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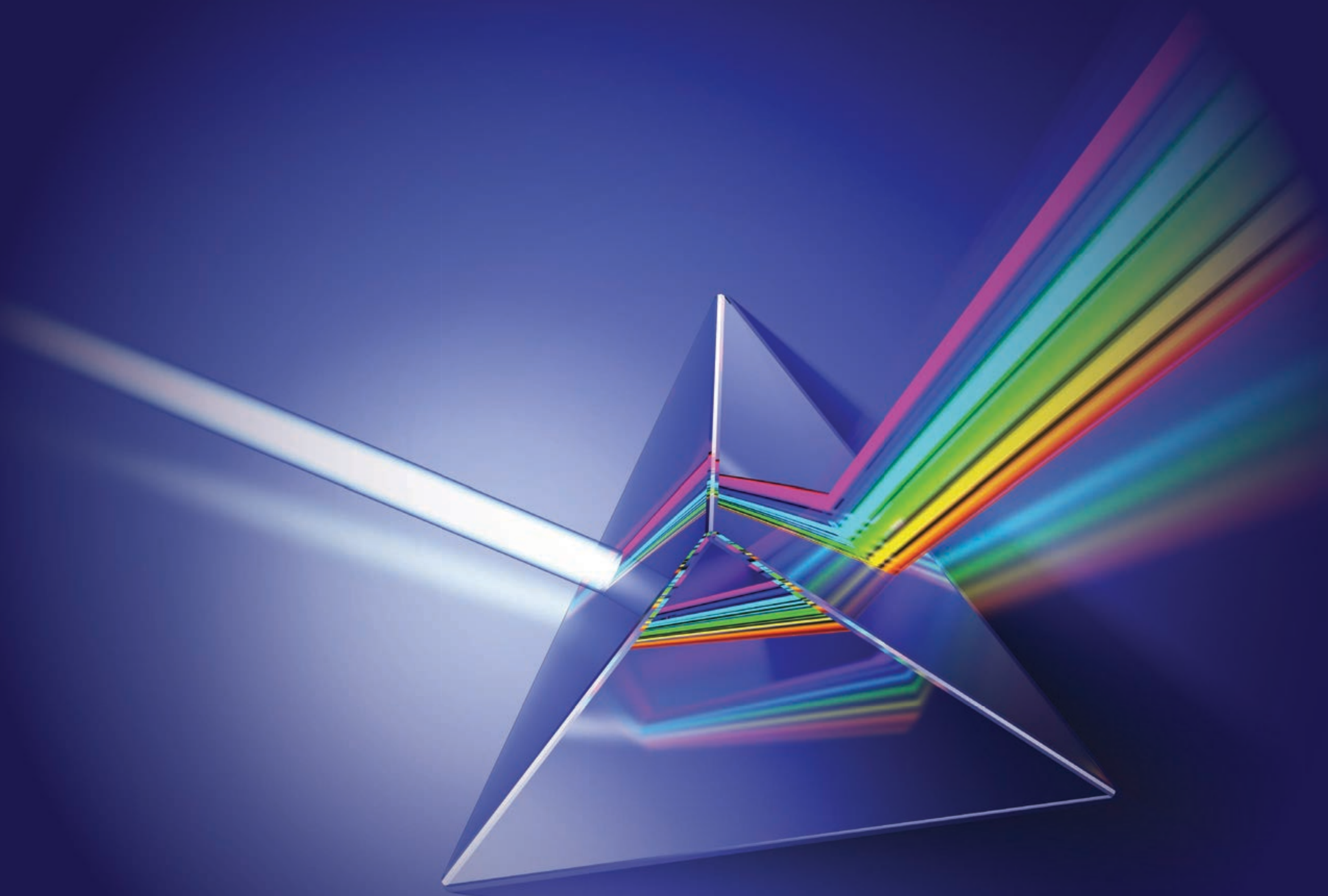
Department of Physics & Astronomy



ANNUAL REPORT 2013

UCLA Physics and Astronomy Department
2012-2013
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Department of Physics & Astronomy

2013 Annual Report

University of California, Los Angeles

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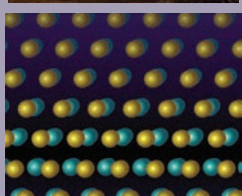
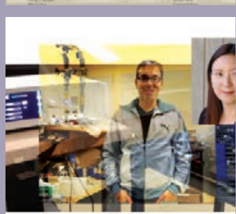
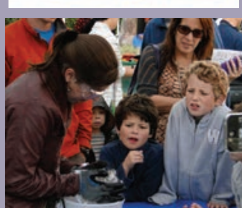






Message from the Chair

As Chair of the UCLA Department of Physics and Astronomy, it is with pride that I present to you our 2013 Annual Report. This document is intended to give an overview of the departmental accomplishments recorded in the last year, extending from recognition of faculty excellence in teaching and research, to the welcoming of new members to our ranks. This report should provide a compelling snapshot of the range of activities taking place in the department over the last twelve months, with the goal of stimulating further interest from you, the reader. As such, I hope that this report provides an informative first step to whetting your interest in our excellent education and cutting-edge research programs. Further information can be gleaned from the departmental website, as well as the individual faculty and research group sites. You should explore these sites to the fullest, as they offer a clearing house of resources for use by students, colleagues, benefactors, and the public at large, in interacting with our department.


James (Jamie) Rosenzweig, Chair

As I look back on the last year, I note with no small satisfaction that the UCLA Department of Physics and Astronomy has not only survived, but indeed has thrived during a decidedly turbulent period. Trends in educational support from the State of California, as well as the research funding from the federal government, have presented many challenges, which both the university as a whole and the department in particular have creatively and successfully met. As a measure of the overall health of the UCLA program in which we are embedded, we note that UCLA Division of Physical Sciences has been for the second straight year rated ninth in the world by the highly regarded Times of London rating.

This ranking translates most directly into attracting the highest quality of graduate students to participate in our research program and to be awarded a doctoral degree. In this regard, I am happy to note that our incoming class of high-achieving graduate students is twice the size of last year's class. We are all excited to see the impact of this tidal wave of new students will bring to our graduate program. In a campus-wide view, we can also note that the UCLA Times of London ranking overall has increased steadily over the years, and I am comfortable that I can speak for many that we feel great pride to be associated with such an august institution of higher learning.

The department's faculty members have continued to garner a high degree of recognition from their peers in the form of prizes and awards. At the junior faculty level, Professor Rahul Roy, a leading young theorist in condensed matter physics, has been awarded a prestigious Sloan Fellowship, one of five assistant professors at UCLA to receive such recognition. We note that only MIT had a higher number (six) of Sloan recipients. In addition, atomic-molecular-optical (AMO) experimental physicist Professor Wes Campbell has been awarded a highly competitive Air Force Young Investigator Research Program grant for exceptional ability and promise in basic research. At a more senior level, Professor Yaroslav Tserkovnyak has been awarded a coveted Simons Fellowship in its inaugural year for his work in theoretical condensed matter physics. And finally we note that for the second year running the winner of the leading American Physical Society award in elementary particle physics theory, the J.J. Sakurai Prize, was from UCLA in the form of Professor Zvi Bern, in recognition of his path-breaking work in scattering amplitudes, which is of overriding fundamental and practical importance in the LHC era.

The annual report contains a wide selection of brief reports from across the spectrum of research in the department. It is also a tradition in our annual report to focus on one particular research area in a featured article. This year the spotlight falls on experimental AMO physics, a nascent area at UCLA, but one with vigorous young practitioners, Professor Wes Campbell and Professor Eric Hudson. AMO physics is of fundamental importance to modern physics and plays an outsized role in modern experimental physics. Indeed, five out of the last twenty-five Nobel Prizes in physics were awarded in AMO. It uses highly sophisticated experimental methods to explore questions that are both foundational and applied, including approaches such as ultra-cold atomic traps, precision laser tools, and atomic clocks. Applications that motivate this rapidly expanding area include quantum computing and simulation, hybrid quantum systems, quantum chemistry, and determination of fundamental constants such as the electric dipole moment of the electron. Quantum computing as an application is particularly compelling among these thrusts, as it provokes a new information theory viewpoint in quantum mechanics, as well as permitting calculations that are impossibly difficult by standard methods. I hope that you enjoy the introduction to this fascinating field provided by the featured article.

A glimpse of the fast moving world of research in physics and astronomy at UCLA is encapsulated in the research group summaries. I hope that you, the reader, will be struck by the variety of curiosity-provoking topics presented, ranging from study of the infinitesimally small at in LHC experiments (which provoked the award of this year's Nobel to

Higgs and Englert) to the astrophysical cosmos. In astronomy alone, the breadth of our program is vast, ranging from exoplanets, to the galactic center, to extragalactic observations and cosmology. In this regard, we note that UCLA will play a central role in developing, in both the science case and instrumentation sides, the most ambitious astronomical instrument in history, the Thirty Meter Telescope (TMT).

The list of departmental research includes leading efforts in established areas of big science: collider-based nuclear physics, fusion-related plasma science, and advanced, novel applications of particle beams, such as the free-electron lasers and plasma accelerators. The department hosts an ever increasing activity in biophysics, which gives strong connections to research in the life sciences and the world-class UCLA Medical School. The department is also well connected with another large external campus unit, the California NanoSystems Institute (CNSI), which provides state-of-the-art instruments for nanoscience research. As such, much of the departmental connection to CNSI concerns our large and varied program in condensed matter physics.

The newest member of our faculty is in fact an experimental condensed matter physicist, Professor Ni Ni. She has arrived this last summer after finishing her prestigious Oppenheimer Fellowship at Los Alamos National Laboratory. In our ongoing faculty renewal efforts we have also recruited Dr. Smadar Naoz. She is a noted astrodynamicist with a strong interest in exoplanets who will finish her current stint at the Harvard-Smithsonian Center for Astrophysics and join us next summer. We also have welcomed an eminent adjunct professor, Slava Turyshev, who also holds appointments at JPL and Skolkovo Institute in Moscow. Professor Turyshev is a theoretical astrophysicist best known for definitive work on resolving the Pioneer Anomaly.

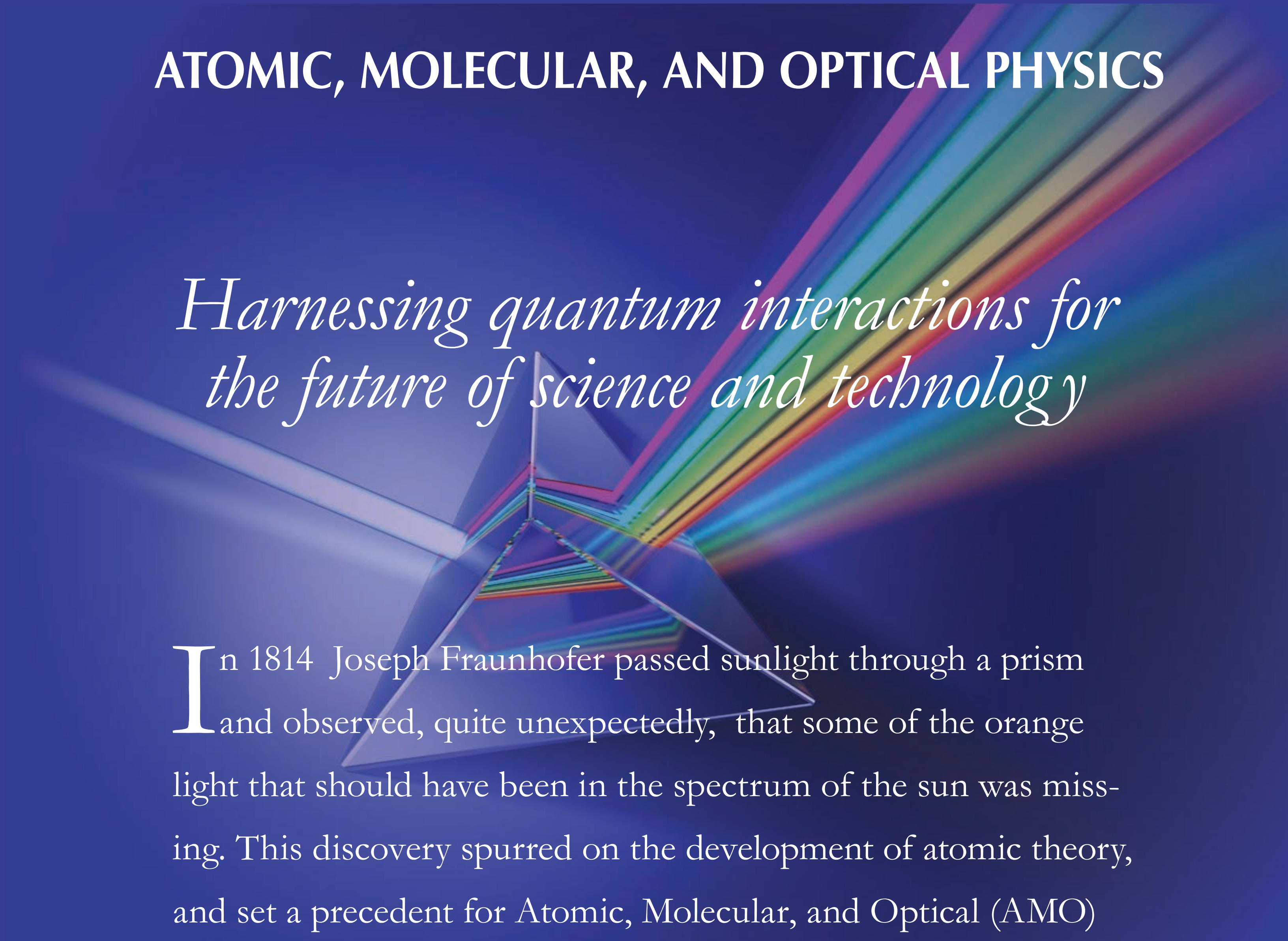
This last year saw a number of new initiatives in teaching in the department. We have begun a dedicated effort in online education with the help of visiting professor Warren Essey, whose primary employment is with Google. In the classroom Professor Roberto Peccei has offered a relevant, topical course on the "Physics of Energy," while on the laboratory side a new upper division lab was offered for the first time, emphasizing topics in AMO — the quantum optics laboratory. Finally, to begin orienting our students towards contributing to society in ways that utilize a scientific background as a springboard to entrepreneurship, we have utilized a gift from the Arman Moossa family to begin a yearly colloquium on science and economic innovation. The inaugural speaker this year, Stuart Parkin of IBM, gave an auspicious start to this series.

