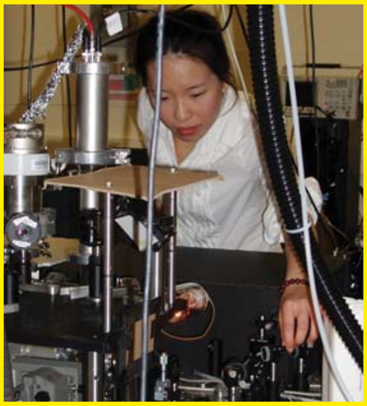
STONY BROOK
STATE UNIVERSITY OF NEW YORK

OPTICAL SCIENCES

- Magnons
- X-ray Optics
- Cold Molecules
- Optical Lattices
- Rydberg Atoms
- Ultra-fast Optics
- Ultra-cold Atoms
- Quantum Control
- Coherent Control
- Quantum Magnets
- Many Body Physics
- Terahertz Spectroscopy
- Ultrastrong Optical Forces
- Laser Cooling and Trapping
- Bose-Einstein Condensation
- Theory of Optical Processes
- X-ray Microscopy and Holography



Department of Physics and Astronomy
Stony Brook University

www.physics.sunysb.edu/physics

Research in Tom Weinacht's Group

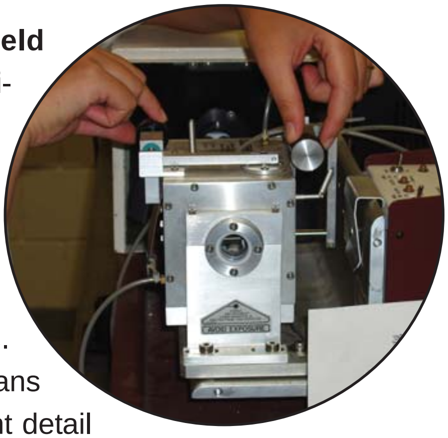
http://ultrafast.physics.sunysb.edu/

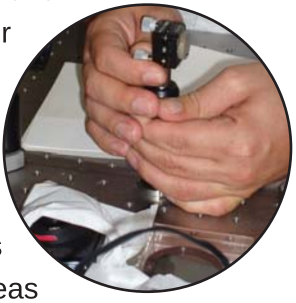
Professor Weinacht's group makes use of shaped, ultrafast laser pulses to control atomic and molecular dynamics. There are two main experimental efforts that overlap and inform each other.

Weinacht's Group

Controlling Molecular Dynamics: Ever since the invention of the laser, physicist and chemists have dreamed of observing and controlling chemical reactions using laser light. Observing a chemical reaction happening in real time requires ultrafast time resolution - strobing the molecule on its natural timescale of 10^{-15} s. Controlling chemical reactions further requires being able to apply strong and controlled forces. Amplified, shaped ultrafast laser pulses provide us with the ideal tool for observing and controlling the molecular dynamics underlying a chemical reaction. They can be focused to intensities greater than the atomic unit of intensity, with electric fields that exceed the field binding electrons to atoms. They can also be made much shorter than the period of a molecular vibration, and shaped to have an arbitrary time dependence. However, in many cases, the laser pulse shape required to drive a particular reaction is very difficult, if not impossible, to calculate *ab initio*. In this case, we make use of learning algorithms to discover pulse shapes capable of controlling the reaction of interest and then we use calculations and further measurements to try to understand the mechanism and dynamics underlying control. This has proven to be an effective approach and has uncovered many interesting and useful control schemes, which we are now applying.

