2014-2015

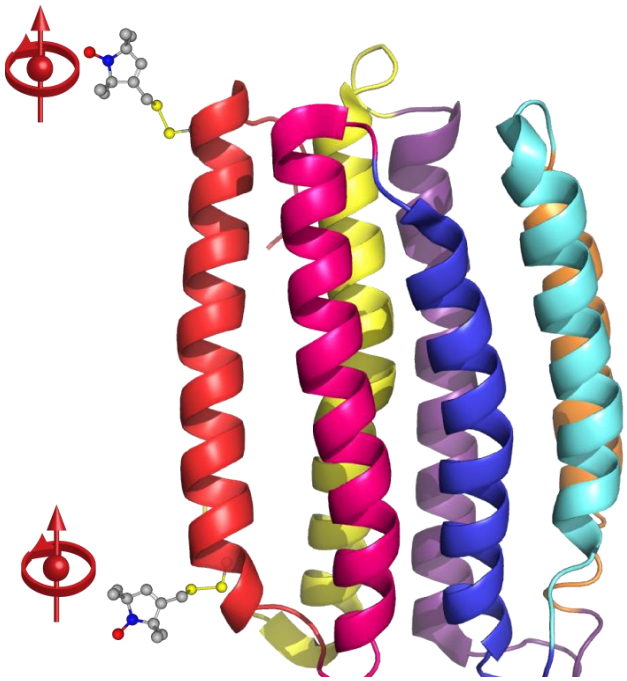
ITST

INSTITUTE FOR TERAHERTZ SCIENCE AND TECHNOLOGY

UCSB

INSTITUTE FOR TERAHERTZ SCIENCE AND TECHNOLOGY

ANNUAL REPORT



"Membrane protein 'labeled' with spins for measurement of distance and motion."
Image credit: Dr. Devin Edwards.

Dr. Mark Sherwin, Director | Rita Makogon, Manager
Website: http://www.itst.ucsb.edu | rita@itst.ucsb.edu

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Mission Statement

The mission of ITST is to

advance science and technology at the heart of the electromagnetic spectrum* while training and inspiring new generations of scientists, engineers, and the public at large and supporting research with outstanding service in a warm, welcoming and fun workplace.

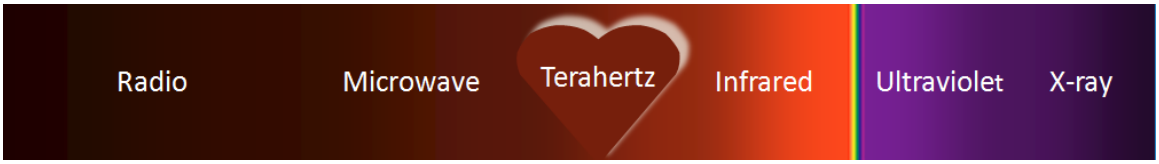


Figure 1: Chart showing ITST's research emphasis at the heart of the electromagnetic spectrum.

*roughly 0.1-10 terahertz (1 terahertz= 10^{12} cycles/s). For reference, cell phones transmit near 1 GHz (10^{9} cycles/s) and the spectrum of visible light stretches from about 400-800 terahertz.

Director's Statement

When the UCSB Free-Electron Lasers (FEL)s first lased in the late 1980s as part of what was then the Quantum Institute, the Terahertz portion of the electromagnetic spectrum was accessible only to a small number of scientists. The preferred source of Terahertz radiation was a hot lamp, and the power emitted was so small that it could only be measured using detectors cooled to 4 degrees above absolute 0 or lower. The UCSB FELs, which delivered pulses containing about 1 kW with a very well defined and tunable frequency, attracted the director to UCSB. The construction of the UCSB FELs positioned UCSB for leadership in Terahertz Science and Technology.

Nearly 30 years later Terahertz landscape is almost unrecognizable. Transistors now exist that operate above 1 THz, and one can purchase electronics test equipment to characterize them. The same technology and fabrication process that enables today's compact and powerful computers and smart phones has recently enabled the fabrication of an oscillator that can emit 1 mW at 0.5 THz. Ultrafast lasers at near-visible wavelengths can also be used to generate Terahertz radiation. The UCSB FELs are now surrounded by a suite modern instruments for Terahertz Science and Technology, which, along with the FELs, are available on a recharge basis.

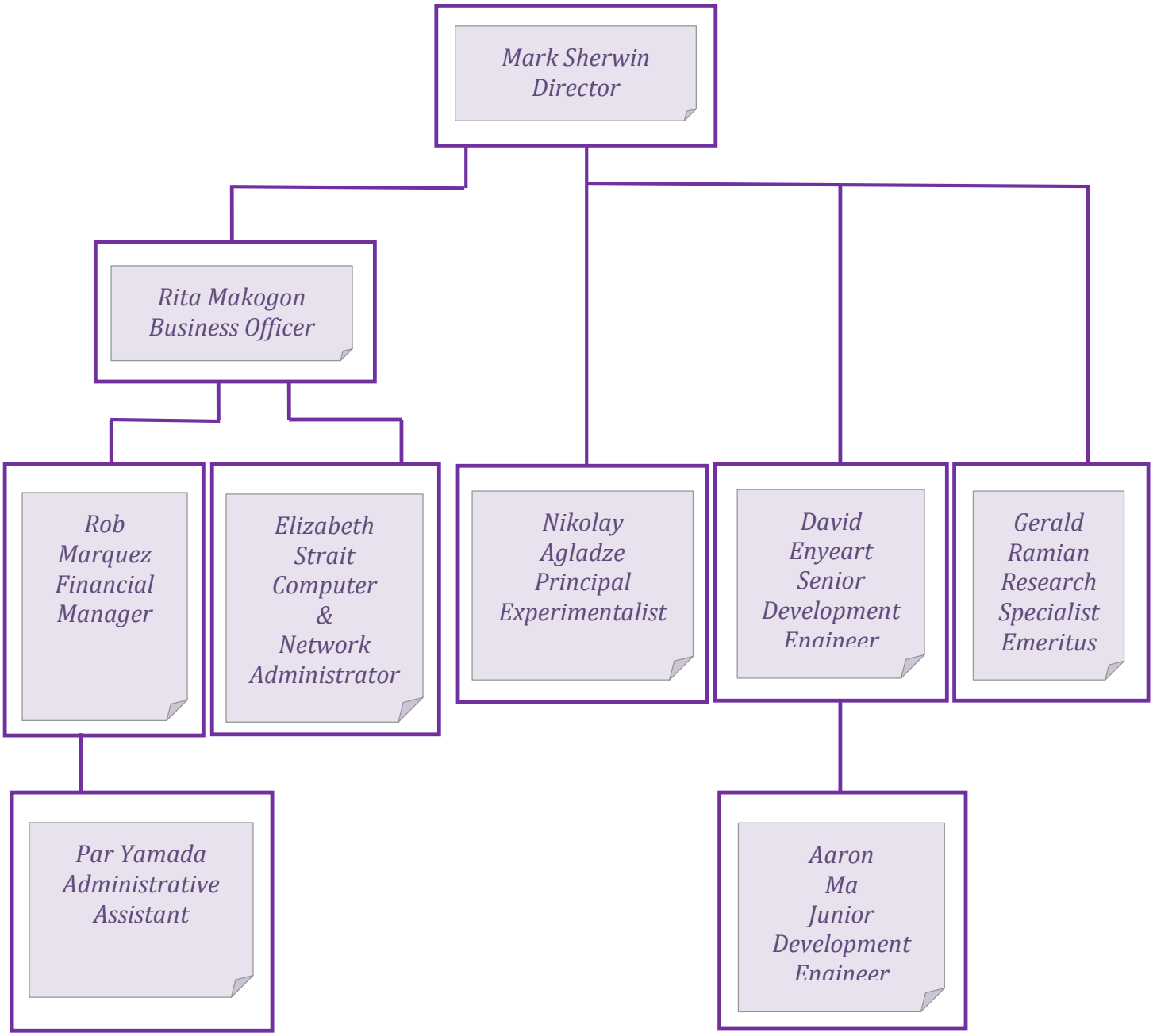
Over the past year the performance of the UCSB FELs is much improved because of an upgrade of the accelerator which drives them. The special niche of the FELs is to emit radiation with high power in an extremely well-defined frequency. Graduate student researchers at ITST recently set what is certainly a UCSB record, and is likely a world record—more than 40 kW in a bandwidth of only 25 MHz near 0.5 THz. This record power has enabled beautiful new studies extending the breakthrough observation of high-order sideband generation that was highlighted in the 2011-2012 Annual Report. The greatly increased reliability of the upgraded accelerator is also improving the productivity of the world's only FEL-powered magnetic resonance spectrometer, which is part of an interdisciplinary effort to "film" proteins like the one depicted on the cover as they perform their biological functions.

The increased availability of instrumentation for the Terahertz frequency range is increasing the demand for facilities at ITST. Over the last year, in addition to serving researchers from the Departments of Physics, Chemistry and Biochemistry, and Materials, users from the University of Washington at Seattle, Washington University in St. Louis, Harvard University, Cornell University, UCLA, UC Berkeley, and the Channel Technologies Group have visited to use ITST facilities. ITST continues to run a lively interdisciplinary seminar series.

This ORU was founded in 1973 by Prof. Herb Broida as the Quantum Institute, with a vision of becoming a regional facility for interdisciplinary research using lasers, which were then a relatively new research tool. Prof. Broida's research lay at the boundary between chemistry and physics. Since 1973, this ORU has evolved and changed its name several times. Since I have been at UCSB, what has not changed have been a focus on fostering the most exciting interdisciplinary research using lasers and other coherent sources of electromagnetic radiation, and a tradition of outstanding service in the administration of contracts and grants.

This will be ITST's last annual report as an ORU. The ITST contracts and grants management unit—brilliantly led by Rita Makogon and supported with unfailing efficiency, professionalism and good humor by Rob Marquez—have become the core of the Physics Department's contracts and grants unit, and will be managed by the Physics Department. Elizabeth Strait, ITST's wonderful information technologist, is bringing her tremendous problem-solving and interpersonal skills to Physics Computer Services. I look forward to continuing to grow ITST's scientific activities as it is reconstituted as a non-ORU Center within the College of Letters and Sciences.