Ian McLean, Vice Chair, Astronomy

The fact that this new colloquium series is based on funding from a gift endowment is indicative of the financial environment we in the department face. In the past year we have seen a slight but encouraging rebound in state support. On the other hand, federal funding, which is the lifeblood of our research program, has taken a serious hit from the effects of the sequester and the recent government shutdown. Uncertainties in financial resources have made the continued generosity of our private donors ever more critical to the department's current and future success. I do encourage all who care about maintaining the excitement of this department's scientific adventure to consider deepening their involvement — enjoy this report, consider visiting us for a public event, and show your support in whatever way is appropriate for you.

James (Jamie) Rosenzweig, Chair

ATOMIC, MOLECULAR, AND OPTICAL PHYSICS



Harnessing quantum interactions for the future of science and technology

In 1814 Joseph Fraunhofer passed sunlight through a prism and observed, quite unexpectedly, that some of the orange light that should have been in the spectrum of the sun was missing. This discovery spurred on the development of atomic theory, and set a precedent for Atomic, Molecular, and Optical (AMO) physics altering our understanding of Nature. In the decades that followed Fraunhofer's experiment, this precedent was repeated over and over again. For example, spectroscopy of atoms led to the development of the Bohr model and quantum mechanics. Optical interferometry experiments rejected the idea of an ether in favor of Einstein's theory of relativity. And improved, high resolution spectroscopy led to the development of Dirac's formulation of relativistic quantum mechanics and eventually the gold standard of all theories, quantum electrodynamics.

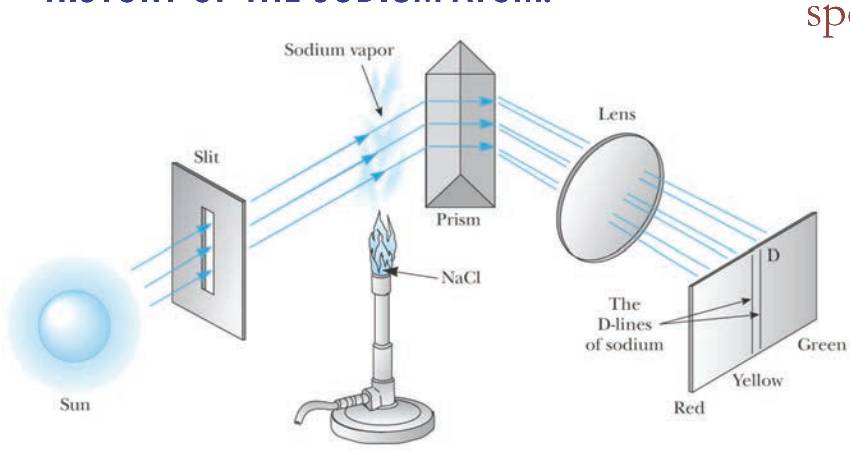
But, in 1978, something revolutionary happened that turned the field of AMO on its head. David Wineland and co-workers flipped their experiments around. Instead of using their laser systems to study atoms, they used their lasers to control how the atoms move. The technique of laser cooling was born and the direction of AMO was forever altered. Following this watershed experiment, AMO physicists everywhere began using the tools and knowledge they had developed for studying atomic properties to manipulate the atoms. Very quickly, techniques were developed that could produce atoms in single quantum states and control their quantum dynamics. Ideas that were previously only thought to be the realm of thought experiments became a reality. At first, experiments were centered on proofs-of-principle, atoms were put into quantum superpositions (like the famous Schrödinger cat experiment), and the counterintuitive ideas of quantum measurement were tested and found to be consistent with reality. However, soon AMO researchers realized that they could harness the power of quantum interactions to improve both technology and fundamental physics knowledge. Fast forwarding to the current day, the benefits of their labor are apparent. The laser, a tool developed to study and control atoms, is now commonplace in everything from supermarkets to computer drives to industrial fabrication. The global positioning systems in our cars and phones require exquisite timing and synchronization to function, which they achieve through the use of highly stable atomic clocks. These clocks realize the necessary precision by employing quantum measurement protocols developed in AMO.i Mass spectrometers, developed by these early experimenters, are now used in medical and forensic labs across the world. And quantum-assisted sensing of magnetic and gravitational fields, again using techniques developed during the AMO revolution, is beginning to be used for everything from locating potential oil and diamond fields to detection of weapons stockpiles. In fact, all totaled, it is estmated that discoveries in quantum physics, such as these, account for 30% of the current U.S. GDP!

On the science side of things, these same techniques have been used to enable the most accurate measurements of the constants of nature, the highest precision tests of quantum electrodynamics, and searches for physics beyond the standard model. These techniques have also been used to confirm our understanding of quantum mechanics and quantum measurement. And they are now being harnessed to usher in a new generation of measurement techniques that exploit the peculiarities of quantum mechanics to allow for even more precise measurements of the world around us.

Looking forward, the future of the field lies in continuing to use the power of quantum interactions to improve science and technology. At UCLA we are working towards this by both developing new techniques to tame the power of quantum interactions and by bringing new systems under the same level of quantum control that laser cooling brought to atoms.

HISTORY OF THE SODIUM ATOM:

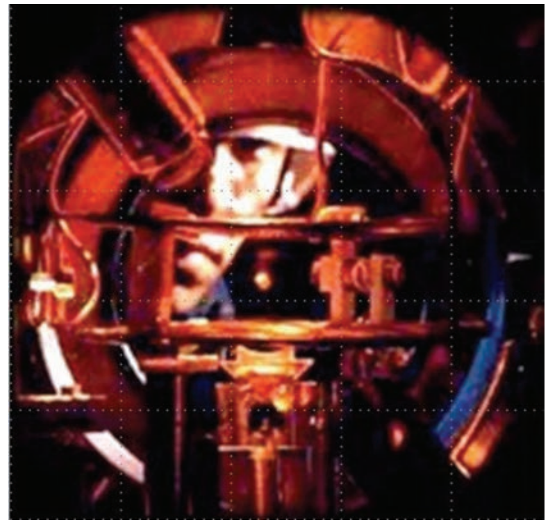
from the discovery of the atomic spectra to the taming of the atom



Fraunhofer's original experiment: When light from the sun was passed through sodium vapor, produced by burning salt, he observed the weak absorption bands in the sun's spectrum got even weaker. This indicated the missing light was due to absorption of light by sodium atoms in the sun. Image Credit: Serway, Moses, and Moyer, Brooks/Cole publishing.

In 1814 Joseph Fraunhofer passed sunlight through a prism and observed, quite unexpectedly, that some of the orange light that should have been in the spectrum of the sun was missing. Fraunhofer was able to prove that this missing light was due to absorption by sodium atoms in the sun through an ingenious experiment (see accompanying figure) that could be considered the birth of the technique of spectroscopy. When he passed the sun's light through a flame containing sodium atoms, he observed that even more of the orange light disappeared, but that other colors of light were not attenuated, proving that sodium atom were absorbing the light.

Almost two centuries later, sodium atoms played another groundbreaking role in the development of AMO physics. In 1987 Bill Phillips and colleagues used lasers to demonstrate a device, called the magneto-optical trap (MOT), which confined atoms and cooled them down to a hundred millionths of a degree above absolute zero! At these temperatures the atoms behaved according to the strange laws of quantum mechanics and scientists now had a new window into that world. The impact of the MOT technique cannot be overstated; it has made nearly countless experimental studies of fundamental physics possible and is now being incorporated in next generation quantum-based technology.

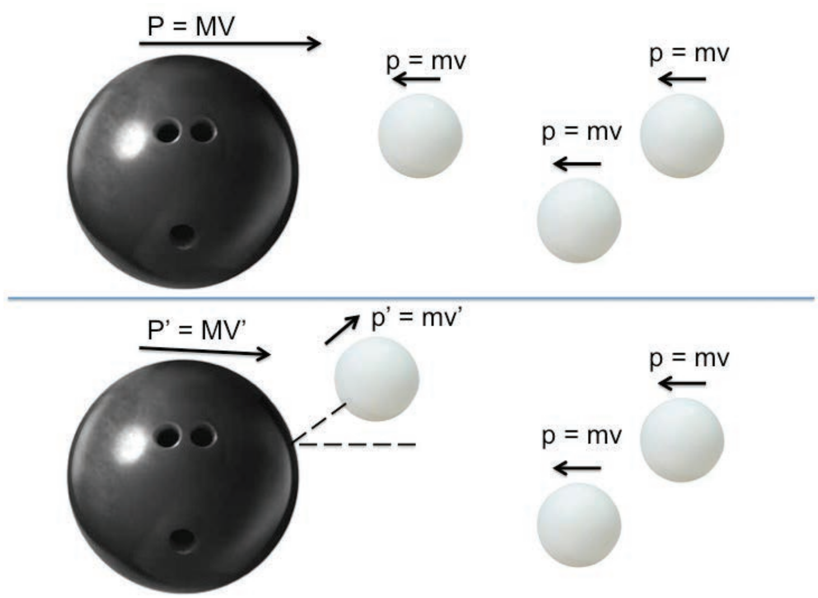


Kris Helmerson of NIST looking into a vacuum chamber at a sodium MOT. The sodium atoms, visible as the bright orange dot in the middle of the picture, are cooled and levitated by lasers.

THE WORKHORSE OF ATOMIC PHYSICS: Laser cooling

The technique of using lasers to cool atoms is as simple as it is powerful. Because photons carry momentum, when an atom absorbs a photon its velocity is changed. If the photon and the atom that absorbs it are moving toward each other, the absorption of the photon results in the atom being slowed (cooled). If the photon and the atom are moving in the same direction, the absorption of the photon speeds up (heats) the atom.

The trick in laser cooling is to find a way to make cooling more frequent than heating. This is accomplished by using the Doppler effect – i.e. the effect that makes a car horn have a higher pitch when the car is coming towards you than when it is going away from you. By tuning the frequency of the laser to be lower than the frequency of the atomic transition, atoms moving towards the photon will see a Doppler shifted photon that is the color they want to absorb, while atoms moving away from the photon will see a photon that is very different from the color they want to absorb. Thus, absorption events that lead to cooling are much more prevalent than those that lead to heating and the atoms are quickly cooled to near absolute zero!



Laser cooling analogy: A bowling ball moving to the right can be slowed down by launching ping-pong balls at it from the direction opposing its motion. Each time a ping-pong ball collides with the bowling ball its motion is slowed. In laser cooling the atom is slowed by photons launched from a laser.

Nobel prizes in atomic physics

Since the development of the technique of laser cooling, AMO physics has been evolving at breakneck speed. Nowhere is this evidenced more clearly than in the list of recent AMO physics Nobel Laureates.

1989. Norman Ramsey, Hans Dehmelt, and Wolfgang Paul: The Nobel Prize in Physics 1989 was divided, one half awarded to Norman F. Ramsey *"for the invention of the separated oscillatory fields method and its use in the hydrogen maser and other atomic clocks,"* the other half jointly to Hans G. Dehmelt and Wolfgang Paul *"for the development of the ion trap technique."*

1997. Steven Chu, Claude Cohen-Tannoudji, and William D. Phillips: The Nobel Prize in Physics 1997 was awarded jointly to Steven Chu, Claude Cohen-Tannoudji and William D. Phillips *"for development of methods to cool and trap atoms with laser light."*

2001. Eric Cornell, Wolfgang Ketterle, and Carl Weiman: The Nobel Prize in Physics 2001 was awarded jointly to Eric A. Cornell, Wolfgang Ketterle and Carl E. Wieman *"for the achievement of Bose-Einstein condensation in dilute gases of alkali atoms, and for early fundamental studies of the properties of the condensates."*

2005. Roy Glauber, John Hall, and Theodor Hansch: The Nobel Prize in Physics 2005 was divided, one half awarded to Roy J. Glauber *"for his contribution to the quantum theory of optical coherence,"* the other half jointly to John L. Hall and Theodor W. Hänsch *"for their contributions to the development of laser-based precision spectroscopy, including the optical frequency comb technique."*

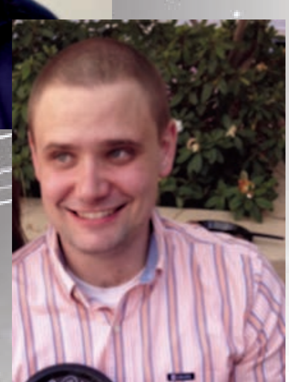
2012: Serge Haroche and David J. Wineland: The Nobel Prize in Physics 2012 was awarded jointly to Serge Haroche and David J. Wineland *"for ground-breaking experimental methods that enable measuring and manipulation of individual quantum systems."*

UCLA AMO alumni off to explore the universe

This year saw the departure of two UCLA AMO scientists (Wade Rellergert and Scott Sullivan) to the Jet Propulsion Lab in Pasadena. Wade and Scott will be taking the techniques they learned at UCLA to build next-generation optical clocks that will be aboard future NASA space probes. These clocks will allow the probes to navigate in deep space and communicate with scientists back on Earth.