Carlos Trallero



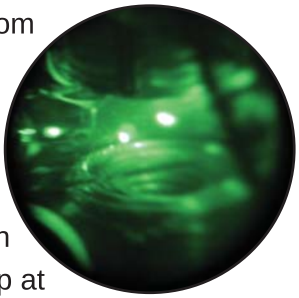


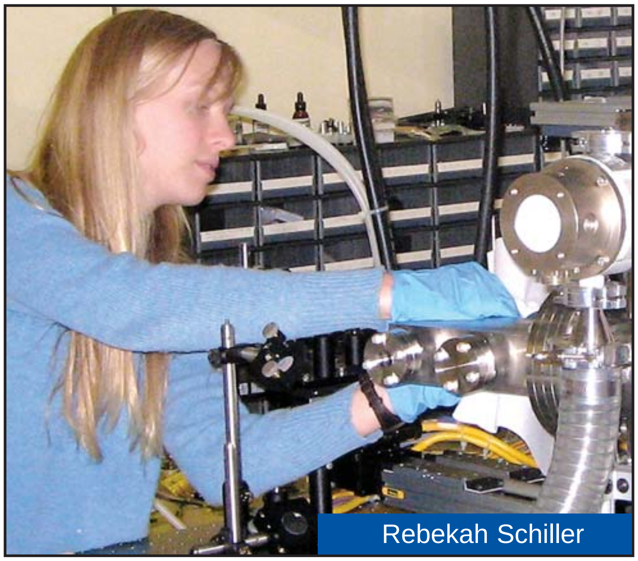
Controlling Strong Field Atomic Dynamics: In addition to our molecular experiments, we are also engaged in a series of experiments that aim to control the dynamics of atoms using strong fields. While molecular Hamiltonians are rarely known in sufficient detail to be able to perform detailed calculations of the dynamics, we are able to integrate the Schrödinger equation for atoms exposed to strong laser fields and make detailed comparisons between our experiments and calculations. This allows us to understand many of the basic physical mechanisms underlying control on both an intuitive and quantitative level. The atomic systems serve as a test bed for new control ideas and schemes, and allow us to build up our 'toolbox' for controlling quantum dynamics.

Research in Dominik Schneble's Group

http://ultracold.physics.sunysb.edu

Professor Schneble's group is in the process of setting up a laboratory for experiments with ultracold quantum-degenerate atomic gases. These gases display quantum behavior on a macroscopic scale and can be used for a wide range of scientific explorations, including new frontiers in atom optics and condensed-matter physics.