Organizational Chart



Advisory Committee

Song-I Han	**Chemistry and Biochemistry, Committee Chair**
S. James Allen	Former iQuest Director, Physics
Mattanjah de Vries	Chemistry
Ania Jayich	Physics
Jon Schuler	Electrical and Computer Engineering
Wim Van Dam	Computer Science
David Weld	Physics
Stephen Wilson	Materials

Ex Officio Members

Rick Dahlquist	Chair, Chemistry and Biochemistry
Fyl Pincus	Chair, Physics
Mark Sherwin	Director, ITST, Physics

Personnel

Administrative Staff-ITST

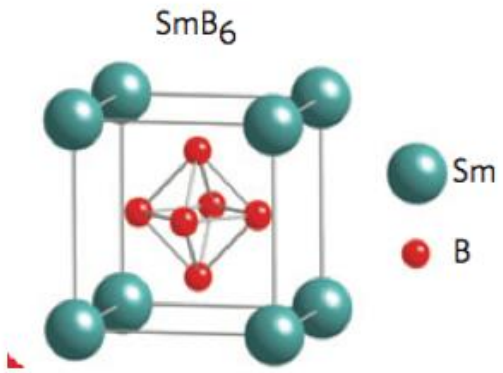
Rita Makogon, Business Officer
Rob Marquez, Financial Manager
Elizabeth Strait, Computer and Network Administrator
Pat Yamada, Administrative Assistant

Technical Staff-ITST

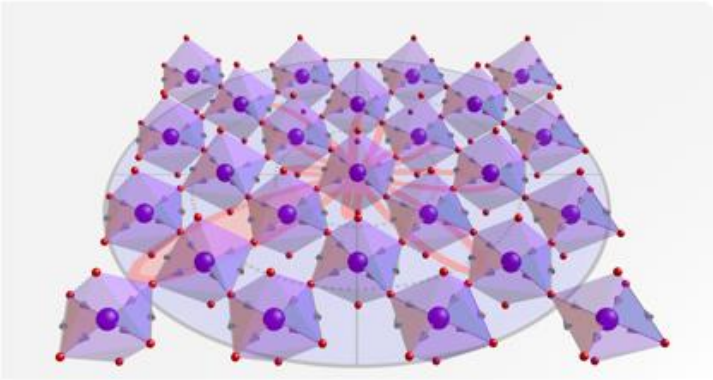
Nick Agladze, Principal Experimentalist
David Enyeart, Senior Development Engineer
Aaron Ma, Junior Development Engineer
Gerald Ramian, Research Specialist Emeritus

Other Project and Activities

Seminars and Workshops



Topological surface state in Kondo insulator SmB_6
Jing Xia, UC Irvine



Subtle structural distortions and hidden magnetic phase in Sr_2IrO_4 revealed using nonlinear optical measurements
David Hsieh, CalTech

ITST continued its very successful lunchtime Seminar Series. Refreshments (usually pizza) were provided. The following seminars took place throughout the year:

Tuesday, August 5, 2014
Speaker: Tim Eichhorn
Topic: Dynamic Nuclear Polarization with Paramagnetic Centers Created by Photo-Excitation
Abstract: http://www.itst.ucsb.edu/itst/Seminar14/Seminar080514.pdf

Thursday, August 7, 2014
Speaker: Steffen Glaser, Technical University of Munich, Department of Chemistry
Topic: Visualization and optimization of pulses and spin dynamics in magnetic resonance
Abstract: http://www.itst.ucsb.edu/itst/Seminar14/Seminar080714.pdf

Monday, August 11, 2014
Speaker: Michael Kozina, Stanford University
Host: Art Gossard

Thursday, October 30, 2014

Speaker: Jing Xia, Department of Physics and Astronomy, UC Irvine
Topic: Topological surface state in Kondo insulator SmB6
Abstract: http://www.itst.ucsb.edu/itst/Seminar14/Seminar103014.pdf

Wednesday, April 8, 2015
Condensed Matter/THz Seminar
Speaker: Zvonimir Dogic

Thursday, April 16, 2015
Condensed Matter/THz Seminar
Speaker: Jason Petta, Princeton
Topic: Landau-Zener Interferometry of Coupled Quantum Systems
Abstract: http://www.itst.ucsb.edu/itst/Seminar15/CMTS04162015.pdf

Thursday, April 23, 2015
Condensed Matter/THz Seminar
Speaker: Mattanjah DeVries, UCSB (Chemistry)
Topic: Shedding Light on Isolated Molecules
Abstract: http://www.itst.ucsb.edu/itst/Seminar15/CMTS04232015.pdf

Thursday, May 7, 2015
Condensed Matter/THz Seminar
Speaker: Dr. Everett You
Topic: Exotic quantum phase transitions in strongly interacting topological insulators.
Abstract: http://www.itst.ucsb.edu/itst/Seminar15/CMTS05072015.pdf

Thursday, May 14, 2015
Condensed Matter/THz Seminar
Speaker: Lukas Buchmann, Physics Department, UC Berkeley
Topic: Dynamics of a dissipative quantum spring
Abstract: http://www.itst.ucsb.edu/itst/Seminar15/CMTS05142015.pdf

Thursday, May 21, 2015
Condensed Matter/THz Seminar
Speaker: Stacy Copp, Physics Department, UCSB
Topic: Optical materials with a "genome": nanophotonics with DNA-stabilized silver clusters
Abstract: http://www.itst.ucsb.edu/itst/Seminar15/CMTS05212015.pdf

Thursday, May 28, 2015
Condensed Matter/THz Seminar

Speaker: David Hsieh, Caltech
Topic: Subtle Structural Distortions and a Hidden Magnetic Phase in SR2IR2 Revealed Using Nonlinear Optical Measurements
Abstract: http://www.itst.ucsb.edu/itst/Seminar15/CMTS05282015.pdf

Thursday, June 4, 2015
Condensed Matter/THz Seminar
Speaker: Dr. Justin Song, Caltech
Topic: Curveball electrons: Valley transport in gapped Dirac materials, and new collective modes
Abstract: http://www.itst.ucsb.edu/itst/Seminar15/CMTS06042015.pdf

Awards Administered

(July 2014 – June 2015)

NOTE: Dates in **red** are the projected end dates and dollar value in **red** is the projected total award value.

Guenter Ahlers
National Science Foundation, DMR-1158514
Turbulent Convection in a Fluid Heated from Below
06/01/12-05/31/16
$640,000

Turbulent convection in a fluid heated from below is of utmost importance in many natural phenomena and in industry. It occurs in Earth's mantle where it contributes to the motion of continental plates and influences vulcanism. In the outer core of the Earth it determines the magnetic field in which we live. It is the important heat-transport mechanism in the outer layer of the Sun and thus impacts the temperature of our environment. It plays a significant role in many industrial processes, where its enhancement or inhibition may have significant economic consequences. These applications range from miniature heat-transport devices in computer applications to the giant cooling systems of power plants. And yet much remains unknown to the scientist and engineer about these processes. The proposed work will extend our understanding of turbulent convection to fluids with properties similar to the Earth's atmosphere; this property range has remained relatively unexplored in the laboratory. The work will also be extended to samples that are rotated about their vertical axis. The rotation will exert a force on the fluid known as the Coriolis force and thus will change the behavior of the system in a manner related to how Earth's rotation modifies the nature of hurricanes and ocean currents. These experiments require the construction of complex apparatus and the automatic computer-control of numerous intricate processes. Thus they are an exceptionally good training ground for our young coworkers, many of whom will evolve into the leaders of the next generation of scientists and engineers.

Dirk Bouwmeester
National Science Foundation, PHY-1206118
Quantum Post-Selected Optomechanics
09/01/12-08/31/16
$520,000 ($670,000)

This proposal is the result of an analysis of the currently limiting factors in achieving macroscopic superpositions of optomechanical systems. We propose a new scheme based on quantum post-selection that will remove two of the main limitations of the current approaches. With the implementation of this new scheme together with proposed advances in the design and fabrication of optomechanical systems

(based on the use of Graphene, Boron Nitride and Carbon nanotube technology) we expect to make very significant progress towards testing quantum mechanics at the macroscopic scale.

Dirk Bouwmeester
National Science Foundation, PHY-1314982
Implementing a Quantum CNOT Gate Using Solid State Cavity QED
09/01/13-08/31/16
$180,000 ($270,000)

By combining single-photon technology with semiconductor electro-optical devices we investigate a scheme for a quantum CNOT gate. Such a gate is a fundamental building block of quantum computers and quantum communication systems. Nanofabrication and material-growth concepts will be implemented to create optical micro cavity structures with embedded artificial atoms in the form of a nanoscale semiconductor structure, called a quantum dots. A quantum dot, if positioned at the center of the cavity and at the cavity resonant frequency, will interact with an incoming photon in such a way that the photon polarization will become entangled with the electronic state of the quantum dot. This interaction establishes the quantum CNOT gate; the quantum state of the photon is changed depending on the quantum state of the electron.

The research topic directly relates to the micro optoelectronics industry as well as to fundamental studies of confined electron properties in semiconductors. Potential applications in classical and quantum information storage and processing are expected to follow from this project. Since the interactions are at the single photon level, the devices will in principle be very energy efficient. It should however be mentioned that this study does require low-temperature operation conditions. Alternative implementations based on different cavity designs and different optical emitters that remain active a room temperature will also be considered.

Michael Bowers
Air Force FA9550-11-1-0113
Litigated Metal Clusters: Structures, Energetics and Reactivity
06/15/11-12/14/15
$620,000

The field of metal clusters, their reactivity and ligand binding energies has undergone a renaissance in recent years. There are two principle drivers: The importance of metal clusters in catalysis and their fundamental importance as bridging agents between the atomic and the solid phases of matter. The Bowers group is uniquely positioned to contribute to this important area of research. They have developed two tools that allow structural determination for size-selected clusters: ion mobility methods that yield accurate cross sections and sequential ligand binding energies that identify equivalent binding sites. These

have been applied primarily to coinage metals but here the group will extend these studies to transition metal clusters.