Dr. Wade G. Rellergert (research scientist) was hired as a permanent Staff scientists at JPL in early 2013. He is leading several projects to build next generation optical clocks for satellite navigation. He is also exploring the effects of microgravity on clouds of ultracold atoms.

Dr. Scott Sullivan (graduate student, 2013) won the prestigious NASA Postdoctoral Program fellowship for his proposal to use printed circuit board technology to produce scalable architecture for a ytterbium ion optical clock. He began working at JPL in October 2013 to implement his experimental vision.



Getting involved

If you would like to learn more about AMO, you are welcome to attend the frequent AMO seminars held on campus. Simply write the department chair's office at chair@physics.ucla.edu and ask to be added to the AMO mailing list. All talks are open to the public.

If you are interested in contributing the UCLA AMO effort with a time or financial commitment, please contact Professor Eric Hudson at eric.hudson@ucla.edu.

The Hudson Group at UCLA

Exploring new frontiers in AMO science

Atomic, Molecular, and Optical (AMO) physics is a unique science. On one hand, the systems studied in AMO offer a variety of technological applications based on understanding and harnessing quantum interactions, ranging from simple measurement and sensing to next-generation time-keeping and quantum computation; yet, on the other hand, these same systems remain simple enough to be calculated from first-principles, allowing sensitive test of fundamental physics. Real progress on both of these fronts of AMO has come whenever new techniques were developed that extended the precision control offered by the field to new systems. The technique of laser cooling brought the external and internal quantum states of neutral atoms and atomic ions under control roughly three decades ago, enabling a scientific revolution with few parallels. Our research program at UCLA is working to push the techniques of AMO physics to two new, unexplored frontiers: the study of ultracold polar molecular ions and a laser-accessible nuclear transition.

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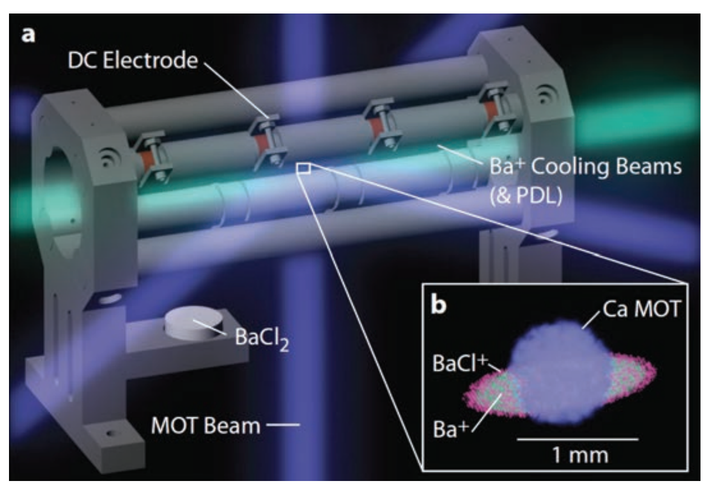
The MOTion trap: Ultracold molecular ions

Without question, the atom has been tamed. With modern AMO techniques it is possible to completely control and manipulate atoms at the quantum level. The same cannot be said, however, of even the simplest molecule, e.g. diatomic molecules made of just two atoms. Because of the extra complexity that comes with a molecular bond – rotation and vibration of the molecule – molecules have evaded all but a few attempts to domesticate them. Nonetheless, it is expected that if and when molecules are brought under control they will enable a scientific revolution that parallels what transpired when atoms were brought under control, with implications ranging from quantum computation to material science.

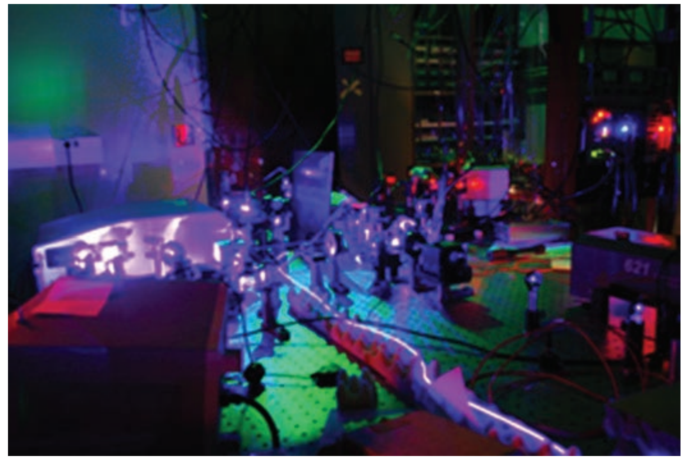
At UCLA we are developing a new method that uses ultracold atoms as "ice cubes" to cool trapped molecular ions into their quantum ground state. Simply put, by spatially overlapping a cloud of ultracold, laser-cooled atoms in a magneto-optical trap (MOT) with a molecular ion trap, we have shown that it is possible to quickly cool both the internal and external degrees of freedom of the molecular ion. The technique promises to be robust and simple since it requires only an ion trap and ultracold atom trapping – both proven technologies.



First-generation MOTion trap system. Molecular and atomic ions are trapped in the middle chamber of the linear quadrupole trap, while ultracold atoms are collected in a MOT. The ultracold atoms quickly cool the molecular ion towards its quantum ground state.

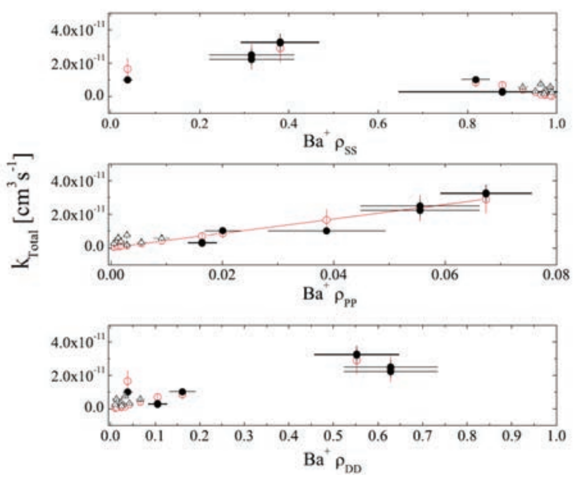
Research Highlights from 2012-2013:

Taming molecules: This year saw the first-ever demonstration of our technique for cooling molecules using laser-cooled atoms. In this demonstration, atomic Ba^+ ions were co-trapped with $BaCl^+$ molecular ions and laser cooled to ~ 1 mK (-273.15 °C). The atomic ions strongly interact with the molecular ions and cool the molecular ions motion to ~ 1 mK. Once the molecular ions translational motion is cooled, an ultracold Ca MOT is turned on and the ultracold atoms cool the internal degrees of freedom of the molecular ions. This successful demonstration of our original 2009 proposal has now opened the door to the production and study of ultracold molecular ions and is reported in a recent manuscript: W.G. Rellergert et al., *Nature* 490, 495 (2013).



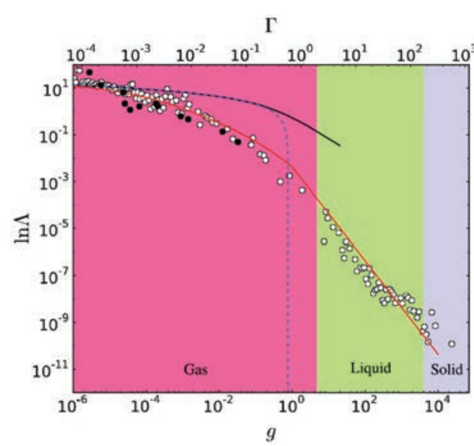
Narrow-band laser system used for laser cooling.

Ultracold quantum chemistry: As the MOTion trap brings ultracold atoms and ions in close proximity, it is an ideal test-bed for studying chemistry in the ultracold regime, where quantum effects become important. Using this system, we have studied reactions between Ca + Yb+, Ca + BaCl+, Ca + Ca, and Ca + Ba+, where the reactants are prepared in individual quantum states. These experiments have revealed a wealth of information about chemistry in the ultracold regime and are challenging current theoretical understanding. The results and the questions they have raised are reported in several manuscripts, including: S.T. Sullivan et al., *Physical Review Letters* 109, 223002 (2012), W.G. Rellergert et al., *Physical Review Letters* 107, 243201 (2011), and S.T. Sullivan et al., *Phys. Chem. Phys.*, 13, 18859 (2011).



Reaction rate between Ca and Ba+, measured as a function of the quantum states of the barium ions.

With a little help from our friends: The dynamics of ions being sympathetically cooled in an ion trap have remained an unsolved problem for over forty years. However this year with help from UCLA Plasma physicist, George Morales, we have been able to use concepts from plasma physics to offer a complete description of the process. This work has changed the way cooling in ion traps is approached and is reported in a recent manuscript. K. Chen et al., *Phys. Rev. Lett.* 110, 173003 (2013).



Results of a measurement of the coulomb logarithm as a function of the plasma coupling parameter g. The parameter g is related to the temperature of the ions – g = 10^3 is approximately T = 1 mK. Colors demarcate the phases of the ion in the trap. With this measurement, it is now possible to analytically predict the dynamics of ions being sympathetically cooled in an ion trap.

The future of ultracold molecular ion research: In the time since our original 2009 proposal (E.R. Hudson, *Phys. Rev. A* 79, 032716 (2009)), ultracold molecular ion research has grown from a small periphery field into one of the "hot" topics in AMO. Several new groups have joined the effort at other US and European universities and, very recently, the Department of Defense has selected ultracold molecular ions as a topic for the highly sought after MURI grant. Thus, while there is certainly a long way to go, it appears that the first fruits of our efforts to open a new frontier in AMO are starting to sprout.

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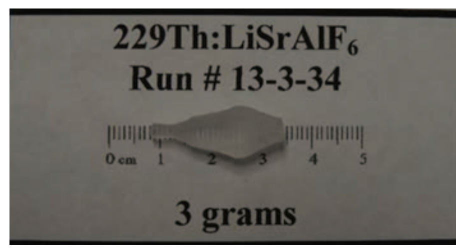
A nuclear clock The technological impact of atomic clocks has been profound, ranging from the successful implementation of global positioning systems and cellular telephones to the synchronization of modern-day electrical power grids. Improved clocks, based on optical frequency standards, are likely to enable several new technologies such as secure data routing, jamming resistant communication, high-resolution coherent radar, and improved global positioning. Furthermore, high-precision clocks have provided a means to probe fundamental issues in physics. For example, atomic clock experiments have provided some of the most stringent tests of General Relativity. Because of these motivations, there is presently enormous effort towards building next-generation atomic clocks. It appears universally recognized that the most promising route to improved clocks uses reference oscillators based on optical transitions. Indeed, several optical atomic clock experiments have already reported better stability than the primary Cesium standard, which keeps time for the nation.

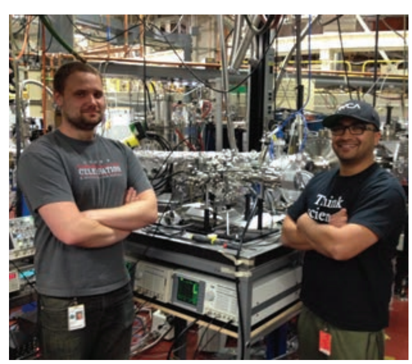
In 2010, we proposed (W.G. Rellergert et al., *Phys. Rev. Lett.* 104, 200802 (2010)) a novel optical frequency standard based on a high-Q transition in the ^{229}Th nucleus, and this "nuclear" clock architecture promises several orders of magnitude improvement in precision over next-generation optical atomic clocks, while simultaneously reducing experimental complexity. This paradigm shift in optical frequency standards is possible because, as indicated by recent data, the ^{229}Th transition has the lowest energy of any known nuclear excitation, making it amenable to study by laser spectroscopy. Furthermore, because nuclear energy levels are relatively insensitive to their environment, the complicated vacuum apparatus of current optical frequency standards can be replaced by a single crystal doped with ^{229}Th atoms.

To date, our work has been focused on two of the most significant experimental challenges for constructing a solid-state optical clock based on the ^{229}Th nuclear transition: finding and constructing a suitable host crystal and determining the clock transition frequency. These efforts are described below.



Picture of bulk ^{229}Th: LiSAF crystal, which is the result of 5 years of crystal growth work.

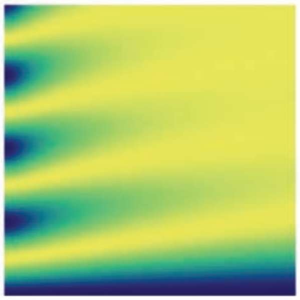
Construction of a ^{229}Th-doped crystal: The appropriate clock crystal must be both transparent in the VUV and resilient to radiation damage (^{229}Th decays via emitting a 4.8 MeV a-particle.) In the last few years, we have performed extensive tests of candidate material and settled on LiSrAlF6, which possesses all of the necessary properties. With the host crystal selected, the most significant challenge remaining for this phase of the project was to obtain a sufficient quantity (a few mg) of the rare ^{229}Th to produce the final crystals. (Our first quote from a commercial supplier for ~3 mg of ^{229}Th was priced at ~\$6M!). Fortunately, working with Oak Ridge National Laboratory and DARPA we were able secure a sample of ~3 mg of ^{229}Th. This sample was received in the middle of last year and the first-ever ^{229}Th doped crystal was grown in December of that year. This work has led to significant development of small crystal growth techniques and is reported in two manuscripts: W.G. Rellergert et al., *IOP Conf. Ser. Mater. Sci. Eng.* 15, 012005 (2010) and M.P. Hehlen et al., *Journal of Luminescence* 133, 91 (2013).


Scott Sullivan (left) and Justin Jeet (right) at the Advanced Light Source in Berkeley, where they are searching for the thorium nuclear transition.