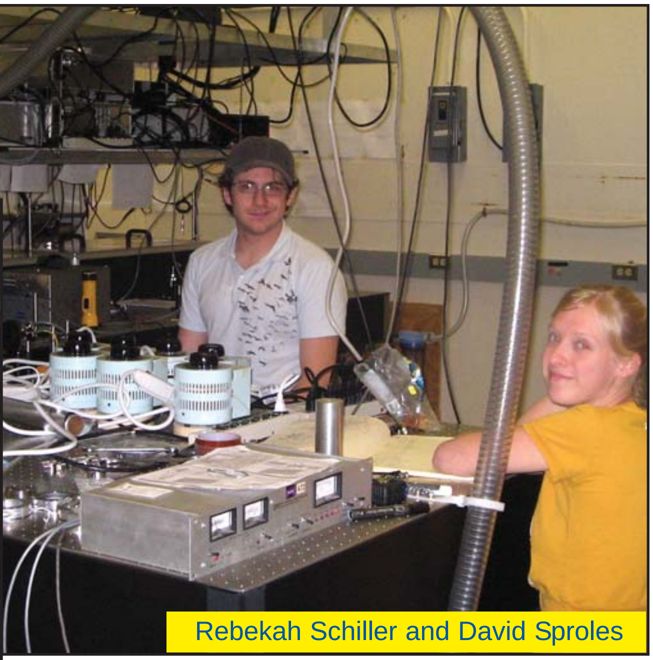




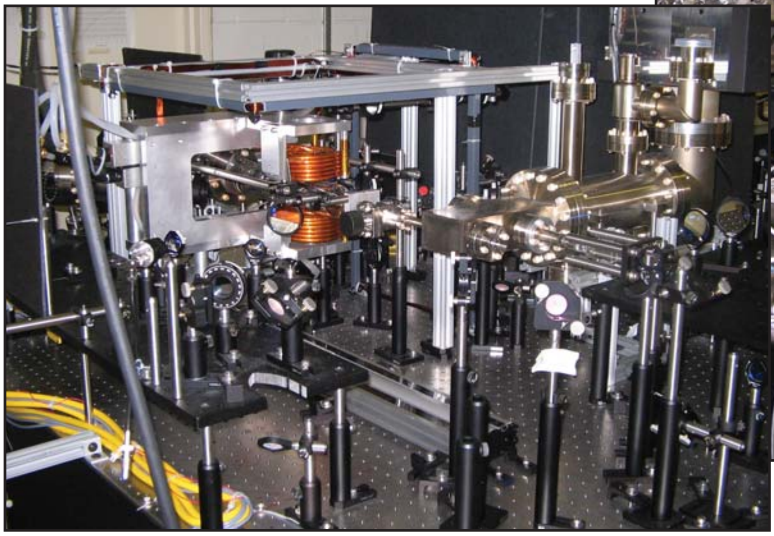
Rebekah Schiller

One of the group's main areas of interest is the physics of Bose-Einstein condensates (BECs) in optical lattices. A BEC forms in a gas of bosonic atoms when their atomic de Broglie waves overlap at decreasing temperature, resulting in a giant matter wave that extends throughout the gas. An optical lattice is a periodic array of light-shift potential minima that is generated by interference of two or more laser beams and forms an artificial crystal structure with a lattice period of half an optical wavelength. By loading such a quantum gas into an optical lattice, a variety of quantum-mechanical models for solid-state materials can be implemented, affording precise control over the important system parameters such as lattice structure and geometry, tunneling, or interactions. Research with ultracold atoms in optical lattices opens intriguing possibilities for the exploration of strongly-correlated many-body states, as well as for quantum computation applications.

In order to reach the quantum degenerate regime in the laboratory, the group makes use of a combination of state-of-the-art techniques for the manipulation of neutral atoms, including laser cooling and trapping, magnetic trapping and transport, as well as evaporative cooling in ultrahigh vacuum to reach temperatures in the nanokelvin range.



Rebekah Schiller and David Sproles



Research in Harold Metcalf's Group

http://ws.cc.sunysb.edu/metcalf/

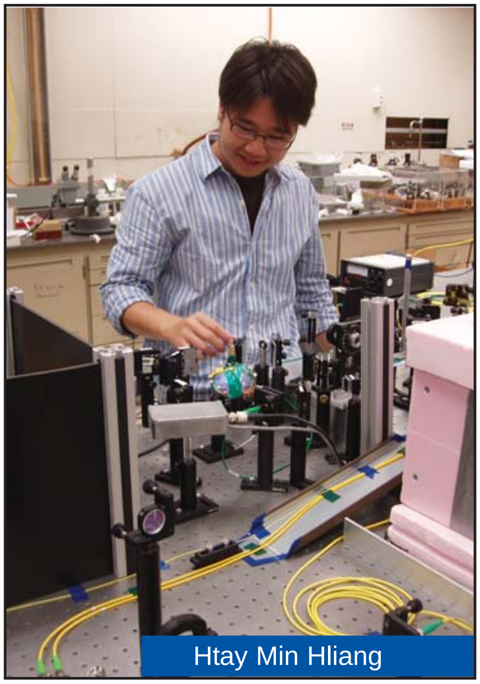
Professor Metcalf's group focuses on manipulation of neutral atoms using electromagnetic fields. The experiments are done in a collision-free environment, usually in atomic beams, and the results are determined by measuring the positions and velocities of the atoms as modified by the fields. From the perspective of atom optics it means we are in the ray optics regime, and from the perspective of quantum mechanics it means we are in the classical motion regime for the atomic centers of mass.

However, the response of the atoms to the fields is definitely quantum mechanical, and our description of their motion involves their internal states. Atoms are subjected to fields that may raise them to excited states and/or shift their energy levels (usually both are important). In the first case, they exchange momentum with the field and thus experience a force, and in the second case their energy may be position-dependent if the fields are spatially inhomogeneous and the force is the gradient of the resultant potential.

Claire Shean

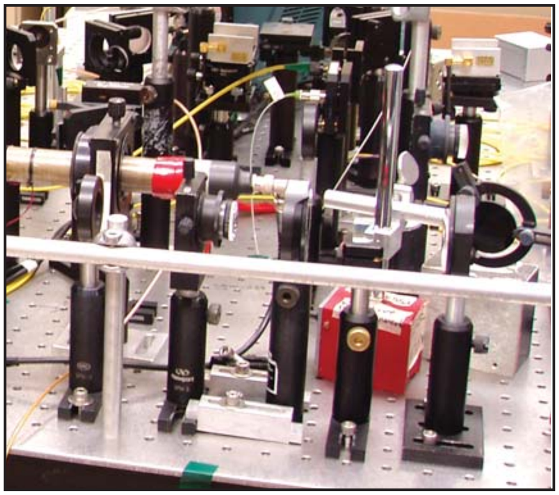
Optical forces have been used for laser cooling for a long time, but we are exploring new kinds of optical forces. The usual ones have certain limitations imposed by atomic properties, but we can get around these limitations to produce forces that are very much stronger and operate over a very much larger velocity range. The price to pay is more laser light, and we exploit many of the newest devices developed by the telecom industries in the last decade.