Michael Bowers
Asian Office of Aerospace R&D, FA2386-12-1-3011
Metal and Litigated Metal Clusters: A New Instrument
7/1/12-01/11/15
$269,309

A request is made is transform a currently existing instrument onto one capable of studying mass-selected metallic and litigated metal clusters. The makeover will require a new cluster source, a new temperature-dependent ion mobility and reaction cell, and several upgrades to the current ion optics. A new laser will be required to generate the clusters. The focal point of the work will be determination of cluster structure and reactivity. The instrument will take advantage of novel structural methods we have developed based on ligand binding energies and entropies as well as ion mobility cross sections. Finally, new work is proposed for metal oxide clusters where the structural methods developed here have yet to be applied.

Michael Bowers
National Institute of Health 1 R01 AG047116-01
Amyloid β-Protein: Wild Type and Familial Mutant Assembly and Inhibition
09/01/13-06/30/17
$883,460 ($1,768,028)

The overarching goal of our research is to determine the molecular basis for amyloid β-protein's contribution to Alzheimer's disease. Specifically we intend to measure early oligomer-size distributions of a series of natural and intentionally mutated Aβ40, Aβ42 and tau fragment peptides, determine their structures and use this information to establish the aggregation mechanism. In parallel, we will investigate the effect of a series of aggregation inhibitors on this process to obtain their inhibition mechanism and evaluate their suitability as potential therapeutic agents. Finally, we will investigate the general mechanism of peptide aggregation using a series of model peptides. We will use ion-mobility-based mass spectrometry (IMS-MS) experimental methods coupled to high-level molecular dynamics simulations in pursuing these goals. My group has pioneered the modern development of IMS-MS and its application to complex macromolecular systems. We first used it to unravel the size-specific structural evolution of carbon cluster growth in arcs, leading to the characterization of the mechanism for fullerene formation. More recently we have focused on aggregating biological systems including prions (mad cow and other TSE diseases), α-synuclein (Parkinson's disease), hIAPP (type 2 diabetes) and amyloid β-protein. This work has depended on complementary high-level simulations which will continue. We feel the excellent progress made to date on Aβ peptides and on other amyloid systems strongly indicates our ability to successfully achieve the goals set out in The Specific Aims of this proposal.

Michael Bowers
National Science Foundation NSF CHE-1301032
Peptide Assembly: Mechanism and Inhibition
09/01/13-08/31/16
$495,000

The award CHE-1301032 provided by the Chemical Structure, Dynamics and Mechanism-B Program (CSDM-B) and the Chemistry of Life Processes of the National Science Foundation to Professor Michael T. Bowers at the University of California at Santa Barbara will be used to investigate the mechanism of peptide assembly. This is currently a very active area of research both for its fundamental importance and because of possible therapeutic applications in neurological diseases. These studies will include the determination of oligomer distributions, the structures of sized selected oligomers and the effect of select inhibitors on this process. Peptides will be selected to test existing models for beta sheet formation and eventual fibrilization and for their possible implications in amyloid based diseases. Experimental methods will include ion mobility spectrometry coupled with mass spectrometry, atomic force microscopy and transmission electron spectroscopy and a newly developed oligomer size selected infrared spectroscopy experiment constructed at the Fritz Haber Institute in Berlin, Germany. The experiments will be complimented by high level theoretical calculations including both DFT and replica exchange molecular dynamics. Inhibitors will include both naturally occurring substances like polyphenols and specially synthesized molecules designed for select peptide attachment.

The two fastest growing major diseases in the US today are Alzheimer's disease and Type 2 Diabetes. These seemingly dissimilar diseases share the common trait of having toxic agents that come from the assembly of ordinarily innocuous agents (peptides) in the body: one process occurring in the brain causing Alzheimer's disease and the other in the pancreas causing Type 2 Diabetes. It isn't clear how these normally safe species assemble into deadly ones nor is it clear how they kill cells once they do assemble. This is a difficult problem to study with the normal tools of biochemistry that can't select specific assembled peptides and hence can't tell their structure or how toxic they are. The thrust of this proposal is to provide a new set of methods that can do this selecting and to apply these methods to model peptide systems to learn the factors that control peptide assembly in general and then test simple molecules that can stop this assembly in its tracks. Finally the results are translated into presentations that can be given to local high schools and each Bowers group member visits several such schools each year to make these presentations.

Steven Buratto
Michael Bowers
Horia Metiu
National Science Foundation NSF CHE-1152229

Model Nanocluster Catalysts: The Role of Size, Shape and Composition on the Catalytic Activity of Small Metal Oxide and Bimetallic Clusters on Oxide Surfaces
04/01/12-03/31/16
$450,000

A large number of industrial processes use nanometer-size clusters (both metal and metal oxide) supported on oxide surfaces to perform reactions that would not take place, or would be commercially unsuccessful if performed on the bulk material. In research supported by this grant the investigators will utilize state-of-the-art experimental and theoretical methods to probe the catalytic activity of well-defined nanocluster catalysts in great detail and develop a fundamental understanding of the catalytic chemistry at the atomic level. The concepts developed through this research will help optimize important industrial processes using these nanoscale catalysts and provide valuable insight into the discovery of new nanoscale catalytic materials. Researchers supported by this grant will also be active in outreach to K-12 schools in the Santa Barbara area. They plan to develop a tutorial presentation on an atomistic view of heterogeneous catalysis that will be included in the currently active outreach program in the department at UCSB. In addition, researchers working on this project will visit high schools in the Santa Barbara and Ventura Counties three times per year to discuss their research and its impact as well as to promote science education.

Steven Buratto
National Science Foundation NSF CHE-1213950
Connectivity and ION Conductance in Field Cell Membranes Probed by Tunneling Atomic Force Microscopy
07/01/12-06/30/16
$283,864

Proton exchange membrane (PEM) fuel cells, which convert chemical energy into electricity using an electrochemical cell, could be used as efficient power sources, offering high power density and low environmental impact. Critical to PEM fuel cell performance is the polymer electrolyte, which is an efficient proton conductor but electric insulator. The most common PEM material is the polymer electrolyte Nafion®, which is composed of a hydrophobic Teflon® backbone and side chains terminated with hydrophilic sulfonic acid (SO_3H) groups. In a Nafion® film the hydrophilic pores, which conduct protons, form via phase separation of the side chains from the polymer backbone. The proton conducting channels in these films are strongly dependent on the film morphology and the environmental conditions. A detailed understanding of proton conduction, in terms of the size and distribution of the chemical domains responsible for transport, is central to both a complete understanding of fuel cell performance and a systematic approach to improving the performance. Toward this end, conductive atomic force microscopy (cAFM) will be used to gain a fundamental understanding of ion conduction in proton exchange membrane fuel cells. Using the nanoscale resolution afforded by cAFM, the size, spatial distribution, and electrochemical activity of ion transport domains in polymer electrolytes will be explored under operation fuel cell conditions.

Bruce Lipshutz
National Institutes of Health, R01 GM086485-04
Transition Metal-Catalyzed Chemistry in Water at Room Temperature
09/01/11-05/31/15
$1,101,093

New technologies are to be developed that "get organic solvents out of organic reactions"; that replace traditional processes that use strictly organic media with a "green" alternative: water. These studies are driven by the potential for decreasing the amount of solvent waste, to be carried out by investigating several reactions in water that are important to the pharmaceutical and fine chemical areas. All are to be done at room temperature, and thus, without any investment of energy for either heating or cooling purposes.

Bruce Lipshutz
NOVARTIS Pharmaceutical SB140127
New Methodologies in Synthesis Using Micellar Catalysis
06/15/14-06/15/16
$182,000 (364,000)

The goal is to develop environmentally benign methods that avoid use of organic solvents as the traditional reaction medium. A postdoctoral student will be hired to develop a variety of new methodologies that rely on nanoreactors formed in water using surfactant technology developed in the group. New Synthetic methodologies in the following fields could be investigated:

Iron-mediated chemistry
Ullman-type chemistry
Oxidation methodologies
Reduction methodologies
Organometallic chemistry (organozincates, others)
Amide bond formation – extension of scope where potential epimerization, catalytic methods
Selective carboxyl reduction methods
C-N bond-formation transformations
Chemistry of highly energetic compounds (nitroalkanes, azides, nitration…)
Gas-mediated transformations (hydrogenations, hydroformylation, hydrocarbonylation…)

.

Bruce Lipshutz

NOVARTIS Pharmaceutical SB150084
New Methodologies Based on Transition Metal Catalysis Enabled by Micellar Catalysis
01/01/15-01/04/17
$470,000

The goal is to develop several environmentally attractive synthetic methods utilizing transition metal catalysts that can involve water alone as the reaction medium, rather than the traditional use of organic solvents. Two graduate students will be hired to investigate applications of our designer surfactant technology in water for several different types of metal-mediated prcesses. Thus, new synthetic methodologies in the following fields will be studied:

- Palladium-catalyzed chemistry, including name reactions, such as Suzuki and Sonogashira couplings, and aminations
- Cyclizations mediated by organogold catalysts
- Isomerizations mediated by catalytic amounts of ruthenium
- Conjugate reductions and addition reactions by organocopper complexes

.

Philip Lubin
Jet Propulsion Laboratory, JPL1367008
Planck Educational and Public Outreach Effort at UCSB
02/10/09-09/30/15
$67,700

This award will fund a cosmology summer session that brings in students from a local high school (Dos Pueblos High and perhaps others) and a local community college (Santa Barbara City College). Graduate students, post doc (Rodrigo) Peter Meinhold and Dr. Lubin will orient the students on the Planck mission and relevant science and technology issues, and then the students will work during the summer as a team on various CMB technology programs for a hands-on summer program. We hope to run this program over a six week period each summer.

Philip Lubin
Freedom Photonics LLC SB140070
Freedom Photonics Atmospheric Modeling
12/01/13-09/30/14
$18,388

UCSB will support aid in the development of atmospheric modeling in the infrared to explore the issues of transmission of IR wavelengths through varying atmospheric conditions such as fog, rain etc. In particular we will explore the ability to transmit information in the 1550 nm range. Primary emphasis will be placed on horizontal paths from 0.1 to 10 Km. Typically we will compute to level of down to 10^{-4} in transmission.

1) Study of atmospheric transmission from 0.3 to 15 microns with varying amounts of fog.
2) Study the sensitivity of transmission to varying rates of rain and raindrop sizes.
3) Study the sensitivity the sensitivity of transmission to varying conditions of dust.
4) Study atmospheric radiance for the above.
5) Study optimal IR atmospheric windows.
6) Plots and summaries will be prepared for all of the above.
7) Study atmospheric scintillation (seeing) effects to determine relevancy.