The future of the solid-state optical clock: Now that the necessary clock crystals have been grown, work is shifting towards determining the nuclear transition frequency more accurately. Because the resolution of the previous measurement (7.8 ± 0.5 eV) of the transition frequency is poor by laser spectroscopic standards, it is necessary to better determine the transition energy before a clock can be built. For this purpose, we are now using the intense, wide-bandwidth VUV light from a synchrotron – the Advanced Light Source (ALS) at Berkeley – to attempt to excite the ^{229}Th nuclei and collect their resulting fluorescence. Once the nuclear clock transition is found at the ALS, work will then shift to constructing the first-ever nuclear clock.

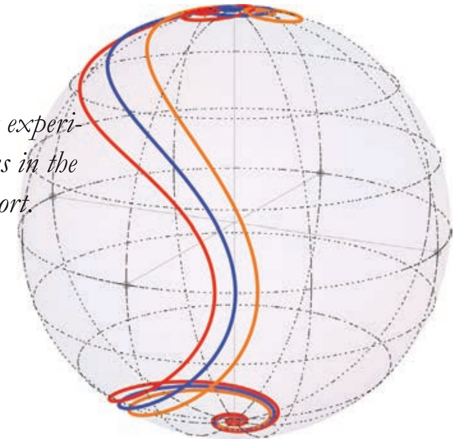
Wes Campbell Group at UCLA

As one of the new research groups this year, the Wes Campbell group has been focused on building experimental infrastructure and assembling the equipment necessary for producing isolated quantum systems in the form of trapped atoms and molecules. Wes Campbell has outlined his research on page 43 of this report.



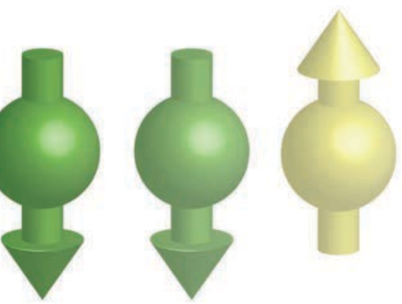
The probability that an ultrafast pulse excites a molecule is shown in color as a function of the strength (vertical axis) and pulse chirp (horizontal axis).

Polar molecules that are electrically neutral (as opposed to molecular ions) need to be cooled to very low temperatures before their dynamics become dictated by the dipole-dipole interaction between molecules. Wes Campbell's group is pursuing a technique to decelerate and cool molecular beams using an all-optical approach. The idea is to use short bursts of light from an ultrafast laser that are carefully tailored to decelerate the molecules without allowing them to spontaneously emit photons, which typically leads to loss. During this deceleration, a single photon can then be used to cool each molecule to a tiny fraction above the absolute zero of the temperature scale. Samples of cold molecules produced in this way are promising platforms for quantum computation and other quantum information tasks.

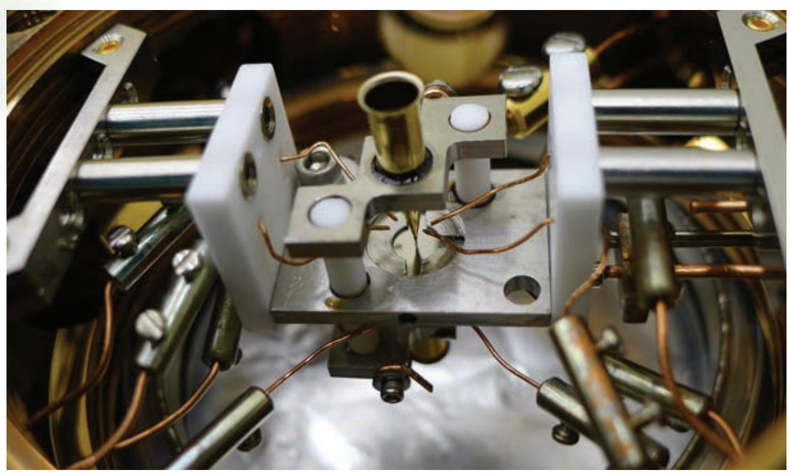


The evolution of a state of a quantum two-level system can be depicted as trajectories on a surface called the Bloch Sphere. Three different paths are shown corresponding to different pulse parameters for exciting molecules using ultrafast bursts of light.

Collections of trapped atomic ions have been used since the mid 1990s as prototype quantum information processors, and current system sizes are now approaching 20 qubits. It is expected that somewhere in the range between 20 and 50 lies the boundary where these "prototypes" can begin to outperform the world's most powerful supercomputer for simulating quantum many-body physics. Single atomic ions have been trapped in Wes Campbell's group this year, and researchers are working on scaling up this system to larger sizes in an experimental context appropriate for using them as a quantum simulator. They hope to use this system to develop an understanding of, among other things, the nature of high-temperature superconductivity z (a conspicuous current mystery in physics) and the behavior of quantum systems that involve strongly-correlated constituents.



Trapped atomic ions can be used to mimic electron spins that interact based on their relative orientation. The spin textures that result may help researchers to better understand exotic forms of magnetism and to design the next generation of magnetic and superconducting materials.



An ion trap used to levitate single atoms in an ultra-high vacuum environment.

UNDERGRADUATE LABORATORY ON QUANTUM OPTICS (PHYS 180Q).

In the last year UCLA has developed, with a grant from the Cottrell Scholar foundation and a donation from Thor Labs, a new undergraduate laboratory on Quantum Optics (Phys 180Q). Please go to page 43 in this report for more information on this new lab and course.

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2012-2013 Donor Impact Stories

"In the Department of Physics and Astronomy, our donors truly make a difference. Each donor to the Department of Physics and Astronomy has a personal story about why they give back. As Chair, I am often privileged to hear these stories and see the impact of these gifts on a daily basis. Some donors remember how they struggled financially as students, and support the next generation. Other donors recognize that by supporting an outstanding faculty member with an endowed chair or students with a graduate fellowship or undergraduate scholarship, they directly contribute to scientific innovation and discoveries. I am also truly impressed when a faculty member or a faculty member's spouse supports the department. Our faculty members already give so much to our students throughout their careers, and we are grateful to faculty who can additionally create a legacy here. Even the smallest gift to the Chair's Discretionary Fund is important, and helps me when unexpected needs arise. While we highlight only a few generous gifts on these pages, every gift to the Department matters, and we are thankful for our donors' passionate philanthropy."
– James Rosenzweig, Chair, Department of Physics and Astronomy

"The Preston Family Fellowship has been incredibly helpful in funding my research here at UCLA. With the award, I am able to focus on my research and be as productive as I can be. I appreciate so much that this has let me make significant progress in my first two years as graduate student, with more coming up soon!" –Anna Boehle, Preston Family Graduate Fellow

"This fellowship makes my dream to attend graduate school a possibility."
–Jared Lodico, recipient of the Eugene Y. Wong Memorial Physics Scholarship

"I don't know how large your donation was, but I do know the portion that made it to me had a significant positive impact on my life. I will do my best to turn that into an impact on science!" –River Snively, recipient of the Kriss Teaching Assistant Award

Cyrus and Diana Arman
Siblings Cyrus and Diana Arman established the Moossa J. Arman Endowed Colloquium Series to honor the memory of their father, Dr. Moossa J. Arman. Dr. Arman earned his M.S. ('69) and his Ph.D. ('72) in Physics from UCLA where he studied under Professor Bernard Nefkens. Following graduation, he returned to the Graduate School of Physics at Pahlavi University in his native Iran, now Shiraz University, where he was Dean from 1973-1979. Dr. Arman returned to the U.S. to serve in advisory positions on the National Research Council for the National Academy of Sciences.

Shirley Saxon
David Saxon Physics Graduate Fellowship Fund

Photo: Eugene Y. Wong
Dorothy P. Wong Eugene Y. Wong Physics Graduate Fellowship

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The Moossa J. Arman Colloquium Series aims to provide physics graduate students with awareness about the variety of career options available to them. The inaugural Moossa J. Arman Colloquium, "The Spin on Electronics! Science and Technology of Spin Currents in Nano-materials and Nano-devices," was presented by Dr. Stuart S.P. Parkin of the IBM Almaden Research Center on May 29, 2013. "My father got his start at UCLA," said Diana. "He always said that the education and support he received from Professor Nefkens and UCLA were instrumental to his success." We look forward to hosting the second Arman Colloquium in Spring 2013.

Dr. Mani Bhaumik

Stemming from "a long standing fascination with the 'Holy Grail' of physics to find unification of the forces of nature," Mani's generous gift established the Zvi Bern Postdoctoral Research Fund. "Einstein devoted the last thirty years of his research solely to this goal, as did Professor Bose of boson fame, adviser for my graduate studies," said Mani. "Although Einstein did not get to see it, his dream has come a long way toward fulfillment. Professor Bern's breakthrough work using the 'unitarity principle' appears very promising. Even though his work is highly regarded by the physics community, it is always difficult to get adequate funding for fundamental research. Sensing that [Professor Bern] is probably a couple of years away from a major breakthrough, I felt compelled to support his pioneering work." Mani is a physicist, author, lecturer, entrepreneur, and philanthropist who made significant contributions to laser technology and the development of the exciter laser at the Northrop Corporation Research and Technology Center. Mani is also an involved member of the Division of Physical Sciences Board of Advisors.

Fred and Joyce Hameetman

Fred and Joyce are passionate about astronomy and contributed to the Andrea Ghez Research Fund in 2013. "The reasons I contributed," said Fred Hameetman "include the fact that Andrea Ghez is a happy, upbeat, optimistic and enthusiastic proponent of science who has used segmented telescopes and adaptive optics to better show and explain Einstein's concepts and Supermassive Black Holes to the layperson." Fred is the Chairman of Cal-American Group, a successful real estate business.

To learn more about giving options, such as endowments and naming opportunities, please contact Kerri Yoder (kyoder@support.ucla.edu or 310-794-9045).


Arthur Levine & Lauren Leichtman

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UCLA ALUMNI

UCLA ALUMNI

Have you been back to campus lately? Physics and Astronomy alumni are always welcome back to visit the department. We host a variety of events throughout the academic year, from technical colloquia on the department's latest research to family-focused activities.

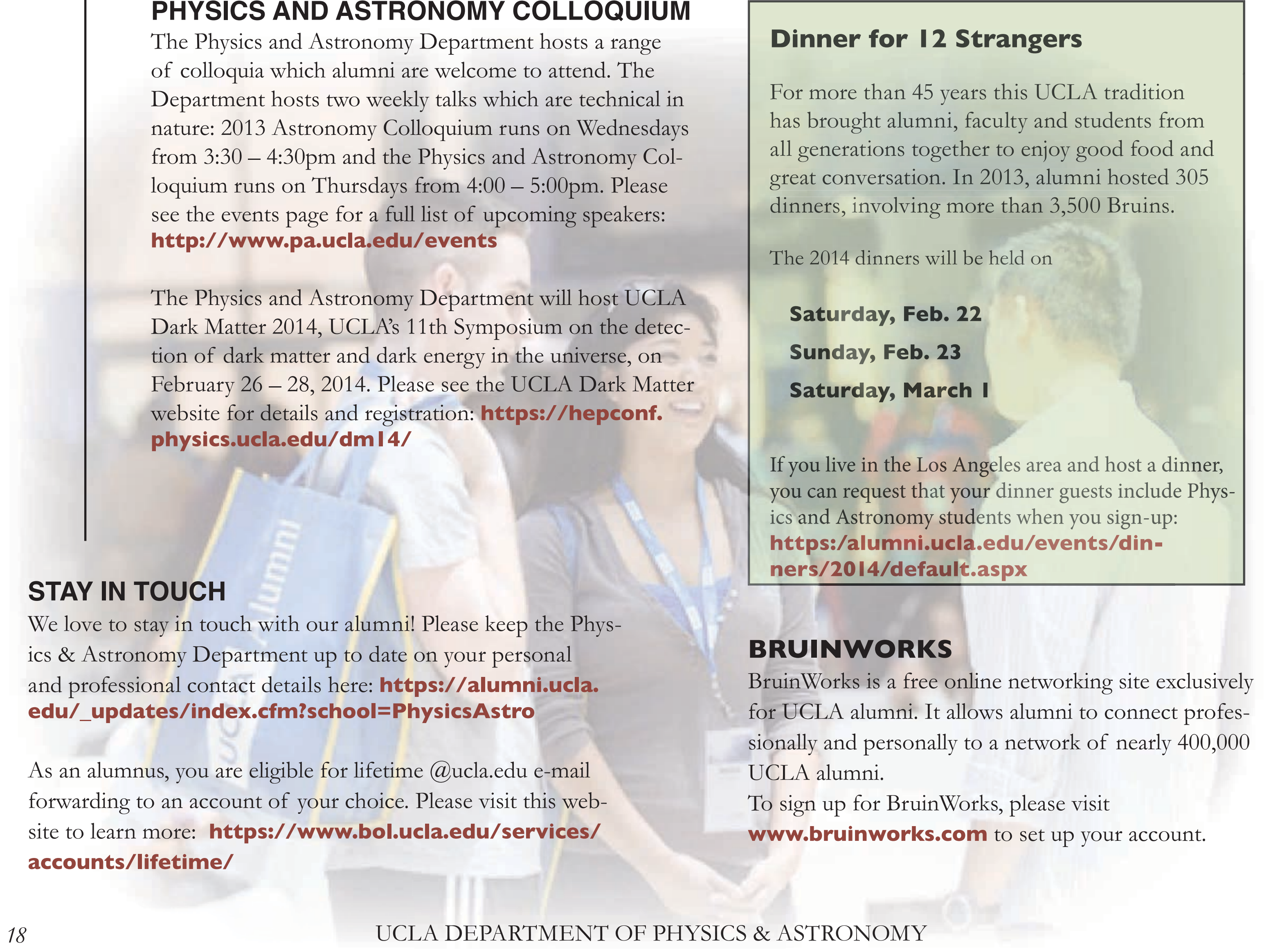
UCLA ALUMNI DAY

UCLA Alumni Day 2013 took place on campus on Saturday, May 18th. Guy Kawasaki (MBA '79) set the tone of the entrepreneurial-focused event with his keynote speech, "The Art of Enchantment." We would like to thank our Physics and Astronomy alumni who joined us for this fun day of family, networking and Bruin spirit. You can see photos from the 2013 event at **http://www.alumniday.ucla.edu/2013/**. We look forward to seeing Physics and Astronomy alumni in May for Alumni Day 2014!

