subsequent research in PNA-DNA bonding has also noted that PNA molecules may open DNA double helix in a bonding event, and can be manufactured to form new shapes with the selected DNA segment. The resulting PNA-DNA duplexes contain both the PNA strain, and the unbound complement to the target DNA strain, which allows the duplex to capture replicas of the target DNA within its shape. Using this technique, our lab is attempting to create a cost-effective, rapid, diagnostic test that can identify hazardous mutation or specific subpopulations in a bacterial sample. In this experiment, we will take various concentrations of circular PNA-DNA duplexes, hybridize them to a silicon/silicon oxide substrate, and bind them with gold nanorods, which have been conjugated with a target DNA sequence. This will allow us to use the Interferometric Reflectance Imaging Sensor (IRIS), a rapid, biological imaging instrument designed by the Boston University Ünlü group, to image the bound nanorods and determine the lowest concentration of duplexes our lab can detect. The recent addition of passive liquid cartridges in our experiments provides a totally liquid environment for binding to occur and allows us to identify concentrations below our previous limit of detection of 100 picomolar. Initial experiments have shown we can detect below 100 femtomolar concentration of PNA-DNA duplexes in a liquid environment. In future experiments, we believe we can lower our limit of detection to 1 femtomolar using PNA-DNA duplexes and also search for bacterial mutations phenotypically through identifying certain mRNA.

Poster 9- Jessica Hankes, Denison University

Optogalvanic Spectroscopy of La I Hyperfine Structure

Precise knowledge of the atomic energy level structure of the elements is used in a wide range of fields, from quantum information and observational astronomy to archaeology, among others. Here we present select energy level data for neutral lanthanum. We measured the hyperfine structure of four lines near 800 nm, and analyzed this data to predict hyperfine coefficients and compare them to literature. Applying this process to currently unknown lines in doubly-ionized lanthanum will aid us in future laser cooling.

Poster 10- Jackson Kock, University of Wisconsin- River Falls

Improving Size Measurements of Optically Trapped Aerosol Droplets

I worked on designing a different lens system that would yield a better illumination of a trapped aerosol droplet in our optical trap. Improved illumination is critical for a more precise measurement of the droplet's size. In order to do so, various lens systems were modeled in the ray-tracing program OSLO EDU. The model was then built for experimental tests on the image's size and intensity. Once the right design was built, it was then implemented into the optical trap. I was able to catch droplets and confirm that all of the equipment was properly aligned. Data of the light scattered off the droplet was measured and used to determine the droplet's size.

Poster 11- Guy Geva, Harvey Mudd College

South Pole Telescope Detector Debugging

The purpose of this research is to use the South Pole Telescope (SPT) to study and analyze the cosmic microwave background (CMB) and how it is polarized, which will help shed light on the origins of the universe and how it has grown. SPT is a 10-meter telescope that can detect extremely small changes in microwave radiation and its polarization, allowing it to create low-noise, high-resolution maps of the CMB. Despite this, there are still many sources of noise and systematic errors that make it difficult to create accurate maps of the CMB. These include errors introduced by magnetic fields acting on the telescope as well as those from imperfect measurement methods. To address this, we analyzed data from several of SPT's observations to better understand what causes these errors and how to reduce them.

Poster 12- Derek Galvin, Williams College

Production of Tungsten Nanoemitters for Ultrafast Electron Diffraction

This lab will research the dynamics of atoms in crystals during structural transformations. To observe the processes, we will probe solids with ~100 femtosecond duration pulses of electrons. The resulting diffraction patterns will evince how macroscopic properties of materials arise from their atomic scale properties; these techniques could advance understanding of strongly correlated materials or lead to the development of novel electronic devices. Our recent goals aim at designing an electron gun able to produce the thinnest possible beam of electrons. One limiting factor is the diameter of the photocathode; smaller diameters produce thinner beams. Using a combination of oxidation-reduction chemistry, high speed sensing circuitry, and mechanical parts, we designed an etching station able to produce tungsten nanoemitters with tip diameters on the order 10-100nm. Future work will include the construction of the station and statistical analyses of its efficacy.