Philip Lubin
LCOGT SB150105
Fiber Spectrometry Alignment System
03/01/14-07/31/14
$5,000

Goal of this project is to design and test a number of small alignment units. The research will consist of research and experimentation to achieve accurate machining at the few micron level. In order to achieve the desired results, a special high speed NSK spindle with micron level run out and a 3 axis machining stage with 1 micron optical encoders will be used. The goal is to achieve fiber to fiber alignment at an accuracy of less than 5 microns. UCSB will conduct some testing in the process of researching the possibility of precision fiber alignment for the fiber fed spectrometer.

Philip Lubin
Raytheon Company SB140137-0001
Task 1: Advanced Camera Development
04/01/14-06/30/15
$167,470

Software development on Xilinx Zynq based FPGA/ ARM core

Douglas Scalapino
Oak Ridge National Laboratory, 4000129396
Studies of the Properties of Strongly Correlated Materials
04/14/14-03/31/16
$159,269 ($253,802)

Using recently developed algorithms and new state of the art computer hardware and architecture, we are seeking to understand the properties of strongly correlated electronic materials. Our work is particularly focused on the challenges posed by the high temperature cuprate superconductors. We believe that an understanding of these materials will open an important area of material science and applications.

Mark Sherwin
National Science Foundation, DMR-1006603
Quantum Coherence and Dynamical Instability in Quantum Wells Driven by Intense Terahertz Fields
08/15/10-07/31/14
$560,000

Beginning when early humans harnessed fire for heat and light, the control of electromagnetic radiation has been central to the development of our species. The notion of electromagnetic radiation is nearly 150 years old, proposed by Maxwell in 1865 and demonstrated with the discovery of radio waves in 1866. Radio waves remained largely a laboratory curiosity for nearly 50 years. It is difficult to imagine modern life without radio waves, microwaves, heat, light, and X-rays, which are now all understood to be manifestations of electromagnetic radiation, listed in order of increasing frequency. However, lying between the frequencies of microwaves and heat, stretching from 0.1 to 10 trillion cycles per second (0.1-10 terahertz) is the so-called 'terahertz gap.' Electromagnetic waves exist in this frequency range, but they are extremely difficult to generate and control. This individual investigator award supports a project that will use the world's brightest pulses of terahertz waves, generated by accelerator-driven 'free-electron lasers', to search for new quantum-mechanical phenomena predicted to occur in nanometers-thick semiconductor devices. The semiconductor devices under study are similar to those used to modulate light in fiber-optic communications, and as ultrafast transistors in cellular telephones. This project will support the education of two PhD students, as well as undergraduate and high-school interns. The students will learn the most advanced techniques to generate and manipulate electromagnetic radiation across the electromagnetic spectrum, preparing them for leadership in the nation's scientific and technological workforce, and bringing mankind closer to harnessing terahertz radiation for future technologies.

Mark Sherwin
Song-I Han
U.S.-Israel Binational Science Foundation 2010130

Development of Gd^{3+}-Based Spin Labels for Probing Structure, Dynamics and Interfaces by Electron Paramagnetic Resonance Techniques
10/01/11-09/30/15
$92,910

EPR and DNP (dynamic nuclear polarization) rely on the introduction of spin probes or labels to intrinsically diamagnetic systems and the standard, widely used spin labels are based on the nitroxide group that has a spin, S=1/2. The recent development of high field EPR opens new opportunities in spin labeling by exploiting the unique spectroscopic properties of half-integer high spin systems at high fields that can offer high sensitivity and resolution. The objective of this proposal is to establish a new family of Gd^{3+} (S=7/2)-based spin labels for probing structure, dynamic and interfaces of molecules and materials using EPR and DNP at high magnetic fields. The basic spin physics and dynamics of Gd^{3+} spin labels at high fields must be explored and understood in order to realize their tremendous promise for EPR and DNP. Using a variety of mono- and bis-Gd^{3+} compounds we will measure spin lattice relaxation, phase memory time and spectral diffusion as a function of field (95 and 240 GHz. 3.5 and 8.5T), temperature and Gd^{3+} concentration. Having established a good understanding of the spin dynamics that is needed for the optimum measurements conditions and the design of appropriate Gd^{3+} chelators we will explore Gd^{3+} spin labels for structure determination through Gd^{3+}-Gd^{3+} distance measurements and their potential to probe protein dynamics and light triggered conformational changes. Finally, we propose to develop a Gd^{3+} spin label based methodology to study polymer interfaces in systems with nanometer scale heterogeneities and phase boundaries using solid state DNP of ^{1}H and natural abundance ^{13}C NMR at 7T

Mark Sherwin
S. James Allen
Christopher Palmstrom
Thuc-Quyen Nguyen
Song-I Han
National Science Foundation, DMR-1126894
MRI: Development of a Free-Electron Laser for Ultrafast Pulsed Electron Paramagnetic Resonance
10/01/11-09/30/15
$992,270

The world's brightest source of tunable terahertz radiation will be developed to manipulate electron spins faster than has ever been possible. This ultrafast spin manipulation will enable pathbreaking studies with applications ranging from development of inexpensive solar cells to understanding how protein molecules fit together and move to regulate the flow of energy, information and matter in living organisms.

Electrons and atomic nuclei both have a property called spin, which makes them behave like (very tiny) magnets. In nuclear magnetic resonance (NMR), which is the basis for magnetic resonance imaging (MRI), a strong external magnetic field aligns nuclear spins, while powerful pulses of radio-frequency electromagnetic radiation manipulate nuclei to discover otherwise invisible information about neighboring

atoms. Electron paramagnetic resonance (EPR), in a fashion similar to NMR, uses an external magnetic field to align electron spins (rather than nuclear spins). Typically, pulses of microwave-frequency electromagnetic radiation manipulate these electrons to learn about local environments over larger neighborhoods. EPR becomes even more powerful when extremely high-frequency terahertz is used.

The free-electron lasers (FELs) at the University of California at Santa Barbara (UCSB) are famous as the world's brightest sources of tunable terahertz radiation. Recently, researchers at UCSB demonstrated that one of the UCSB FELs could be used to rotate electron spins 50 times faster than ever before at .25 terahertz. This project will fund the construction of an even more powerful FEL. The new FEL, which will be used by scientists from all over the nation and world, will be 100 times more powerful than the existing one, and will pulse ten times faster, enabling at least 1000 times more rapid acquisition of experimental data. The EPR spectrometer powered by this new FEL will create an unprecedented capability to observe the structure and ultrafast dynamics of molecules, materials and devices at nanometer length scales.

Mark Sherwin
National Science Foundation, MCB-1244651
Robust GD^{3+} -Based Spin Labels for Structural Studies of Membrane Proteins
01/01/13-12/31/15
$848,526

Understanding the structure and functional dynamics of membrane proteins in a life-like environment is one of the grand challenges of biology.
Site-directed mutagenesis and spin labeling (SDSL) combined with electron paramagnetic resonance (EPR) enables quantitative studies of the structure and dynamics of membrane proteins and protein complexes. If two sites are labeled on a protein or protein complex, the distance between them can be measured using EPR. The spin ½ nitroxide moiety forms the basis for nearly all spin labels in use today. The goal of this research is to develop a new class of spin labels that are based on the spin 7/2 Gd^{3+} ion. The attributes of nitroxide and Gd^{3+} -based spin labels are very different and make them optimal for environments that are largely complementary. In particular, the Gd^{3+} ion, with its paramagnetic core shielded by outer electrons, is less sensitive to its local *chemical* environment than the nitroxide moiety, which is delocalized between nitrogen and oxygen atoms. Unlike for nitroxides, phase memory times and linewidths of Gd^{3+} spin labels are relatively insensitive to nearby protons, enabling them to be useful for cw and pulsed EPR on sites and in environments that are not deuterated. The paramagnetic attributes of the Gd^{3+} ion are particularly favorable at high magnetic fields and frequencies, one of the frontiers of EPR. The development of Gd^{3+} spin labels is expected to enable structural studies under a variety of conditions that are biologically important but difficult or impossible to study with nitroxide spin labels.

Mark Sherwin
University of Pittsburgh 2013PR0455
Nanoscale Terahertz, Infrared and Plasmonics Platform Using Graphene-Complex Oxide Heterostructures
07/31/13-07/30/16
$346,875

Sherwin/UC Santa Barbara will hire 1 graduate student researcher for the duration of this proposal. They will perform the following tasks:

1) Measure x3 and x5 frequency multiplication from CVD graphene: Illuminate CVD graphene sample with ~1 kW pulses from the UCSB free-electron lasers tuned to a frequencies near (a) 0.6 THz and (b) 3 THz. For case (a), measure output at 1.8 and 3 THz. For case (b) measure output at 9 and 15 THz.
2) Construct a spectrometer to measure high-order frequency multiplication: We will construct a spectrometer which is capable of measuring frequency multiplication of 0.6 THz by more than a factor of 10.
3) Design and fabricate slot antennas to enable high-order harmonic generation from subwavelength size (~10 µm) samples. Exfoliated graphene samples and patterned GCO structures are considerably smaller than the wavelength of terahertz radiation. A simple slot antenna will enable effective coupling to study harmonic generation from samples with ~10 µm dimensions.
4) Measure Terahertz harmonic generation from mechanically-exfoliated graphene flakes. Flakes will be placed in slot antennas, then terahertz harmonic generation experiments will be performed.
Measure plasmon-enhanced harmonic generation from GCO nanostructures. GCO nanostructures will be patterned by Levy group and inserted into slot antennas. These structures will be sent to UCSB for measurements of frequency multiplication.