PHYSICS AND ASTRONOMY COLLOQUIUM

The Physics and Astronomy Department hosts a range of colloquia which alumni are welcome to attend. The Department hosts two weekly talks which are technical in nature: 2013 Astronomy Colloquium runs on Wednesdays from 3:30 – 4:30pm and the Physics and Astronomy Colloquium runs on Thursdays from 4:00 – 5:00pm. Please see the events page for a full list of upcoming speakers: **http://www.pa.ucla.edu/events**

The Physics and Astronomy Department will host UCLA Dark Matter 2014, UCLA's 11th Symposium on the detection of dark matter and dark energy in the universe, on February 26 – 28, 2014. Please see the UCLA Dark Matter website for details and registration: **https://hepconf.physics.ucla.edu/dm14/**



STAY IN TOUCH

We love to stay in touch with our alumni! Please keep the Physics & Astronomy Department up to date on your personal and professional contact details here: **https://alumni.ucla.edu/_updates/index.cfm?school=PhysicsAstro**

As an alumnus, you are eligible for lifetime @ucla.edu e-mail forwarding to an account of your choice. Please visit this website to learn more: **https://www.bol.ucla.edu/services/accounts/lifetime/**

EXPLORING YOUR UNIVERSE

Please join us on November 17th for Exploring Your Universe 2013! Exploring Your Universe is a free family-friendly day of science activities that is open to the public. Activities include workshops, faculty and graduate student talks, planetarium shows and telescope viewing, physics demos, comet-making and more! Please see the event website for the full schedule and directions to campus: **http://www.astro.ucla.edu/~outreach/eyu2013.html**

UCLA PLANETARIUM

The UCLA Planetarium, run entirely by astronomy and astrophysics graduate students, hosts a free public planetarium show every Wednesday at 8:00pm during the academic year. On clear nights, visitors are also invited to look through one of the department telescopes following the show. For more information, please visit: **http://www.astro.ucla.edu/planetarium/**

Dinner for 12 Strangers

For more than 45 years this UCLA tradition has brought alumni, faculty and students from all generations together to enjoy good food and great conversation. In 2013, alumni hosted 305 dinners, involving more than 3,500 Bruins.

The 2014 dinners will be held on

Saturday, Feb. 22

Sunday, Feb. 23

Saturday, March 1

If you live in the Los Angeles area and host a dinner, you can request that your dinner guests include Physics and Astronomy students when you sign-up: **https:/alumni.ucla.edu/events/dinners/2014/default.aspx**

BRUINWORKS

BruinWorks is a free online networking site exclusively for UCLA alumni. It allows alumni to connect professionally and personally to a network of nearly 400,000 UCLA alumni.
To sign up for BruinWorks, please visit **www.bruinworks.com** to set up your account.

ASTRONOMY & ASTROPHYSICS

INFRARED LABORATORY GROUP 2012-13

Ian McLean, James Larkin and Michael Fitzgerald

Now in its 24th year of operation, the Infrared Laboratory for Astrophysics (IR Lab) at UCLA has been recognized across the world as a center of excellence for the development of powerful new instruments for astronomy. For example, all four of the currently operational infrared cameras and spectrographs on the 10-m Keck telescopes on the summit of Mauna Kea, Hawaii, came entirely or in part from the UCLA IR Lab. The latest of these, MOSFIRE, is now in regular use and enabling a wide range of science from studies of exoplanets to high redshift galaxies. The IR Lab also provided the integral field spectrometer (IFS) for the Gemini Planet Imager (GPI), which is now beginning its commissioning phase on the 8-m Gemini South telescope in Chile. During this past year, work also continued on the preliminary design of IRIS, the Infra-Red Integral-field Spectrograph for the proposed Thirty Meter Telescope (TMT), and FLITECAM, the infrared camera for NASA's Stratospheric Observatory for Infrared Astronomy (SOFIA).

In September 2012, after achieving "first light" on the Keck 1 10-meter telescope in April of that year, the MOSFIRE team led by Professor Ian McLean completed all of its commissioning tasks and the instrument was formally handed over to the Observatory for "shared risk" observing. Then, in February 2013, this restriction was lifted and this powerful new scientific instrument became open to the entire community of astronomers using the Keck Observatory. With its remarkable field of view for direct imaging and its unique multi-object sensitivity for spectroscopic observations, MOSFIRE is heavily in demand. One of the first results to emerge from the new instrument was just published in the *Astrophysical Journal* by UCLA graduate student Kristin Kulas, together with Professors Ian McLean and Alice Shapley (UCLA) and other members of the MOSFIRE team.

Using only seven hours of on-sky time with the new instrument, the team was able to analyze the differences in chemical composition among faint, distant galaxies, thought to be members of a young cluster just forming some 10 billion years ago. Previous work in this field required many nights of observation spread over two to three years. Until MOSFIRE provided a multi-object capability, each galaxy had to be observed one at a time. Since delivering MOSFIRE Professor McLean has also been working on FLITECAM, an infrared camera/spectrograph for NASA's Boeing 747 flying observatory. The UCLA team is currently preparing for flights later in 2013. UCLA graduate student Sarah Logsdon (below) has been working on FLITECAM over the past year and will fly on the upcoming missions.

To image planets more than a million times fainter than their host stars and located less than one arcsecond away, the Gemini Planet Imager combines one of the most advanced adaptive optics (AO) systems, an apodized coronagraph, a shearing interferometer and an integral field spectrograph (IFS) as the final science instrument. The goal is to detect solar systems with architectures like our own (Jovian planets located in the outer regions) in order to understand how rare or common our arrangement is.

The overall project is led by our own former student Bruce Macintosh (now a professor at Stanford). Professor James Larkin led the design and construction of the IFS at UCLA. Like the OSIRIS instrument delivered by James to the Keck Observatory in 2005, the IFS employs a lenslet array to dissect the image and take more than 40,000 spectra simultaneously over the full dark hole. In this spectral data cube, the speckles change positions as a function of wavelength while a true planetary companion stays fixed. This technique gains another factor of 10 to 100 of additional contrast against the central star, depending on the location of the planet, and should therefore allow us to see the planet directly. During 2012-2013 the entire GPI was tested thoroughly at the integration site at the University of California, Santa Cruz. The instrument was shipped to the telescope in Chile in August 2013 and "first light" is expected later in the year. Graduate student Jeffrey Chilcote has been extremely active in all aspects of the design, construction and integration of the IFS and is participating in its installation in Chile.

UCLA Graduate student Jeffrey Chilcote in front of the Gemini International Telescope at Cerro Pachon, Chile. Jeff was part of the installation team for the Gemini Planet Imager scheduled to begin its hunt for planets in November 2013.

Professor Larkin also leads an international team designing an imaging spectrograph (IRIS) for the Thirty Meter Telescope, being constructed on the summit of Mauna Kea in September 2013. With a primary mirror roughly the size of a baseball diamond, the telescope will have an unprecedented sensitivity and spatial resolution. IRIS utilizes the advanced adaptive optics system NFIRAOS (led from the Hertzburg Insititute for Astronomy in Victoria, Canada) and has integrated on-instrument wave front sensors (OIWFS) to achieve diffraction limited resolutions at wavelengths longer than 1 μm. The spectrograph offers four plate scales ranging from 4 to 50 milliarcseconds and can take up to 10,000 spectra simultaneously in a filled rectangular pattern. IRIS will be a general- purpose instrument working at distances from our Solar System to the edge of the observable Universe and the very first galaxies. The IRIS spectrograph will complete its preliminary design phase in the summer of 2014 and first light is planned for 2022.

While the IR Lab is hard at work on the IRIS design, it is also aiming to increase the sensitivity and scientific reach of the previously delivered Keck instruments OSIRIS and NIRSPEC by upgrading their detectors and optics. Professor Larkin is leading a project funded by the National Science Foundation to modernize the detector in the OSIRIS integral field spectrograph. The new detector will have improved sensitivity and reduced electronic artifacts, maximizing the scientific potential of the sharp images it is able to measure spectroscopically. The OSIRIS instrument has an imaging arm in addition to the integral field unit. Professor Michael Fitzgerald is studying a potential upgrade to the optics and detector in the OSIRIS Imager, so that it can finely sample the sharp images delivered to the adaptive optics system with a modern detector, and potentially serve as the first-light imager for Keck's proposed Next Generation Adaptive Optics system.

Fitzgerald is also leading an effort, supported by the Keck Observatory, to upgrade the detectors in the NIRSPEC instrument. The new detector in the NIRSPEC spectrometer is expected to provide, by more than a factor of 3, improvements in sensitivity at short wavelengths compared to the current system. The IR Lab team, including second-year graduate student Emily Martin, is currently testing the special mount and readout circuitry for the new detector in the laboratory, and hopes to upgrade the detector and electronics in the near future.

Ian McLean has continued as Vice Chair for Astronomy, Director of the Infrared Lab, and Associate Director for the University of California Observatories (UCO). He also continued as co-chair for the SPIE conference series on astronomical instrumentation that occurs every two years. He supports graduate students Gregory Mace, Sarah Logsdon and Emily Martin. Kristin Kulas obtained her Ph.D. with Professor McLean in June 2013 and is now at NASA's Ames Research Center. Using NIRSPEC and MOSFIRE at the Keck Observatory, and FLITECAM on NASA's SOFIA, McLean's research includes the study of the coolest sub-stellar objects known as brown dwarfs, as well as star formation in the local and high-redshift universe.

James Larkin focuses on the early development of galaxies like our own Milky Way. Using his instrument OSIRIS at the Keck Telescopes, he and his former graduate student Shelley Wright (now a faculty member at University of Toronto) measure the internal motions of galaxies more than 9 billion light years away at a time soon after their formation. A primary goal of this research is to learn when and how these vast structures began to mature into the stable rotating disk galaxies we see in the Universe today. As a byproduct of these measurements they are also able to identify black holes growing at the galaxy centers and can measure the composition of the gas going into the early generations of stars. Larkin's effort to construct the Gemini Planet Imager spectrograph has been assisted by graduate student Jeffrey Chilcote.

Mike Fitzgerald studies the relationship between exoplanets and dusty circumstellar debris disks, which act as tracers of planet formation processes. He has applied the NIRC2 camera and the Keck AO system to search for faint emission from planets and disks around nearby stars, and has developed similar techniques for the Gemini Planet Imager (GPI). He has worked with graduate students Jeffrey Chilcote, Thomas Esposito, and Li-Wei Hung to develop and apply high-contrast imaging techniques to these systems. He is looking forward to applying these methods with GPI on the sky in the near future. Meanwhile, he is also leading upgrade proposals for existing Keck instruments, and is working with the Ghez group to model the field-dependent aberrations in Keck AO imaging via the AO Optimization project.

HIGH-REDSHIFT GALAXIES

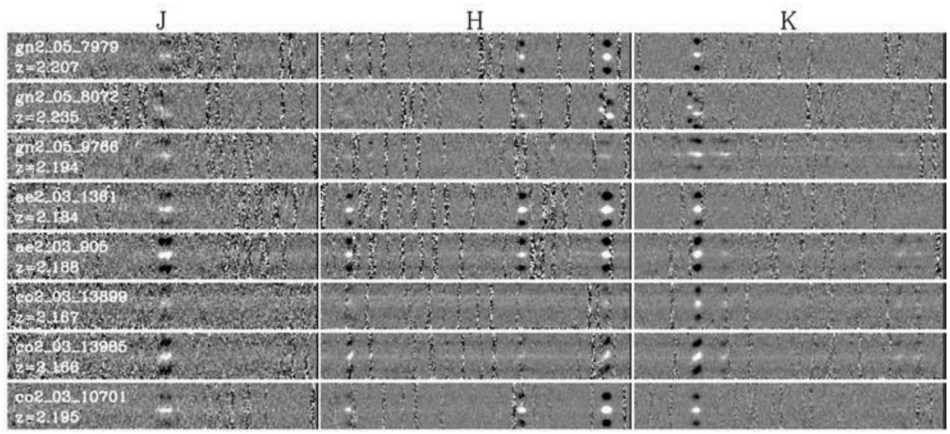
Alice Shapley

A few billion years after the Big Bang, the growth rates of galaxies and the supermassive black holes that they host were at their peak levels. Currently our knowledge of fundamental galaxy properties is extremely limited during this important epoch. Key questions include: What are the physical processes driving star formation in individual galaxies? How do galaxies exchange gas and heavy elements with the intergalactic medium? How are stellar mass and structure assembled in galaxies (in situ star formation vs. mergers)? What is the nature of the co-evolution of supermassive black holes and galaxies?

Starting in Spring 2013, Alice Shapley and collaborators at the University of California have embarked upon the MOSFIRE Deep Evolution Field (MOSDEF) survey (http://astro.berkeley.edu/~mariska/MOSDEF/Home.html) to address these questions. The MOSDEF survey has been awarded 44 nights over the next four years to use the brand-new MOSFIRE near-infrared spectrograph on the Keck I telescope (built here at UCLA, with Professor Ian McLean as co-PI).