Poster 13- Dagan Hathaway, University of Wisconsin- River Falls

A Study of Quantum Optics

Pairs of single photons produced by spontaneous parametric down conversion were used to explore the wave-particle duality of light and perform the which-way experiment. The tests showed that single photons are capable of being both like a wave and a particle depending on how one chooses to measure them. The test used for the wave-like nature of light used a Mach-Zehnder interferometer, which was also used in the which-way experiment, and gave a fringe visibility of ~0.25 with single photons. The which-way experiment results followed those expected by the quantum mechanics explanation of the phenomena.

Poster 14- C. Baumbauer, B. Moon, A. Hohne, E. Keeler, M. Stevenson, D. Dickensheets, W. Nakagawa, Montana State University

Phase-Resolved Characterization of Reflective Infrared Nanostructured Half- and Quarter-Wave Plates

We present fabrication and characterization of both half- and quarter-wave plates operating in reflection at infrared wavelengths. The waveplates are sub-wavelength period gratings of silicon directionally coated with a thin layer of gold, and were fabricated using standard silicon microfabrication techniques. They were characterized using an interferometer to measure phase delay between TE and TM polarization components, and it was found that the grating fill factor controls the phase delay.

Poster 15- Brad Shaw, California Polytechnic University San Luis Obispo

Diffusing Wave Spectroscopy of Colloidal Systems

Diffusing wave spectroscopy (DWS) is an evolution of Dynamic Light Scattering that is useful for much more turbid solutions. DWS involves shining a laser beam onto a sample, then analyzing either the backscattered or transmitted light. An intensity autocorrelation function is retrieved from the scattered light, and behaviors of the system can be inferred from these functions. Solutions analyzed with this method included latex or polystyrene spheres in water, and was applied to probe the dynamics of industrially important colloidal suspensions. DWS is important as it permits rheological measurements to be made at very short time scales, beyond those accessible by mechanical means.

Poster 16- Benjamin Moon, Carol Baumbauer, Sean Nicolaysen, Marquette Stevenson, James Dilts, David L. Dickensheets, and Wataru Nakagawa, Montana State University

Nanostructured Linear Polarizer Arrays for Infrared Wavelengths

Nanostructured linear polarization filters for infrared wavelengths around 1.55 μm have been designed and fabricated. Filters have been realized by fabricating sub-wavelength grating structures on silicon using established nanofabrication techniques. Gold-coated silicon grating structures exhibit form-birefringence, which results in polarization selectivity for incident light. Gratings with varying physical parameters have been fabricated and characterized in a controlled testing environment. Optical characterizations show high levels of polarization selectivity with typical extinction ratios greater than 200 and transmission of the desired linear state through the grating that exceeds transmission through bare silicon. Varying grating orientation in a repeating array pattern allows for adjacent gratings to filter different linear states. Individual polarizer performance was determined through optical characterizations of the gratings in order to assess the effectiveness of the polarizer array devices.

Poster 17- Benjamin Cvarch, Colgate University

Creating Monstar Singularities with Symmetric & Asymmetric Q-Plates

I investigated an unexplored method for creating vector beams with monstar singularities using q-plates. This method consists of sending a beam of light in the near field through a series of symmetric and asymmetric q-plates. And one variety of Ic=0 monstar was found using two q=1/2 q-plates.

Poster 18- B. Plimmer, V. Pepel, J. Chen, A. Douglas, S. Prahl, Oregon Institute of Technology. J. Kerr, Kerr Avionics.

Improving Runway Visual Range in Fog using Pulsed Synchronous Detection

Improving the runway visual range can allow aircraft to land in poorer visibility conditions than would normally be possible. In collaboration with Kerr Avionics, we are using pulsed synchronous detection of LED runway lights to implement an instrument qualified visual range (IQVR) system. The system uses GPS signals to synchronize the light with the camera, enabling us to apply correlated double sampling to the entire image to discover differences between video frames with the LEDs on and those with the LEDs off. This project will explore the potential of using both visual and shortwave infrared wavelengths to increase runway visual range in controlled conditions in the fog chamber at Sandia National Labs. Digital image stabilization algorithms will be evaluated in MATLAB and the most promising algorithms will be implemented on a FPGA.