Mark Sherwin
NSF DMR-1405964
Terahertz Electron Hole Recollisions
07/01/14-06/30/17
$565,000

In high-energy physics, the structure of matter is explored by accelerating and colliding elementary particles like electrons and protons. In condensed matter physics, the fundamental excitations are called quasi-particles. The most familiar quasi-particles are electrons and holes in semiconductors, which can be created for example in a solar photovoltaic cell - by light with a sufficiently short wavelength. In this project, electrons and holes will be created by a weak near-infrared laser with a wavelength slightly longer than is visible to the human eye, and will be made to accelerate and then recollide with one another by a very strong electric field oscillating nearly 1 trillion times per second (1 Terahertz). The recollision process will be studied by analyzing the spectrum (which wavelengths are present) in the transmitted near-infrared light. This spectrum has been shown to contain up to 18 separate nearinfrared wavelengths, or sidebands, in addition to the wavelength of the near-infrared laser that creates electron-hole pairs. This research will elucidate how much quasiparticles can be accelerated without being disturbed by defects or the motion of atoms in their host material. The proposed research may lead to faster and more energy efficient optical communications and internet, and improved optical clocks that are necessary in the global positioning system. This project will support the training of two Ph. D. students, who will learn a variety of skills that are critical to preserving U. S. competitiveness in the high-technology sector.

High-order sideband generation, a new phenomenon in the interaction of light with matter, was recently discovered in the PI's research group. A relatively weak, continuous-wave near-infrared (NIR) laser at frequency ~350 THz, and an intense laser at frequency ~0.5 THz are incident on a thin film of semiconductor. A comb of equally-spaced sidebands is emitted, with sharp lines at sideband frequency = NIR frequency + 2n THz frequency, where n is an integer. Combs with up to 14 sidebands (order up to 2*14=28) above NIR frequency have been observed. The high-order sidebands can be understood in terms of a semiclassical model similar to one that was first introduced to explain high-order harmonic generation, an analogous phenomenon that occurs for atoms in intense laser fields. In high-order-sideband generation (HSG), the NIR laser creates excitons, bound electron-hole pairs. The strong THz field ionizes the excitons, and accelerates the resulting electron and hole into a large-amplitude oscillation. When the electron and hole recollide, the excess kinetic energy is carried off in sidebands above the NIR frequency. This project will explore the onset of high-order sideband generation, whether there is a fundamental limit on the number of observable sidebands, whether the shape of the sideband spectrum can be controlled, and whether, in the case of a circularly-polarized terahertz field, the polarization of the near-ir radiation is rotated. By exploring the limits of HSG, the proposed research will elucidate potential applications of HSG to electro-optic technologies ranging from optical communications to optical clocks.

Jatila van der Veen
Phillip Lubin
Jet Propulsion Laboratory, JPL 1388406
The Planck Visualization Project: Education and Public Outreach Effort of the U.S. Planck Mission
10/01/09-06/30/16
$514,915 ($581,515)

Planck is a mission to measure the anisotropy of the cosmic microwave background (CMB), sponsored by the European Space Agency (ESA) with significant input from NASA. Launched on May 14, 2009, Planck will measure the sky across nine frequency channels, with temperature sensitivity of 10^{-6} K, and spatial resolution up to 5 arc minutes.

NASA participation in Planck is approved and funded, and is manages by the Planck Project at the Jet Propulsion Laboratory in Pasadena, California. The US Planck project is required by NASA to perform Education and Public Outreach (E/PO) as an integral part of the science development. This award serves at the focal point for the E/PO activities of the US Planck team.

Contracts/Grants Awarded 2014-2015

Jet Propulsion Laboratory

Jatila van der Veen
1388406 10/01/09-06/30/2016 $ 107,500
The Planck Visualization Project: Education and Public Outreach Effort of the U.S. Plank Mission

Jet Propulsion Laboratory Subtotal $ 107,500

Las Cumbres Observatory Global Telescope Network

Philip Lubin
SB150105 03/01/14-07/31/14 $ 5,000
Fiber Spectrometry Alignment System

Las Cumbres Observatory Global Telescope Network Subtotal $ 5,000

NIH National Institute on Aging

Michael Bowers
1 R01 AG047116-01 07/01/14-06/30/15 $ 442,284
Amyloid β-Protein: Wild Type and Familial Mutant Assembly and Inhibition

NIH General Medical Sciences

Bruce Lipshutz
R01 GM086485 06/01/14-05/31/15 $ 251,936
Transition Metal-Catalyzed Chemistry in Water at Room Temperature

National Institute of Health Subtotal $ 694,220

National Science Foundation

Guenter Ahlers
DMR-1158514 06/01/12-05/31/16 $ 160,000
Turbulent Convection in a Fluid Heated from Below

Dirk Bouwmeester
PHY-1206118 09/01/12-08/31/16 $ 150,000
Quantum Post-Selected Optomechanics

Dirk Bouwmeester
PHY-1314982 09/01/13-08/31/16 $ 90,000
Implementing a Quantum CNOT Gate Using Solid State Cavity QED

Mark Sherwin
MCB-1244651 01/01/13-12/31/15 $ 247,806
Robust Gd3+ -Based Spin labels for Structural Studies of Membrane Proteins

National Science Foundation Subtotal $ 647,806

Novartis Pharmaceutical

Bruce Lipshutz
SB150084 01/01/15-01/04/17 $ 470,000
New Technologies Based on Transition Metal Catalysis Enabled by Micellar Catalysis

Novartis Pharmaceutical Subtotal $ 470,000

Oak Ridge National Laboratory (Department of Energy GOCO Operated by UT Batelle, LIC.)

Douglas Scalapino
4000129396 04/01/14-03/31/16 $ 31,511
Study of the Properties of Strongly Correlated Materials

Oak Ridge National Laboratory Subtotal $ 31,511

Raytheon Company

Philip Lubin
SB140137-0001 04/01/14-06/30/15 $ 26,000
Task 1: Advanced Camera Development

Raytheon Company Subtotal $ 26,000

U.S.-Israel Binational Science Foundation

Mark Sherwin

2010130	10/01/12-09/30/13	$ 23,515

Development of Gd3+-based spin labels for probing structure, dynamics and interfaces by electron paramagnetic resonance techniques

U.S-Israel Binational Science Foundation Subtotal $ 23,515

Research Support Summary
(2014-2015)

Federal			
Jet Propulsion Laboratory	7%	5%	107,500
Las Cumbres Observatory Global Telescope Network	0%	0%	5,000
National Institute of Health	47%	35%	694,220
National Science Foundation	44%	32%	647,806
Oak Ridge National Laboratory	2%	2%	31,511
Federal Totals	100%	74%	$1,486,037

International			
U.S.-Israel Binational Science Foundation	100%	1%	23,515
International Totals	100%	1%	$23,515

Private			
Novartis Pharmaceutical	95%	23%	470,000
Raytheon Company	5%	1%	26,000
Private Totals	100%	25%	$496,000

Awards Summary

Federal Totals	74%	$1,486,037
International Totals	1%	$23,515
Private Totals	25%	$496,000