With MOSDEF we will collect rest-frame optical spectra and observe the stellar, gaseous, and chemical content of approximately 2,000 galaxies as seen when the Universe was only 1.5 to 4.5 billion years old. With its rich dataset, MOSDEF will transform our knowledge of basic galaxy properties in the early universe. The MOSDEF survey was also just awarded a ~$1M grant from the National Science Foundation.

In the figure below, we show examples of spectra collected as part of the MOSDEF survey. Each row contains the spectrum of a single target galaxy (or, in one case, a merging pair!), increasing in wavelength from left to right. The galaxies shown here all have redshifts of roughly 2, corresponding to distance of more than 10 billion light years away. Strong emission lines (white blobs) are visible, which arise from ionized hydrogen, oxygen, nitrogen, and sulfur gas.



THEORETICAL ASTROPHYSICS

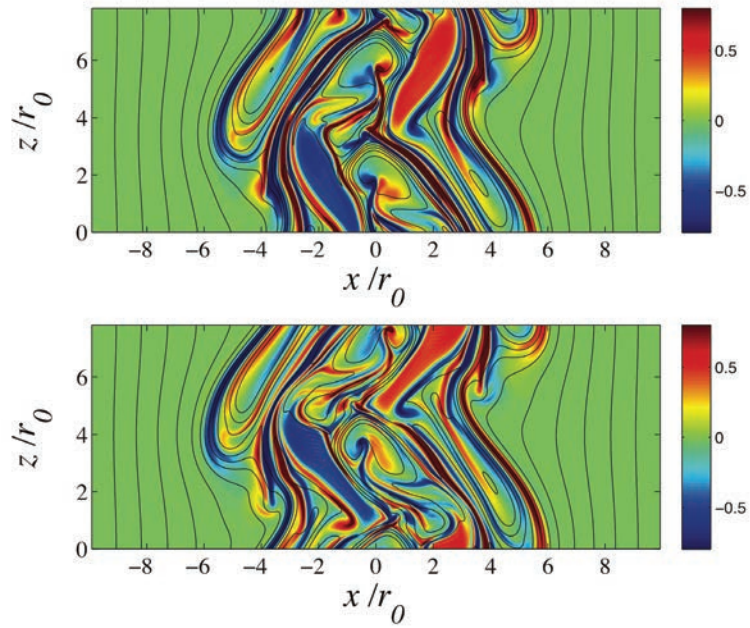
William I. Newman

My research interests pertain to problems in theoretical astrophysics and plasma physics, as well as to condensed matter physics and computational physics.

During the past year my graduate student, Nathaniel D. Hamlin, completed his dissertation on the role of the Kelvin-Helmholtz instability in magnetized relativistic sheared flows. The principal application of this theoretical and computational undertaking is to explain bipolar flows emerging from active galactic nuclei as well as to some plasma fusion devices. We published a paper in Physical Review E describing this research and have an additional paper under review relating to the computational methodology that had been developed for this study. Nat has accepted a postdoctoral appointment in the Laboratory of Plasma Studies at Cornell University. This figure was obtained from our simulations and provides two snapshots of the complex flow structure that emerges in such regimes (color indicates vorticity of the flow while solid lines show recombinant magnetic field lines).

My other work involves the kinematics of complex rotating objects in the presence of gravitational fields in the analytic calculation of the resultant torques. This is relevant to dynamical problems emerging in solar and extra-solar planetary systems in the calculation of planet-satellite orbits. For example, the theory facilitates the demonstration of the stability of the Earth's moon and its spin axis over billions of years. Related to this effort is my work with colleagues Kevin Grazier and Philip Sharp on a numerical algorithm for computing, using a multi-scale methodology orbital evolution of close approaches in self gravitating systems such as those associated with solar and extrasolar planetary systems and in stellar dynamics.

My major effort has focused on problems emerging from pattern formation in random processes. This follows from the Langevin equation of statistical mechanics in circumstances ranging from completely random events to Brownian motion. These closed-form results, published with Donald Turcotte and Bruce Malamud, were then compared with observed data associated with natural phenomena ranging from major earthquakes to magnetic substorms to eruptions of the Old Faithful geyser in Yellowstone National Park, as well as to the Standard & Poor's 500 index. Finally, I developed a simple model for population cycles in mammalian species that characteristically have periods of 3 to 4 years, demonstrating that a simple physics-based model can find important applications in the realm of biology.



STELLAR ASTRONOMY

Benjamin Zuckerman

A planetary system in the Hyades, the Nearest Rich Star Cluster

Astronomers have deduced that most stars, including our Sun, are born in clusters that contain numerous stars of various types. By far the nearest star cluster to Earth is the Hyades whose brightest members can be seen with the naked eye. Very little is currently known about the presence of planetary systems in orbit around stars in star clusters, including the Hyades. As astronomers learn more about the existence and properties of planetary systems in star clusters, they hope to learn more about our own origins.

In October 2012, Ben Zuckerman and his UCLA colleagues Siyi Xu, Beth Klein, and Mike Jura used the 10-m diameter Keck telescope at Mauna Kea Observatory in Hawaii to search for evidence of planetary systems in orbit around stars in the Hyades. The technique they used is sensitive only to planetary systems that orbit stars called white dwarfs that have undergone major changes during their lifetimes. Eventually the Sun, which now is 4.6 billion years old, will become a white dwarf, but this will take another 5 billion or so more years. By contrast, the white dwarfs in the Hyades cluster became white dwarfs only about 600 million years after they were first born.

Dr. Zuckerman and his colleagues were successful in their search and found strong evidence for a planetary system in orbit around one of the white dwarfs in the Hyades. This planetary system contains rocky material, probably not too different from the kind of rocky material that pervades our solar system, and perhaps also some large gaseous planets. Future studies, hopefully including some with the Hubble Space Telescope, should illuminate more about this planetary system and may reveal other planetary systems in the Hyades cluster.

Photograph of the region of the northern sky in the constellation of Taurus the Bull. In the upper right corner is the naked-eye star cluster the Pleiades (or Seven Sisters) and in the lower left corner is the naked-eye cluster the Hyades where the newly reported planetary system is located. The Hyades is about 140 light years from Earth, which is about 3 times closer to us than is the Pleiades.

STELLAR PLANETARY SCIENCE

Brad Hansen

Brad Hansen, along with Mike Rich, published an age estimate for the globular cluster 47 Tucanae, which established the existence of an age difference between this cluster and another globular clusters in the halo of the Galaxy. This study was conducted using data obtained with the Hubble Space Telescope and in collaboration with scientists from the Space Telescope Science Institute, as well as universities in Canada and Australia. The method uses the luminosity of the oldest, coolest dead stars in the cluster to estimate the age, and yields important information about the history of how the Milky Way Galaxy formed.

Working with Travis Barman of the University of Arizona, and UCLA graduate Ian Crossfield, Professor Hansen published a measurement of the transmission spectrum of the Neptune-mass extrasolar planet GJ3470b. This measurement was obtained with the newly installed MOSFIRE spectrograph on the Keck telescope, and provides a constraint on the chemical composition of this enigmatic class of planet. In particular, the planet is inferred to possess a gaseous envelope, unlike terrestrial planets, although it is substantially richer in heavier elements than a giant planet like Jupiter.

In collaboration with Norm Murray from the University of Toronto, Professor Hansen has extended the calculation of their scenario for the formation of compact planetary systems to the case where such systems would be observable with the Kepler satellite. They are able to demonstrate that the simple model of in situ planetary assembly matches the observed data in terms of distribution in orbital period as well as in terms of the spacings of planets in multiple systems.

EXTRASOLAR PLANETARY SYSTEMS

Michael Jura

The goal of our efforts has been to learn more about the bulk compositions of extrasolar rocky planets. We first identify white dwarfs whose atmospheres are polluted by the accretion of heavy elements derived from minor planets. Then we determine the relative abundances of this material by analyzing the stellar spectrum. Currently, this technique is a unique and powerful tool for determining elemental compositions of extrasolar rocky planets.

During the past year, we have made substantial progress. (1) Contrary to some recent calculations, no extrasolar planetesimals have been found to be composed largely of refractory species with elemental compositions dominated by aluminum, calcium and oxygen. (2) Unexpectedly, H2 was discovered in the photospheres of white dwarf stars with temperatures as high as 13,000 K. (3) The asteroid accreted onto GD 362 has a composition similar to that found among mesosiderites, a rare kind of solar system meteorite. (4) We have identified the relics of an ancient planetary system in a white dwarf in the Hyades, a nearby well studied cluster of stars.

The papers reporting these results are:

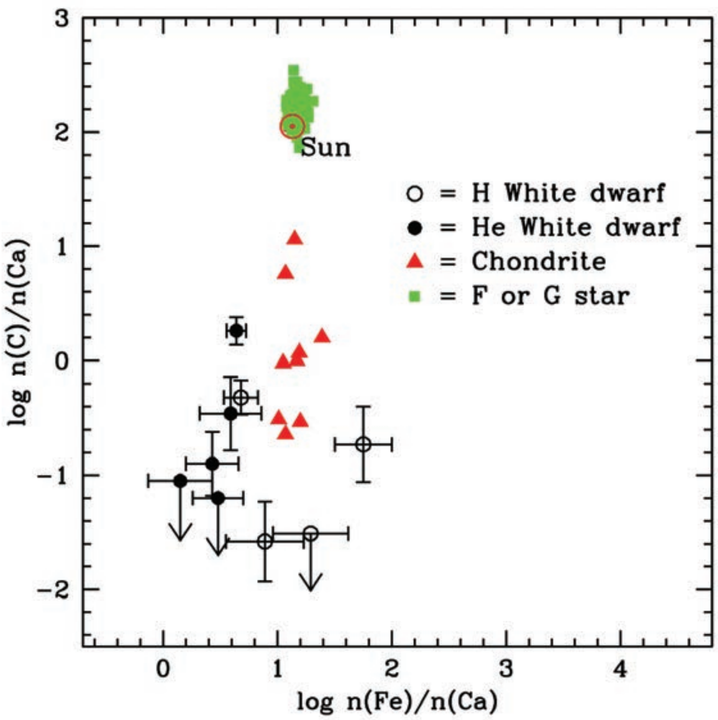
1. Jura, M. & Xu, S. 2013, *Astron. J*, 145, 30. "Extrasolar refractory-dominated planetesimals: an assessment"

It has been predicted that planetesimals that form within the inner regions of protoplanetary disks might be largely composed of very refractory minerals and therefore largely composed of calcium, aluminum and oxygen. We assess this possibility be examining published surveys of about 60 externally-polluted white dwarfs and intensive studies of about 10 such stars. We find there is no evidence for the long-term survival of these exotic planetesimals. We argue that if such planetesimals form, likely they would be entrained within the star during a very luminous red giant phase before becoming a white dwarf.

2. Xu, S., Jura, M., Klein, B., Koester, D. & Zuckerman, B. 2013. *Astrophys.J.* 766, L18. "Discovery of molecular hydrogen in white dwarf atmospheres." With the Cosmic Origins Spectrograph on board the Hubble Space Telescope, we have detected molecular hydrogen in the atmospheres of three white dwarfs with effective temperatures below 14,000 K, G29-38, GD 133, and GD 31. This discovery provides new independent constraints on the stellar temperature and surface gravity of white dwarfs.

3. Xu, S., Jura, M., Klein, B., Koster, D., & Zuckerman, B. 2013. *Astrophys. J.* 766, 132. "Two beyond-primitive extrasolar asteroids."

Using the Cosmic Origins Spectrograph on board the



Hubble Space Telescope, we have obtained high-resolution ultraviolet observations of GD 362 and PG 1225-079, two helium-dominated, externally polluted white dwarfs. In combination with previous optical data, we find strong evidence that each of these two white dwarfs has accreted a parent body that has evolved beyond primitive nebular condensation. Differentiation appears to be key in the evolution of the parent bodies.

4. Zuckerman, B., Xu, S., Klein, B.& Jura, M. 2013. *Astrophys. J.* in press. "The Hyades cluster: identification of a planetary system and escaping white dwarfs."

We surveyed the seven classical single Hyades white dwarfs and the newly identified (escaping) Hyades white dwarfs and found calcium in the photosphere of LP 475-242 of type DBA (now DBAZ), thus implying the presence of an orbiting planetary system.

In addition to these papers, Professor Jura was invited to give a plenary talk on this material at the 221st meeting of the American Astronomical Society held in Long Beach, California, during January, 2013. Professor Jura also has been asked to write a manuscript for the 2014 edition of *Annual Reviews of Earth and Planetary Science.*

GALACTIC CENTER SCIENCE

Andrea Ghez

This year has been an exciting year for the Ghez Group. In the fall, Professor Ghez and her team reported the discovery of a star, S0-102, which is orbiting the Milky Way's supermassive black hole in 11.5 years, the shortest known orbit near the black hole (Meyer et al. 2012, *Science*). This discovery will allow Ghez and her Galactic Center group to determine the geometry of space and time near the black hole, testing Einstein's theory of General Relativity. This discovery was enabled through the development of a new algorithm, which provided a ten-fold enhancement of the sensitivity of her first decade of high resolution data, which was obtained with speckle imaging from the Keck Telescopes, and thereby allowed her team to track stars that they have discovered with the more advance technology of adaptive optics over a much longer time baseline. At last count, this has been covered in over 100 media outlets and in at least 10 countries, including the following

two fun examples:

Slate News
http://www.slate.com/blogs/trending/2012/10/08/ speeding_star_near_milky_way_black_hole_tests_einstein_s_relativity_.html

The BBC World news
http://www.bbc.co.uk/programmes/p00yk1pw

This spring, the group reported their results on G2, a putative gas cloud plunging toward the supermassive black hole at the center of our Galaxy with a predicted closest approach (originally predicted for this summer) at a distance of only 3,000 times the event horizon. If this object is indeed a gas cloud, it would be ripped apart by the tidal forces of the black hole during closest approach, potentially producing a rare opportunity to follow a predicted accretion event capable of teaching us about black hole accretion physics. The Ghez group observations test the gas cloud hypothesis and timing of closest approach (Phifer et al. 2013 *Astrophysical Letters*). Altogether these observations suggest that while G2 has a gaseous component that is tidally interacting with the central black hole, there is likely a central star providing the self-gravity necessary to sustain the observed compact nature of this object (and reducing the potential for black hole fireworks). These observations also suggest a closest impact date that is still at least a year away, postponing the ultimate test of the alternative hypothesis of a stellar core – its survival through closest approach!