Jonathan Kaufman



Htay Min Hliang

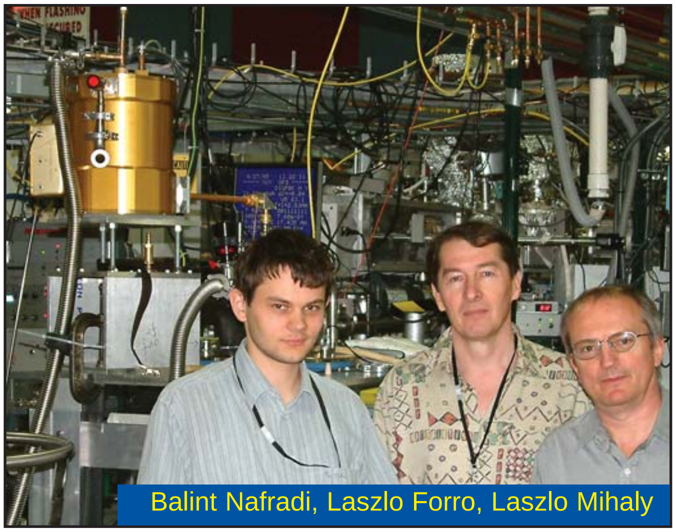
Forces from dc fields have also been around for a long time, but ground-state neutral atoms are not very responsive to these fields. We put atoms in highly excited states (principal quantum numbers n in the 20's) where the electron is so far from the nucleus (distance scales as n^2) that they have large dipole moments and therefore respond well to inhomogeneous electric fields. We have made a lens for our Rydberg atoms this way and have focused the atoms to a spot.



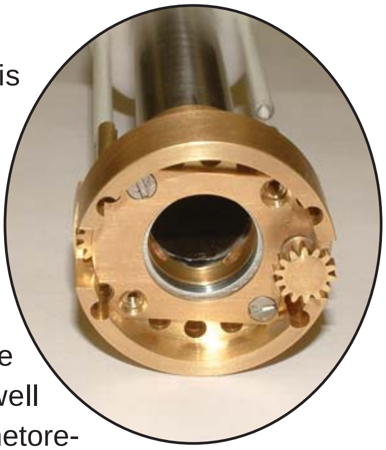
Research in Laszlo Mihaly's Group

http://buckminster.physics.sunysb.edu
http://solidstate.physics.sunysb.edu

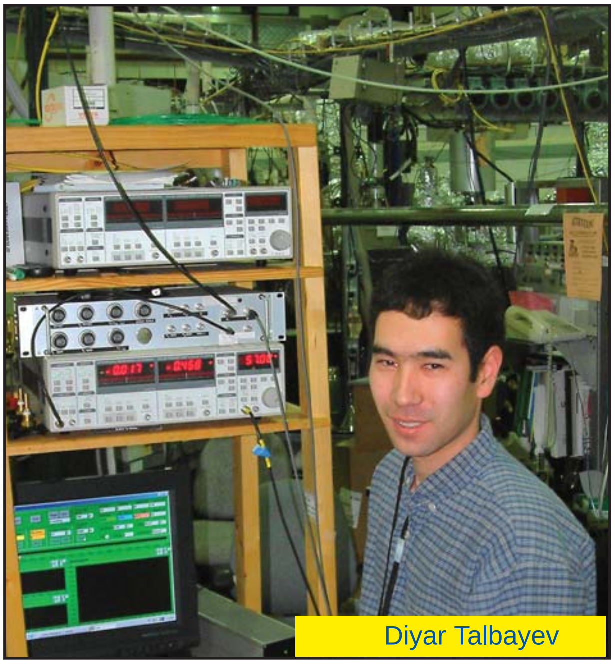
Professor Mihaly's group is using infrared spectroscopy to probe the response of electrons in various interesting solids, like fullerenes, high temperature superconductors and exotic magnets. We combine spectroscopy with high magnetic fields in an instrument that can create a two-dimensional map of the IR absorption for a material. A particularly interesting application of this method is electron spin resonance at high fields.


Balint Nafradi, Laszlo Forro, Laszlo Mihaly

The instrument is installed at the National Synchrotron Light Source in Brookhaven Lab, and it has been used to study a variety of compounds with unconventional magnetic order. Measurements were done on $LaMnO_3$, a well known antiferromagnet, and the parent compound of the so-called colossal magnetoresistance materials; on $LiCu_2O_2$, where the electron spins have a one dimensional helical order; on $NaNiO_2$ exhibiting a triangular array of magnetic ions; and on $Ni_5(TeO_3)_4Cl_2$ with complex array of magnetic moments within the unit cell. In all of these materials the internal magnetic fields, due to the interaction between the electrons, causes a spin resonance feature at zero magnetic field, and the application of the field moves (sometimes splits) the resonance line.