TOTALS	**100%**	**$2,005,552**

Charts and Graphs

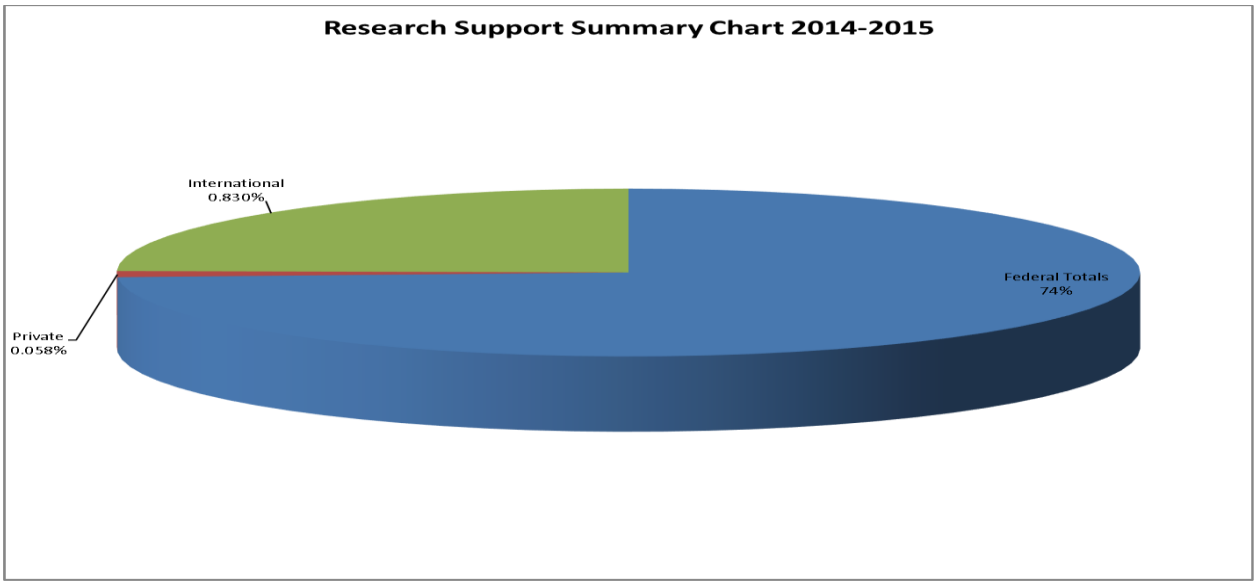


Chart 1: Research Support Summary Chart

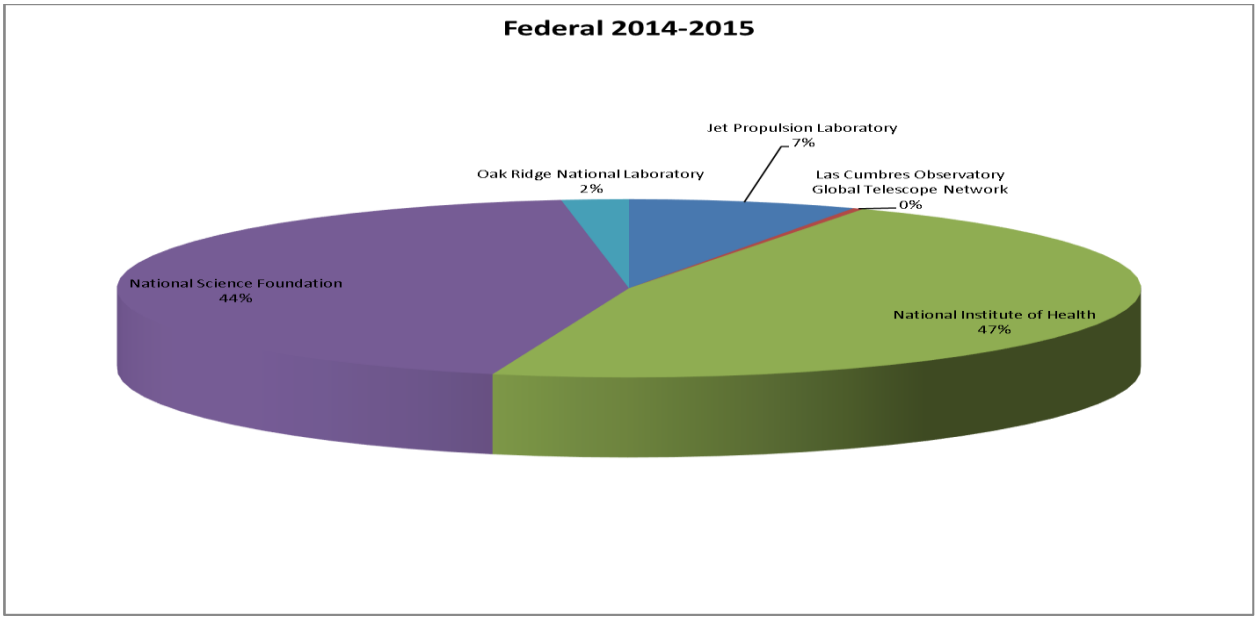


Chart 2: Federal Research Support Summary Chart

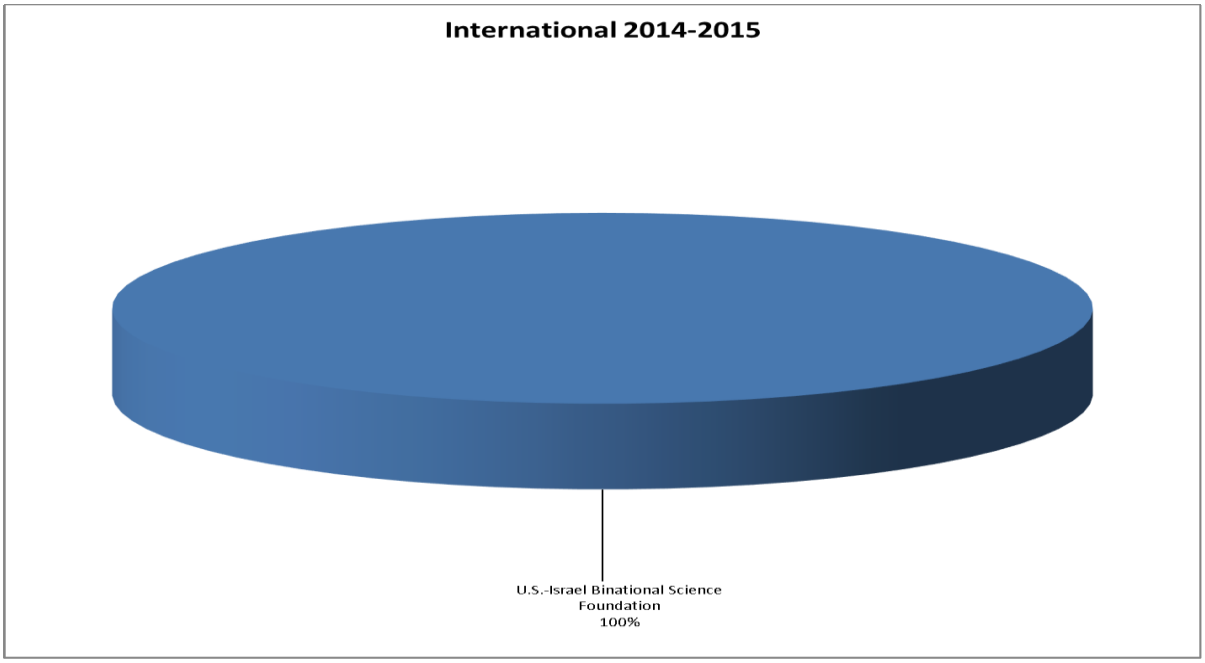


Chart 3: International Research Support Summary Chart

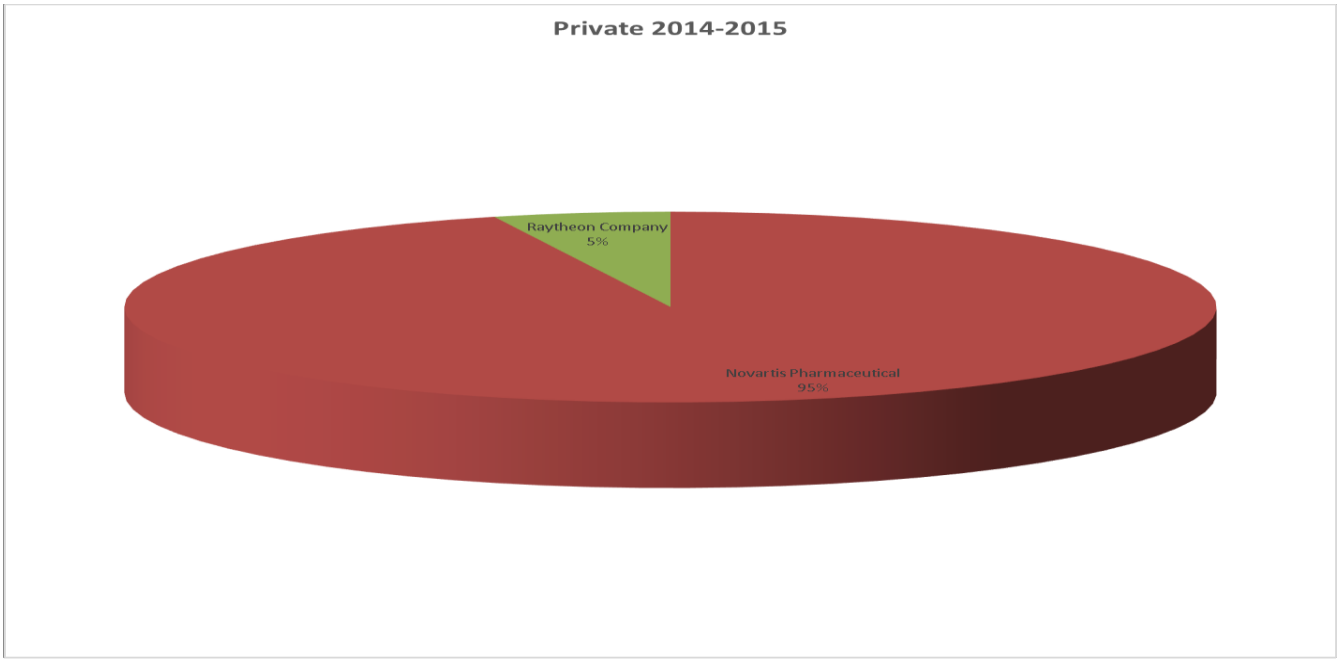


Chart 4: Private Research Support Summary Chart

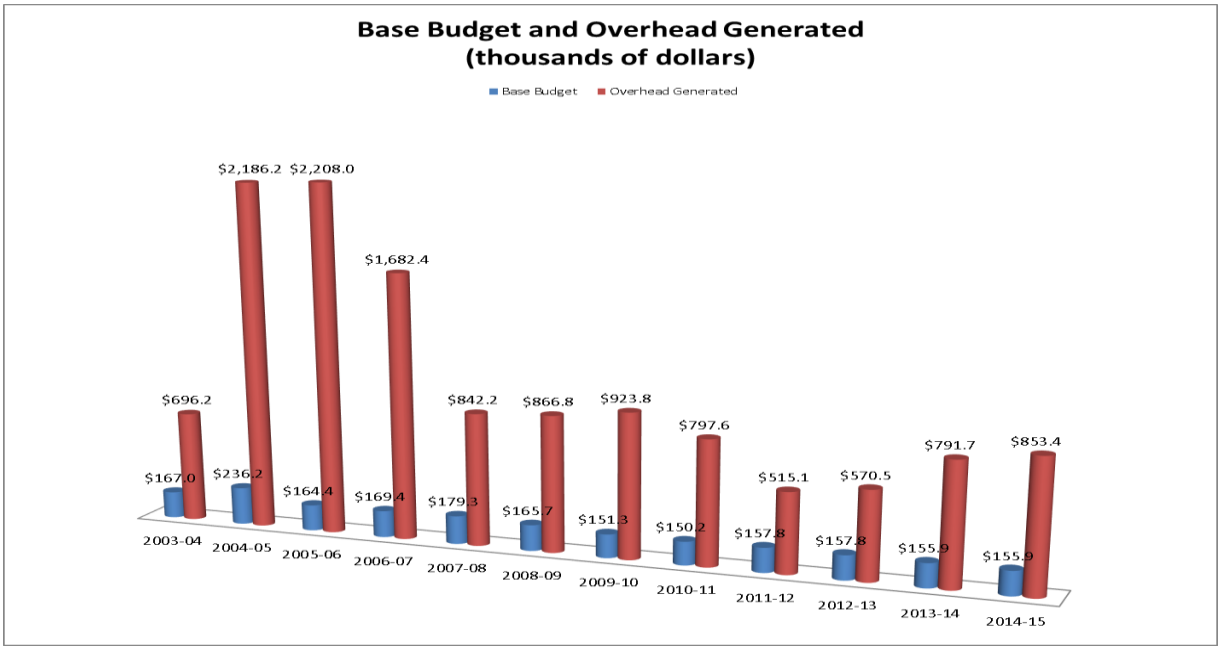


Chart 5: Base Budget and Overhead Generated

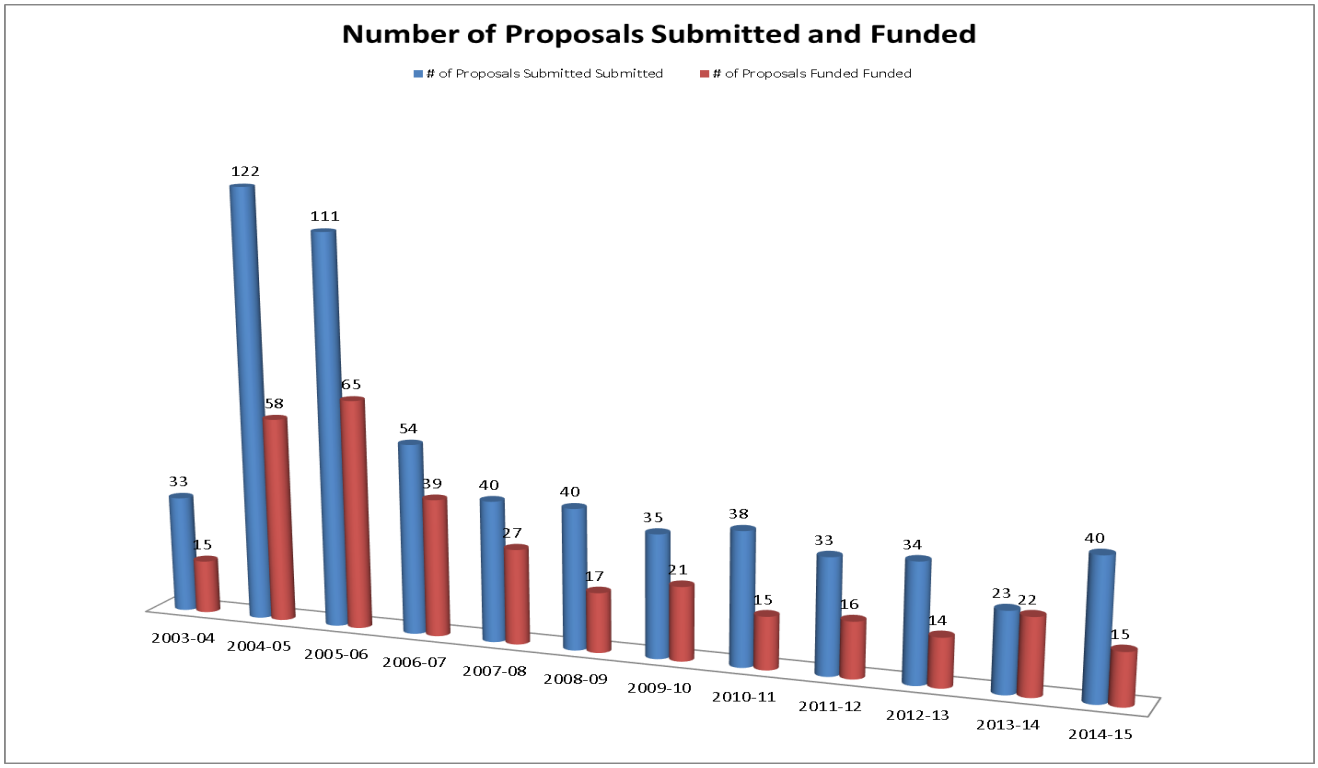


Chart 6: Number of Proposals Submitted and Funded

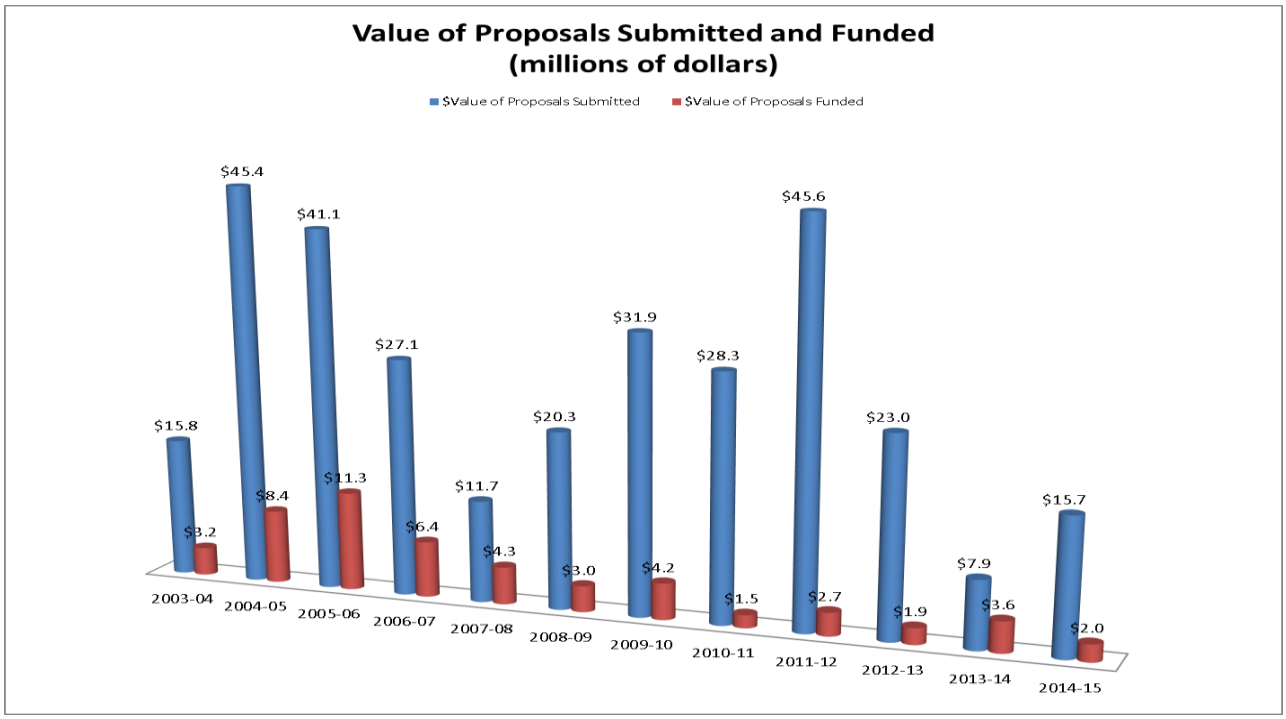


Chart 7: Value of Proposals Submitted and Funded

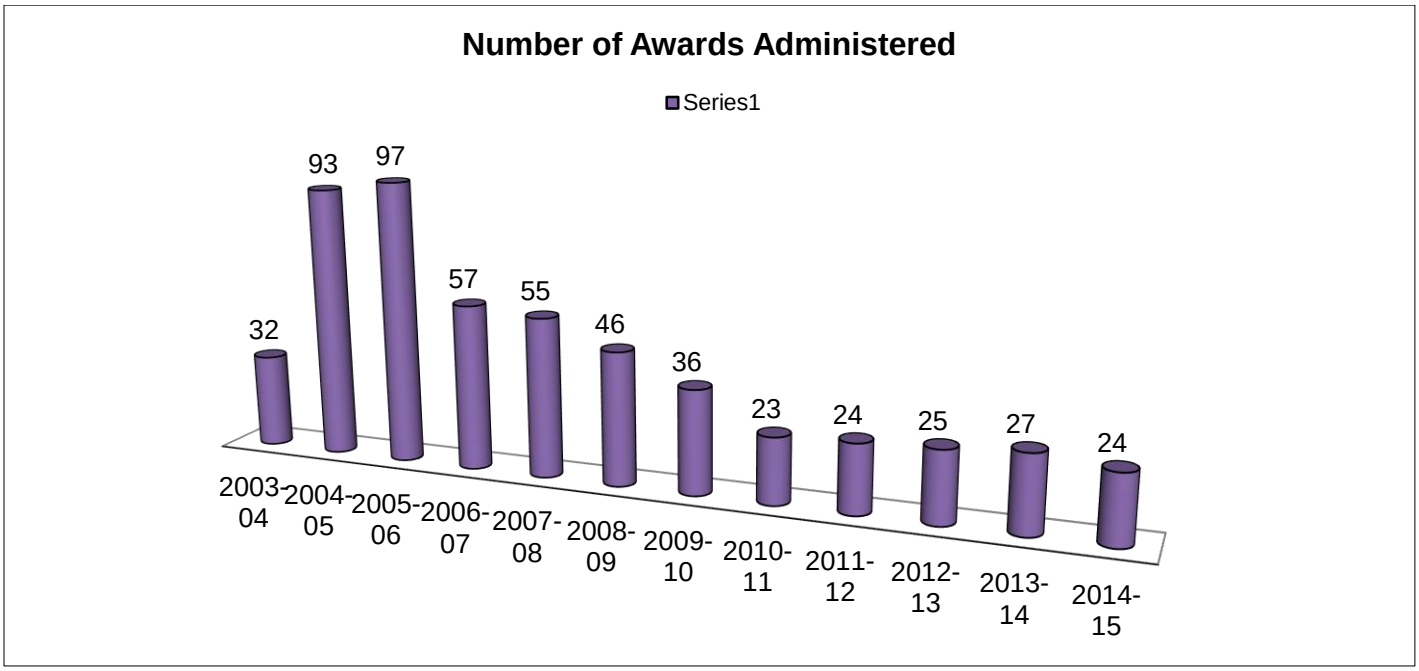


Chart 8: Number of Awards Administered

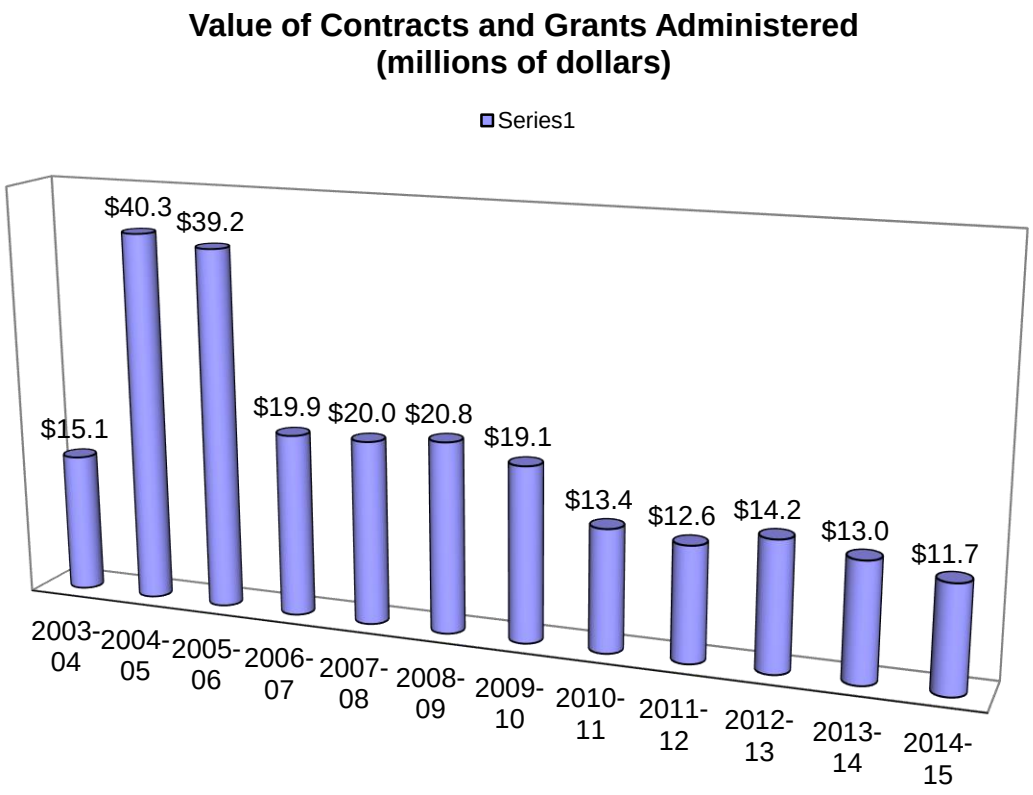


Chart 9: Value of Contracts and Grants Administered

Statistical Summary for ITST

1. Academic personnel engaged in research:			
	a.	Faculty	19
	b.	Professional Researchers (including Visiting)	1
	c.	Project Scientists	2
	d.	Specialists	3
	e	Postdoctoral Scholars	5
	f	Postgraduate Researchers	
		TOTAL	**30**
2. Graduate Students:			
	a	Employed on contracts and grants	30
	b.	Employed on other sources of funds	
	c.	Participating through assistantships	
	d.	Participating through traineeships	
	e	Other (specify) Visiting Grad Students	5
		TOTAL	**35**
3. Undergraduate Students:			
	a.	Employed on contracts and grants	6
	b.	Employed on other funds	
	c.	Number of volunteers, & unpaid interns	35
		TOTAL	**41**
4. Participation from outside UCSB: (optional)			
	a.	Academics (without Salary Academic Visitors)	5
	b.	Other (City College Student)	1
5. Staff (Univ. & Non-Univ. Funds):			
	a.	Technical	6
	b.	Administrative/Clerical	3
6. Seminars, symposia, workshops sponsored			12
7. Proposals submitted			40
8. Number of different awarding agencies dealt with*			20
9. Number of extramural awards administered			24