Other group news from this year includes new Ghez group member Gunther Witzel, who joined the group in May as a postdoc after completing his Ph.D. from the University of Koeln. A new member is Sylvana Yelda, who defended her Ph.D. at the end of the summer and began a postdoc position with the Ghez group. Professor Ghez was named on the 25 most influential people in space by *Time* magazine http://issuu.com/bobjacobs/docs/timespace and she received the University of Chicago's Distinguished Alumni Award (May 2013). The group has also been making ample use of the advent of Laser Guide Star Adaptive Optics on both Keck Telescopes (see images).

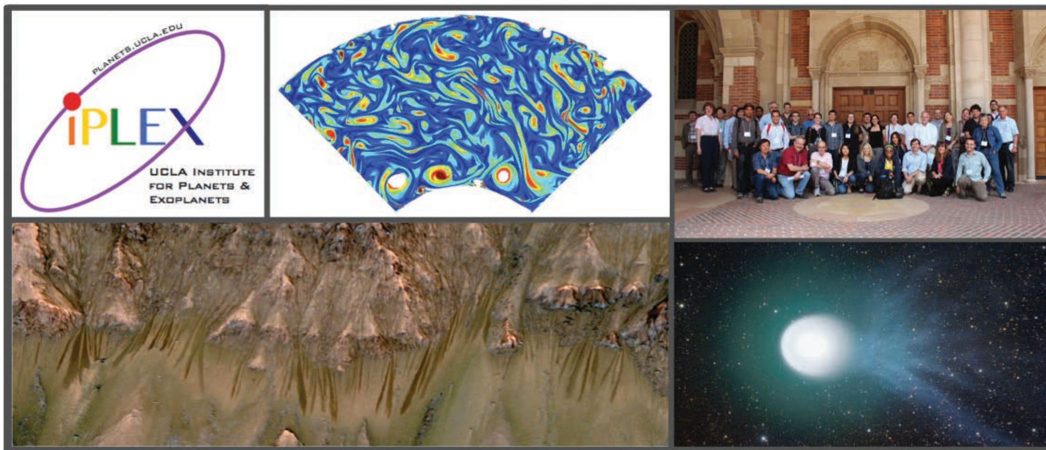
INSTITUTE FOR PLANETS AND EXOPLANETS (iPLEX)

David Jewitt

The Institute for Planets and Exoplanets (iPLEX) hosted three meetings that drew more than 150 planetary scientists to the UCLA campus to discuss the latest research in their fields.

The first meeting in the 2012-2013 series, dubbed "Ices and Organics in the Inner Solar System," brought together scientists studying ice and other volatiles far inside the 5 AU snow line, where standard models assume ice is not stable due to heat from the Sun. Scientists at the June 2012 conference explored cold-traps on the surfaces of bodies inside the snow line including the Moon, Mercury and main-belt asteroids, which appear able to preserve water ice, organics and perhaps other volatiles delivered by impact from cometary source reservoirs.

A second iPLEX meeting held in February 2013 explored new research concerning the surface of Mars, where high-resolution data from orbiting spacecraft have revealed features suggesting the presence of liquid



UCLA's Institute for Planets and Exoplanets Workshops and Conferences, 2012-2013

brines at or near the surface. Scientists at the "Present-Day Habitability of Mars" meeting discussed implications of the new data for the possible existence of current life on Mars. The meeting was broadcast live on the web by the NASA Astrobiology program and featured remote presenters from six different countries. Special guest and strong proponent of Mars science, astronaut Buzz Aldrin, was in attendance.

In June 2013 a third iPLEX meeting was held in the form of a workshop for scientists studying applications of fluid dynamics to geophysics and astrophysics. Researchers who attended the "Connecting Theory to Experiments in Fluid Dynamics" workshop experimented in UCLA Professor Jonathan Aurnou's SPINLab and discussed the big-picture applications of their work. iPLEX workshops and conferences contribute to the institute's objective of developing and advertising planetary and exoplanetary-themed research at UCLA.

PLANETS AND EXOPLANETS

Jean-Luc Margot

Research efforts in our group centers on describing planets and planetary systems with high-precision measurements of spin and orbital dynamics. We rely on a combination of telescopic and spacecraft data at wavelengths ranging from optical to radio.

In the past year, graduate student Julia Fang used data from the Kepler spacecraft to study important properties of planetary systems. We quantified the number of planets orbiting other stars, the spacing between planets, and their orbital inclinations. We found that the aspect ratio of planetary systems is somewhere between that of crepes and pancakes. We also found that a substantial fraction of planetary systems are on the edge of stability: throw one more planet into the mix, and the whole thing goes berserk.

Our own solar system happens to have properties similar to those of planetary systems observed by Kepler.

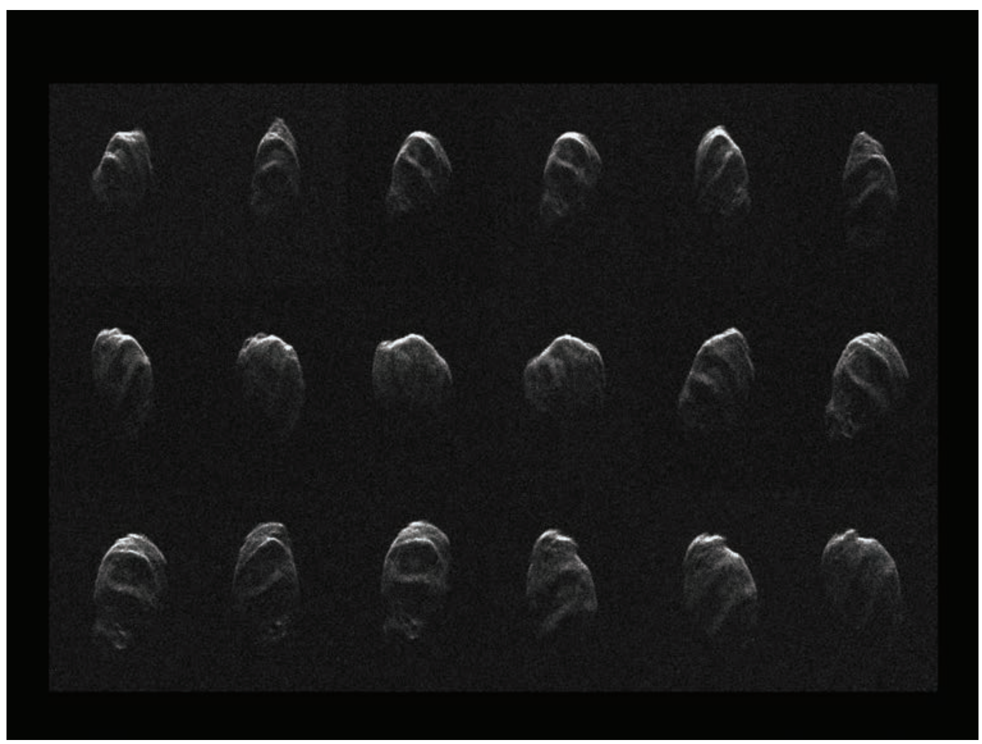


Fig. 1. Arecibo Planetary Radar images of Near-Earth Asteroid 2000 ET70. These 15-m resolution images were obtained when the asteroid made a close approach (19-27 lunar distances) to Earth February 12 – 17, 2012. The asteroid is designated as a Potentially Hazardous Asteroid. It has an effective diameter of ~2.3 km (~1.4 mi) and a spin period of ~9 hours.

A video recording of some of these results is available at http://alturl.com/c26mq.

With graduate student Shantanu Naidu of the Department of Earth, Planetary, and Space Sciences, we used the radar system on the largest telescope on Earth, the Arecibo telescope in Puerto Rico, to obtain high-resolution (15 m or 45 ft) images of a near-Earth asteroid designated 2000 ET70 (Fig. 1 page 27). With this sequence of images we were able to measure the size and spin state of the asteroid, and even to reconstruct a detailed shape model that allowed us to quantify the gravitational environment on this small (2.3 km or 1.4 mi) body.

Jean-Luc Margot presented a talk on the role of radar astronomy in assessing and mitigating the asteroid impact hazard at the 2013 Planetary Defense Conference.

UCLA scientists interested in hosting related science workshops or conferences on-campus should contact David Jewitt (jewitt@ucla.edu).

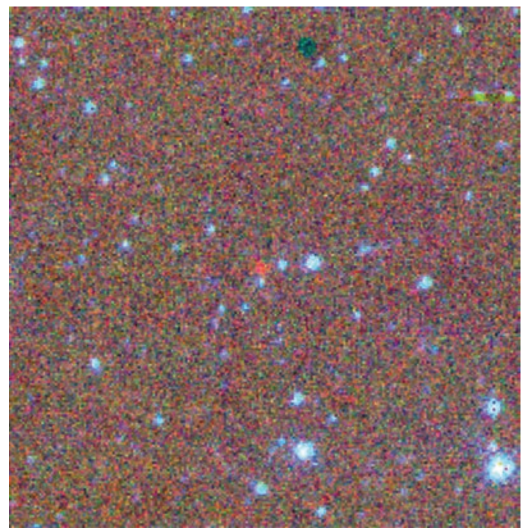
COSMOLOGY

Edward (Ned) L. Wright

Edward L. Wright continues to work primarily on the Wide Field Infrared Survey Explorer (WISE). Currently WISE is analyzing all the data collected from January 2010 through January 2011, and looking for stars that move slightly in six months. These are all neighbors of the Sun, and we estimate that a few thousand previously unnoticed nearby stars will be identified.

In addition, NASA has decided to restart WISE to search for more Near Earth Objects (NEOs). Wright has been working on thermophysical modeling of the infrared data from asteroids to derive accurate diameters with well-determined uncertainties.

Professor Wright was honored to have a WISE-discovered asteroid named after him: given the preliminary designation 2010 CK9 when WISE discovered it in February 2010, it is now known as 241527 Edwardwright. It is 3.5 +/- 0.2 km in diameter.



Asteroid 241527 Edwardwright is the red dot in the center. This is a 3-color composite of the WISE 3.4, 4.6 and 12 μm bands as blue, green and red. The asteroid is much brighter at 12 μm so it appears red.

GALACTIC ASTROPHYSICS

R. Michael Rich

During the 2012-2013 year R. Michael Rich and collaborators used a novel telescope of 0.7 m to discover a new dwarf galaxy companion to the nearby starburst galaxy NGC 4449 (Rich et al., *Nature* 482, 192). The galaxy appears to have experienced a near collision with the nucleus of NGC 4449.

In Figure 1 which includes the negative image, the full extent of NGC 4449B is revealed by subtracting the light of the bright galaxy. While NGC 4449B is only 1/1000 the brightness of the Milky Way, if placed at the Sun's position its most distant stars would reach to our Galaxy's center.

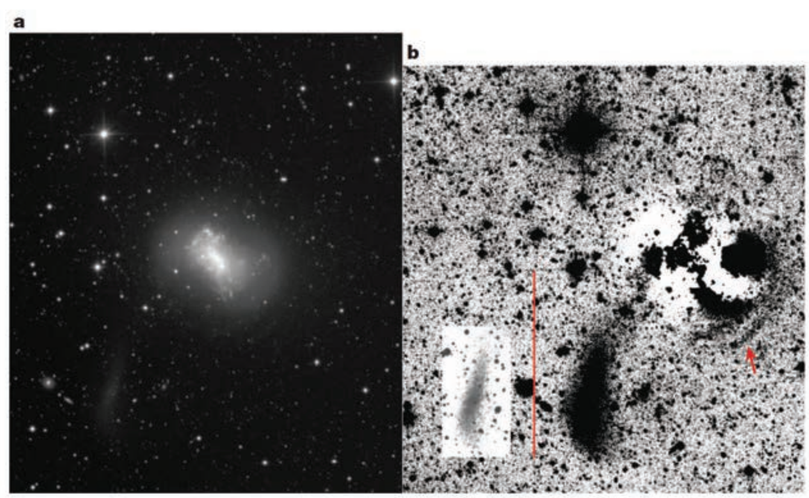


Figure 1. A nearby starbursting galaxy, NGC 4449 was discovered by Rich and collaborators to have a remarkable companion (right-hand panel) nearly the size of the Milky Way, but 1/1000th as bright as our galaxy. The strange tadpole-like appearance of this galaxy is due to a close encounter with the nucleus of NGC 4449, which may be a supermassive black hole in formation. The red bar is 10 kpc in length, roughly the distance of the Earth to center of the Milky Way galaxy.

Rich and former UCLA postdoc Andreas Koch (now at University of Heidelberg) sought galaxies with similar properties and discovered a mysterious galaxy disrupting with no obvious nearby companion (Figure 2).

Rich also finished a major review article on the Galactic Bulge, for Cambridge University Press's monumental series, Planets, Stars and Stellar Systems. The article will be a "living" review and will be updated by Dr. Rich every five years. Cambridge Press is reissuing the monumental series "Stars and Stellar Systems" published by the University of Chicago Press in the 1960s.