Poster 19- Ashay Patel[1], Paul Lett[2], Kevin Jones[1], Brian Anderson, Bonnie Schmittberger, 1) Williams College, 2) University of Maryland Joint Quantum Institute

Investigation of Losses in Four-Wave Mixing Squeezed Light Experiments

Squeezed states are nonclassical states of light with noise in either their intensity or phase below the standard quantum limit of those of a coherent state. The noise properties of squeezed states can be used to improve the sensitivity of the finest interferometers like LIGO, which has the capacity to detect gravitational wave activity. Furthermore, squeezed states are testbeds to study basic questions about quantum entanglement and quantum information. Our lab produces intensity-difference squeezed, entangled twin beams through four-wave mixing in a hot rubidium vapor cell. Since any loss in this system leads to the introduction of random vacuum fluctuations that reduce the measured squeezing, our experiments are very sensitive to minor losses. This project is an investigation of losses in the four-wave mixing setup in order to eliminate them and optimize the measured squeezing. I devised an improved, easily implemented scheme to heat the rubidium vapor cell to prevent metallic rubidium plating out onto the cell windows, causing loss. Furthermore, I designed, built, and tested a low noise, balanced photodetector for use in the squeezed light experiments. The group tested potentially higher quantum efficiency photodiodes, which show promise to improve the measured squeezing in the four-wave mixing experiments.

Poster 20- Alisha Vira, Smith College

Precision Spectroscopy of the Neutral Beryllium Atom

The goal of our research is to perform high precision spectroscopy on neutral beryllium. Currently, the precision of experimental measurements of several beryllium energy states lags behind that of theoretical estimates by more than an order of magnitude. Improved experimental measurements will provide critical feedback about theoretical predictions and help to test quantum electrodynamics. We have already begun performing spectroscopy on the

235 nm singlet line and are setting up to perform spectroscopy on the 457 nm singlet line and the 455 nm triplet line. To measure the energy levels, we need to know the frequency of the laser to as high of a precision as possible. We are currently working on improving the precision of our measurements by stabilizing our laser to an ultra low expansion (ULE) cavity using a Pound-Drever-Hall lock. We will then use tellurium as a frequency reference to characterize the ULE cavity and determine the frequency of our laser in order to perform high-precision sub-Doppler spectroscopy on beryllium.

Poster 21- Alexander Rosner[1], Korok Chatterjee[2], Sayeef Salahuddin[2], 1) University of Notre Dame, 2) University of California Berkeley

Terahertz Switching in Ferroelectric HfO_2

Hafnium Oxide's (HfO2) compatibility with the CMOS process and its ferroelectric phase make it a desirable material for the gate of a transistor. However, its response time while it switches polarization could limit its applications in certain high-performance devices. By introducing an induction term in the Landau-Khalatnikov equation, which describes the dynamic motion of the ferroelectric polarization, we hope to better understand the frequency response of HfO2 and its limitations. The classical damped oscillator model also can model polarization and be fitted to optical data to determine its coefficients. Together, these two models can predict an internal resistivity that determines the fastest switching time of HfO2.

Poster 22- Alexander Frenett, Amherst College

Precision Timing Control Using a Modified Consumer Microcontroller Board

Poster 23- Aeli Olson, Bethel University

Super-resolution Snapshot Chemical Imaging with Plasmonic Substrates

We show super-resolution chemical imaging with plasmonic nano holes through the combined use of Surface Enhanced Raman Spectroscopy (SERS) and Stochastic Optical Reconstruction Microscopy (STORM). Spectral and spatial content are obtained simultaneously by imaging through filters or gratings. Differing chemical signatures can be observed in the imaging of Type I Collage from a background layer of methylbenzenethiol as well as bacteria cell adhesion point analysis of gram-positive and gram-negative bacteria.

Poster 24- Aashu Jha and Niccolo Bigagli, Bates College

Nonlinear Dynamics of Vertical-Cavity Surface-Emitting Lasers Subject to Optical Injection

We have been studying the dynamics of vertical-cavity surface-emitting lasers (VCSELs) under different optical injection schemes. Control parameters include frequency detuning and power of the injected beams. We explored the behavior of VCSEL in its single and double transverse regimes. The injection schemes include single and double beam injection in both parallel and orthogonal polarizations. By observing the optical and power spectra of the VCSEL, we constructed dynamics maps for the observed behaviors. Observed features include polarization switching, frequency locking, as well as fluctuations such as period one, period two and irregular dynamics. Our final goal is to identify the most chaotic dynamical regime of the VCSEL which can be useful in applications like secure data communication and random number generation.