10. Dollar value of extramural awards administered during year**			$11,718,050
11. Number of Principal Investigators***			21
12. Dollar value of other project awards ****			$316,288
13. Number of other projects administered			6
14. Total base budget for the year (as of June 30, 2015)			$160,146
15. Dollar value of intramural support			$429,238
16. Total assigned square footage in ORU			7,700
17. Dollar value of awards for year (08 Total)			$2,055,552

* Count each agency only once (include agencies to which proposals have been submitted).

** If the award was open during the year, even if for only one month, please include in total.

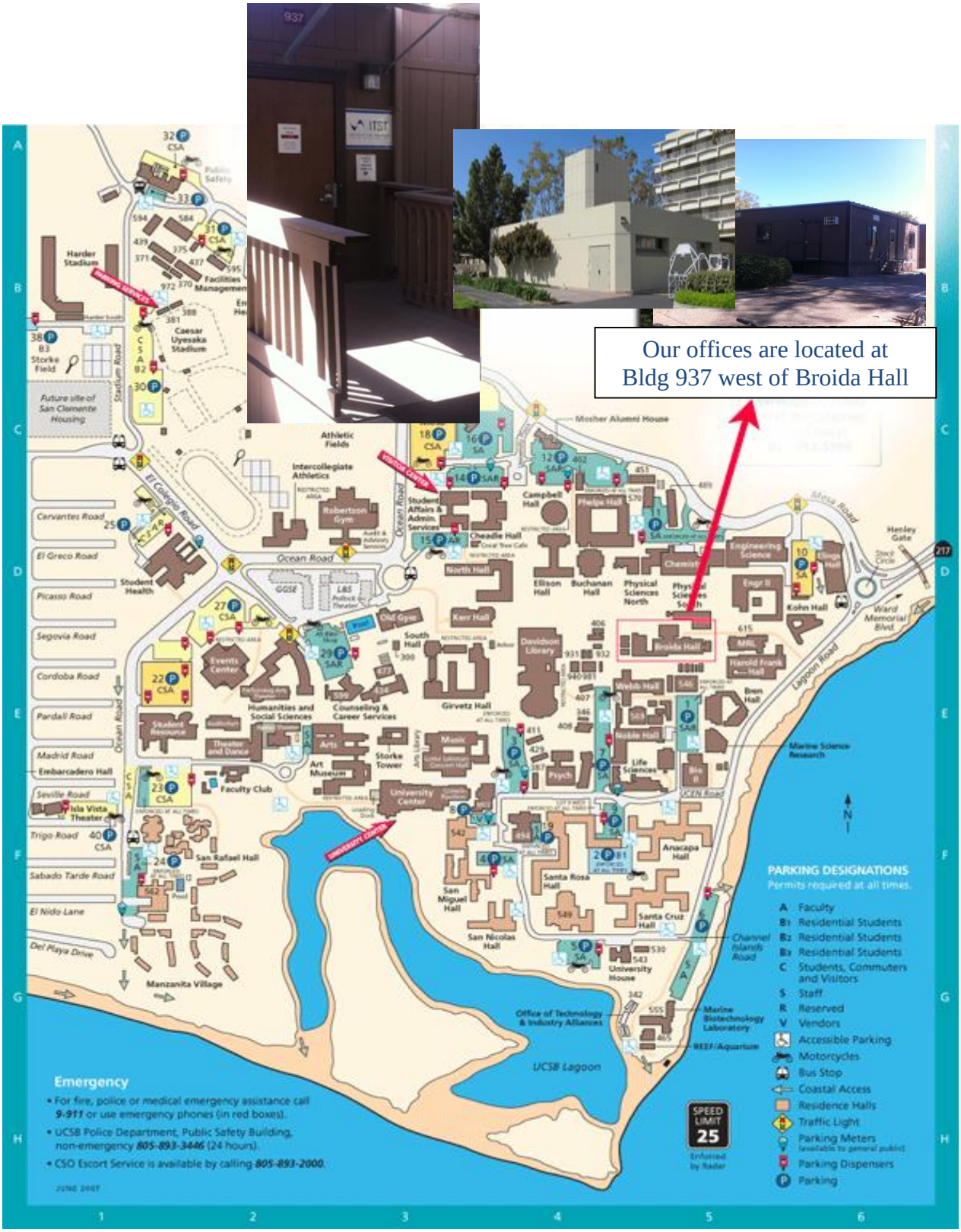
*** Number of PIs, Co-PIs and Proposed PIs (count each person only once.)

**** Other projects - such as donation, presidential awards, fellowships, anything that isn't core budget, extramural, or intramural.

Principal Investigators

Guenter Ahlers	Research Professor	Physics
S. James Allen	Research Professor	Physics
James Blascovich	Professor	Psychological and Brain Sciences
Dirk Bouwmeester	Professor	Physics
Michael Bowers	Professor	Chemistry and Biochemistry
Steven Buratto	Professor	Chemistry and Biochemistry
Deborah Fygenson	Associate Professor	Physics
Elisabeth Gwinn	Professor	Physics
Song-I Han	Associate Professor	Chemistry and Biochemistry
Michael Liebling	Assistant Professor	Electrical and Computer Engineering
Everett Lipman	Associate Professor	Physics
Bruce Lipshutz	Professor	Chemistry and Biochemistry
Philip Lubin	Professor	Physics
Peter Meinhold	Associate Researcher	Physics
Horia Metiu	Professor	Chemistry and Biochemistry
Nguyen, Thuc-quyen	Professor	Chemistry and Biochemistry/Center For Polymer & Organic Solids
Chris Palmstrom	Professor	Electrical and Computer Engineering Computer Engineering
Douglas Scalapino	Research Professor	Physics
Mark Sherwin	Professor	Physics