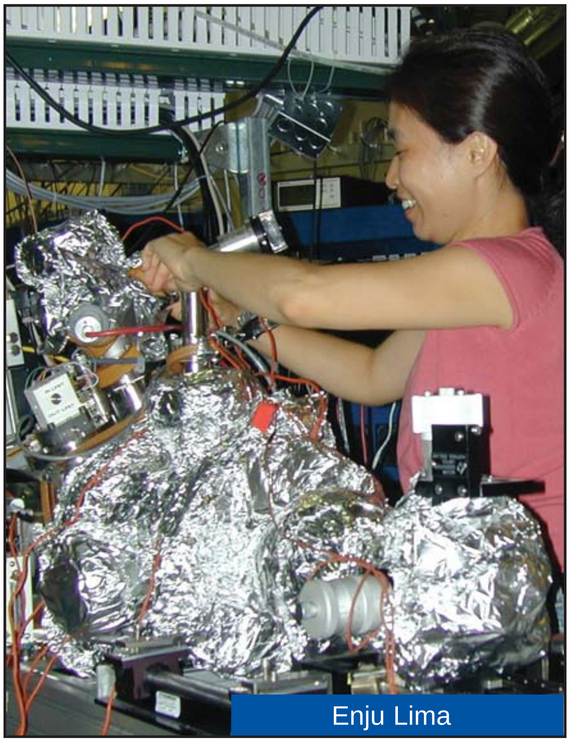
Using a new facility like this one provides ample opportunity for graduate studies in an exciting and inspiring environment. Working in Brookhaven Lab means constant exposure to the latest ideas and technology. Although we are using a large synchrotron facility, ours are in many ways simple "table top" experiments, where the experimenter has a direct control over every detail, and the few participants (typically a grad student and a postdoc) are in close personal contact all the time.


Diyar Talbayev

Research in Chris Jacobsen's Group

http://xray1.physics.sunysb.edu

Professor Jacobsen's group works on the development and applications of X-ray imaging methods, which is an effort started by Professor Janos Kirz who is retiring from the department. This research program has included electron beam lithography of sub-30 nm resolution zone plate optics in collaboration with Don Tennant of Bell Labs; it is expected that this effort will go forward in the future in the nanofabrication facility (of which Jacobsen is co-director) planned for the Center for Functional Nanomaterials at Brookhaven National Laboratory.

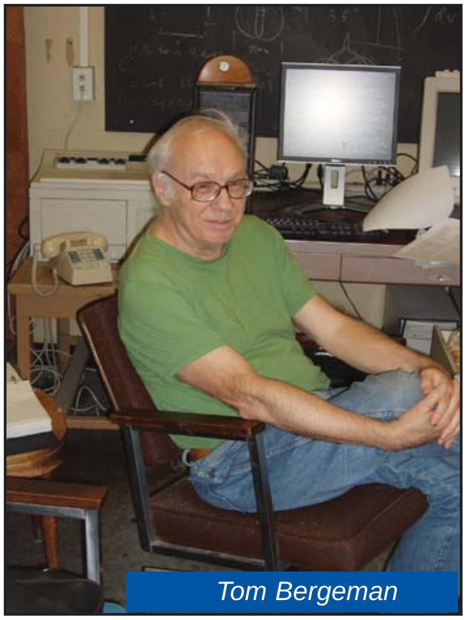

Enju Lima

The group has developed a pair of scanning transmission X-ray microscopes operating at a soft X-ray undulator (X1A) at the National Synchrotron Light Source (NSLS) at Brookhaven National Lab just 30 minutes from campus. In these microscopes, images are formed by scanning the specimen under computer control through a 30 nm resolution X-ray focus. A frequent mode of operation of the microscope is to take a series of images at closely-spaced photon energies; one then arrives at spectrum-at-a-pixel data which can be used to reveal chemical state information on organic materials. This is used for National Institutes for Health (NIH) funded research in biological imaging, and for studies in a National Science Foundation (NSF) funded Center for Environmental Molecular Sciences (www.cems.stonybrook.edu) of which Jacobsen is a member. In addition, a segmented detector and special image reconstruction methods are used to extract X-ray phase contrast images from scanning microscopy. This is used both in experiments at Brookhaven, and in NSF-funded work in X-ray microprobe studies at Argonne National Lab into the role of trace metals as biotic limiters in the ocean (this latter work is in collaboration with Nick Fischer of the campus Marine Science Research Center).