Jatila Van Der Veen	Research Associate	Institute for Terahertz Science and Technology/Lecturer College of Creative Studies
David Weld	Assistant Professor	Physics

Map


Our offices are located at
Bldg 937 west of Broida Hall
937
ITST
Harder Stadium
Caesar Uyesaka Stadium
Storke Field
Future site of San Clemente Housing
Stadium Road
Athletic Fields
Intercollegiate Athletics
Robertson Gym
El Colegio Road
Cervantes Road
El Greco Road
Picasso Road
Segovia Road
Cordoba Road
Pardall Road
Madrid Road
Embarcadero Hall
Seville Road
Isla Vista Theater
Trigo Road
Sabado Tarde Road
El Nido Lane
Del Playa Drive
Manzanita Village
Ocean Road
Student Health
Events Center
Humanities and Social Sciences
Counseling & Career Services
Girvetz Hall
Art Museum
Storke Tower
Faculty Club
University Center
San Rafael Hall
Campbell Hall
Phelps Hall
Cheadle Hall
North Hall
Ellison Hall
Buchanan Hall
Physical Sciences North
Physical Sciences South
Engineering Science
Kohn Hall
Broida Hall
Davidson Library
Kerr Hall
Old Gym
South Hall
Webb Hall
Noble Hall
Life Sciences
Psych
Anacapa Hall
Santa Rosa Hall
Santa Cruz Hall
San Miguel Hall
San Nicolas Hall
University House
Mosher Alumni House
Alvarado Road
Henley Gate
Ward Memorial Blvd.
Lagoon Road
Marine Science Research
UCSB Lagoon
Office of Technology & Industry Alliances
Marine Biotechnology Laboratory
Channel Islands Road
Emergency
• For fire, police or medical emergency assistance call 9-911 or use emergency phones (in red boxes).
• UCSB Police Department, Public Safety Building, non-emergency 805-893-3446 (24 hours).
• CSO Escort Service is available by calling 805-893-2000.
SPEED LIMIT 25
PARKING DESIGNATIONS
Permits required at all times.
A Faculty
B1 Residential Students
B2 Residential Students
B3 Residential Students
C Students, Commuters and Visitors
S Staff
R Reserved
V Vendors
Accessible Parking
Motorcycles
Bus Stop
Coastal Access
Residence Halls
Traffic Light
Parking Meters
Parking Dispensers
Parking