Bjorg Larson and Jeff Gillow

Another approach to X-ray imaging is to simply record far-field diffraction patterns of non-crystalline specimens and use image reconstruction algorithms to obtain a view of the specimen with no optics-imposed resolution limits. This approach was initiated by Dr. David Sayre and Kirz, who have since been joined by Jacobsen in this work. The group now carries out experiments with this approach at a beamline at the Advanced Light Source at Lawrence Berkeley Lab, where our apparatus is used for Department of Energy (DoE) supported work on the basic methodology and NIH supported work on its application to biological imaging.

Research in Tom Bergeman's Group


Tom Bergeman

Experiments with Bose-Einstein condensates have demonstrated that quantum phenomena can be "macroscopic" and have led to new perspectives on many-body effects under uniquely controllable conditions. For example, experiments planned by Professor Schneble described elsewhere in this brochure involve placing such BEC's in lattices formed by standing waves of laser light. By varying the laser parameters, the degree of confinement can be varied in a way that is impossible in a normal solid.

A 2006 Stony Brook Ph.D., David Ananikian, developed an improved theoretical model for condensates in just two wells so as to calculate the frequency of oscillation from one well to the other. This theory provided a quantitative interpretation of experiments performed in Germany. We are now working to develop models to describe the damping of such oscillations from a background of thermal atoms.

A second area of theoretical work pertains to the development of methods to produce cold molecules. Techniques used to cool atoms typically cannot be applied for technical reasons, so we consider starting with laser-cooled atoms and forming molecules. This requires precise knowledge of molecular energy levels and we are modeling these to fit data from many other laboratories.

Research in Peter Koch's Group

Working with Stony Brook graduate students and collaborators from other institutions, **Professor Peter Koch** has used microwave devices and techniques to study a number of topics related to wave and matter optics, on the one hand, and quantum chaos, on the other. Although Professor Koch is now Chair of the Department, he still retains his interest and connections with this kind of research.

The familiar Helmholtz equation is used to describe a closed, electromagnetic cavity resonator. The boundary conditions lead to discrete eigenvalues that give the resonant frequencies of the various cavity modes, which are described by the eigenfunctions that are enumerated by sets of integers that count them. A simple three dimensional electromagnetic cavity involves vector fields and both transverse electric (TE) and transverse magnetic (TM) modes. A quasi-two dimensional (q2d), planar electromagnetic cavity (one thin dimension), however, supports only TM modes from its lowest eigenfrequency up to some higher frequency. If the cavity dimensions are chosen with care, there can be hundreds of these q2d, TM modes available for study. They are interesting because they are solutions of a scalar Helmholtz equation that is mathematically equivalent to the Schroedinger equation of nonrelativistic quantum mechanics. Such a q2d cavity turns out to be an analog for an equivalent q*2d quantum billiard* that has the same shape as the cavity. This allows experiments to be done with macroscopic microwave cavities that deal with the same physics as electrons (or other quantum wave/particles) confined within tiny enclosures made with modern nanofabrication techniques. Many of the recent experiments in Professor Koch's group have focused on so-called ray *splitting phenomena*.

The Department of Physics and Astronomy at Stony Brook University is ranked among the top Departments in the country because of its nationally recognized program. Our activities span a broad range at the forefront of each field, giving our students great research opportunities. Our facilities are complemented by the unique resources available at nearby Brookhaven National Laboratory.

Graduate research in the Optical Sciences is supported by multiple individual grants to the Optics Consortium members whose groups are described in this brochure. More information is available at:

http://www.physics.sunysb.edu/physics

as well as at the address below. In addition, there is our unique Laser Teaching Center that is dedicated to individual student projects at levels ranging from high school to graduate school. Please visit it at:

http://laser.physics.sunysb.edu

The Optical Sciences groups sponsor seminars almost every week all year round featuring speakers from a very wide range of specializations. Schedules are at:

http://ultrafast.physics.sunysb.edu

We also offer the unique Optical Rotation course that provides the opportunity for students to get a taste of the research in each of our groups.

For further information about what we have to offer, contact:
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Phone: **631-632-8100** Fax **631-632-8176**

For information about Graduate program, visit us at
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