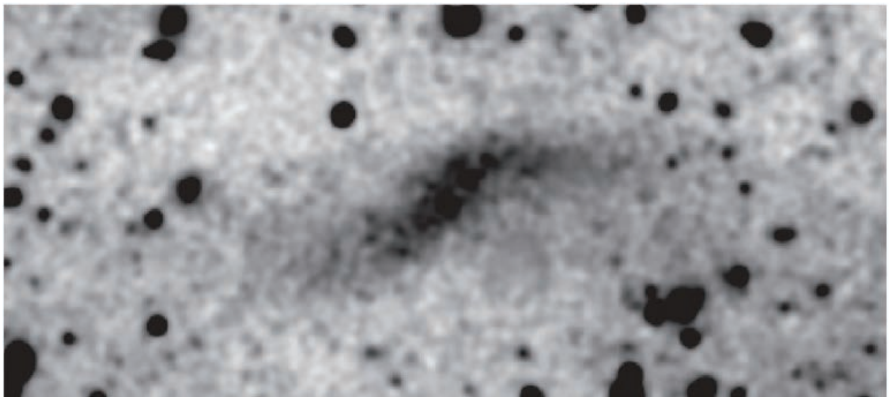


Figure 2. The discovery of NGC 4449B pointed toward another unusual galaxy imaged with the ESO Very Large Telescope in the hydra cluster of galaxies (Koch et al 2012). This object, christened HCC087, appears to have been affected by a close encounter with a giant elliptical galaxy in the cluster, but ongoing theoretical models are continuing to attempt to to understand its origin. The paper by former UCLA postdoc Andreas Koch (now Emmi Noether Fellow) appeared in the *Astrophysical Journal Letters* in 2012.

EXTRAGALACTIC ASTROPHYSICS

Matthew Malkan

Matthew Malkan has worked extensively with many different instruments on the Hubble Space Telescope. He observed quasars with the spectropolarimeter in the first year Hubble was launched.

Over the last 25 years, Professor Malkan has been Principal Investigator of more HST observing programs than any other astronomer. One major effort has been to exploit 'free' time on Hubble. While one instrument is staring intently at a target, Malkan and his team use an infra-

red camera to survey an adjacent piece of random 'empty' sky. Since in reality, any direction in the sky is covered with numerous galaxies, these free parallel observations provide detailed infrared spectra of tens of thousands of very distant galaxies. Such a project is impossible from Earth because of the itense infrared airglow of the night sky covering ground-based telescopes.

Hubble's final re-servicing mission installed a far more powerful infrared camera, which Professor Malkan has used for the 5 years it has been onboard. The photographs show this Wide-Field-Camera-3 in the laboratory and then being acronym, WISP, stands for WFC3 Infrared Spectroscopic Parallels. WISP finds an extraordinary abundance of small star-forming galaxies that cannot be discovered by other telescopes. WISP has mapped out three quarters of the cosmic history of star formation in galaxies, how it is shut down, how it can be buried by the absorption from interstellar dust grains, and how it builds up the abundances of heavy elements. In short, WISP is seeing how all modern galaxies and their contents have come about. Four members of the WISP group have or are currently obtaining Ph.D.s from UCLA.

EXTRAGALACTIC ASTROPHYSICS

Jean Turner

Professor Jean Turner continues her work on gas and star formation in local galaxies. A team led by former student Chao-Wei Tsai has produced high-resolution images of the Brackett γ emission made with OSIRIS on the Keck Telescope in the bulgeless galaxy NGC 6946. The OSIRIS images reveal a significant variation of star formation efficiency on ~25 light year scales across the nuclear region of the galaxy. The team established that, contrary to the usual assumption, the young star clusters exciting the Brackett nebulae are very unlikely to have formed where they are observed, but that they have migrated.

The team posits that low star formation efficiency, together with the presence of a strong nuclear bar, is a mechanism by which molecular clouds can "assist" the migration of star clusters radially inward toward the nucleus. Professor Turner has been working with undergraduate John Arban Lewis III on the analysis of NIRSPEC spectroscopy of Brackett lines in local galaxies. She is part of a continuing program of high resolution kinematical studies of large extragalactic star-forming regions using the TEXES spectrograph, in collaboration with Sara Beck (Tel Aviv) and John Lacy (Texas.)

Professor Turner also continues her studies of the "supernebula" in NGC 5253 with imaging of CO(J=3-2) with the Submillimeter Array. This experiment has finally revealed the very hot cloud of gas surrounding this young super star cluster, and promises to give the best constraints to date on the mechanisms of starburst feedback on molecular clouds.

THEORETICAL ASTROPHYSICS

Steven Furlanetto

Theoretical astrophysicist Steven Furlanetto's research focuses on the formation of galaxies, quasars, and other luminous sources and their interactions with their environments and each other.

Much of his recent attention has focused on the "reionization" of intergalactic helium, the second most abundant element in the universe. This event was the last phase transition in the universe's history, occurring about two billion years after the Big Bang at the height of the quasar era. Graduate student Keri Dixon (now a postdoc at the University of Sussex) developed a computer code to efficiently model this process and compare to state-of-the-art observations. Meanwhile, graduate student Fred Davies has explored the interactions of the reionization process with gas clumps in the intergalactic medium. He has shown the self-consistency between these absorbing clouds and measurements of the radiation backgrounds during this time.

UCLA postdoc Joseph Muñoz has also led a new effort to model the details of galaxies during their initial formative stages. His models follow the buildup of gas, stars, and black holes as the galaxies are built during the first billion years of the universe's history. He has developed predictions for the next generation of large telescopes (including both the Atacama Large Millimeter Array and the James Webb Space Telescope) as well as tests to understand better their internal physics.

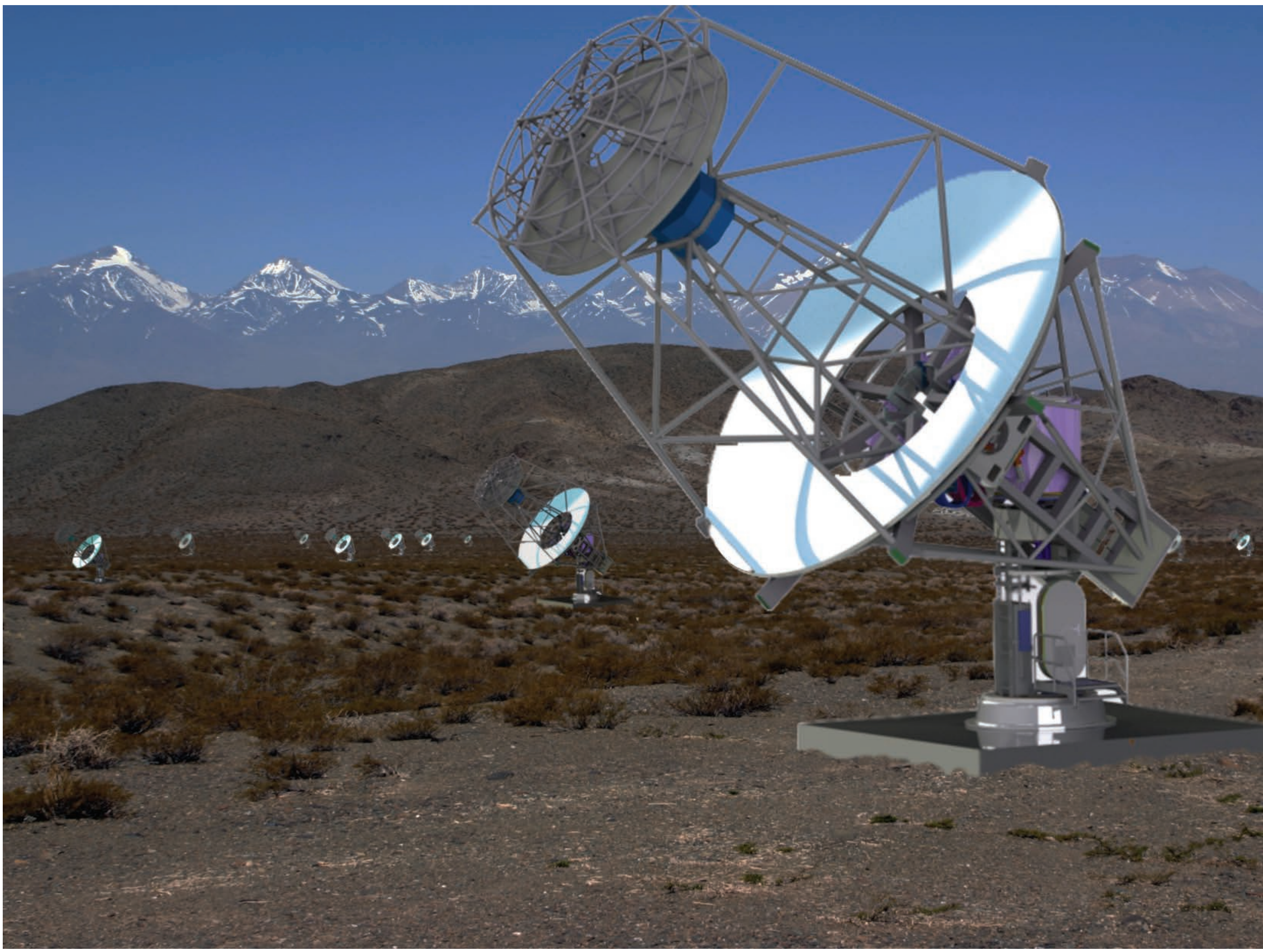
Furlanetto has also co-authored, with Avi Loeb of Harvard University, a graduate-level textbook, *The First Galaxies in the Universe,* published by Princeton University Press in 2013. The book presents an overview of the fundamental physics of galaxy formation as well as detailed applications to models of the first galaxies and methods to measure their properties.

ASTROPARTICLE PHYSICS

VERY HIGH-ENERGY (VHE) ASTROPHYSICS

Rene Ong and Vladimir Vassilev

The VHE astrophysics group led by Rene Ong and Vladimir Vassiliev carries out research in a broad range of science topics at the intersection between physics and astronomy. The main focus of their studies involves exploring violent phenomena in the universe, which are capable of producing high-energy (100 MeV – 100 GeV) and very high-energy (>100 GeV) photons. These gamma rays can be generated in non-thermal cosmic accelerators such as supernova remnants (SNRs), pulsars and their nebulae, active galaxies and gamma-ray bursts. At these energies gamma rays can also be created from physics processes beyond the standard model of particle physics, such as from the annihilation of unknown particles composing dark matter in the universe, or from the evaporation of primordial black holes (which could have been produced in the early universe evolution). Through



Artist representation of the concept of SCT telescope for a future CTA installation is shown in the figure above.

their interaction with the cosmological low energy (radio through UV) diffuse radiation fields, very energetic photons also provide unique opportunities to probe these fields and the intergalactic magnetic fields also. These studies could provide key information about the UV/infrared diffuse radiation produced throughout the history of the universe and about the origin of magnetic fields in the galaxies and other astrophysical systems.

The detection and study of sources of VHE gamma rays has been greatly advanced by the imaging atmospheric Cherenkov technique. VHE gamma rays interacting in the upper atmosphere create showers of relativistic particles that are beamed towards the ground. These particles emit Cherenkov light that can be detected on the ground by large optical reflectors that focus the light onto imaging cameras at the focal plane. UCLA is a major partner in the Very Energetic Radiation

Imaging Telescope Array System (VERITAS), which is located at the Whipple Observatory in southern Arizona and consists of an array of four 12m-diameter reflectors. VERITAS has been operating very successfully since 2007 and has detected many dozens of sources and produced a number of important discoveries.

Within the last year the UCLA group was instrumental in several key publications, including the discovery of a new VHE source near the gamma-Cygni SNR; the detailed characterization of the first unidentified VHE source TeV J2032+4130; and characterization of radiation from AGN 1ES 0229+200, which hints at signatures of effects produced by the intergalactic magnetic fields.

The research with VERITAS is substantially augmented by the observations made at lower gamma-ray energies by the Large Area Telescope (LAT) of the Fermi satellite. UCLA scientists use the Fermi-LAT data to provide broader spectral coverage of gamma-ray sources. In the last year, Ph.D. student Timothy Arlen, Vassiliev, and coworkers published a significant new study on constraining the intergalactic magnetic field, using observations of distant active galaxies made by VERITAS and Fermi-LAT. In other work, Ph.D. students Alexis Popkow and Ryan Sanders use Fermi-LAT data to determine several promising targets in the Galactic plane for observation by VERITAS. Initial observations of these sources started in 2012-2013 and should continue in the upcoming year.

The VHE astrophysics group is heavily involved in the plans for the next-generation ground-based gamma-ray observatory called the Cherenkov Telescope Array (CTA). CTA is expected to have an array in both the northern and southern hemispheres, with each array consisting of up to 75 imaging atmospheric Cherenkov telescopes (IACTs) covering an area greater than 1 square kilometer. UCLA has made a significant effort led by Rene Ong to propose two possible sites in Arizona to host the CTA-North facility.

U.S. members of the large international CTA consortium, including nearly 30 countries, are working on the development of the novel Schwarzschild-Couder Telescope (SCT) for CTA, designed to achieve superior performance and wider field of view compared to conventional designs of IACTs such used by VERITAS. The UCLA group pioneered this new instrumentation development for VHE gamma-ray astronomy and is now leading the effort of more than a dozen institutions to construct the prototype SCT at the VERITAS site location. A recent multi-million dollars award from the NSF under the MRI program (PI Vladimir Vassiliev) supports this work. SCT construction and commissioning is planned for the next two years and both VERITAS and CTA related activities of the UCLA astrophysics group are expected to provide exciting research and instrumentation development opportunities for both graduate and undergraduate students. The artist representation of the concept of SCT telescope for a future CTA installation is shown in the figure.

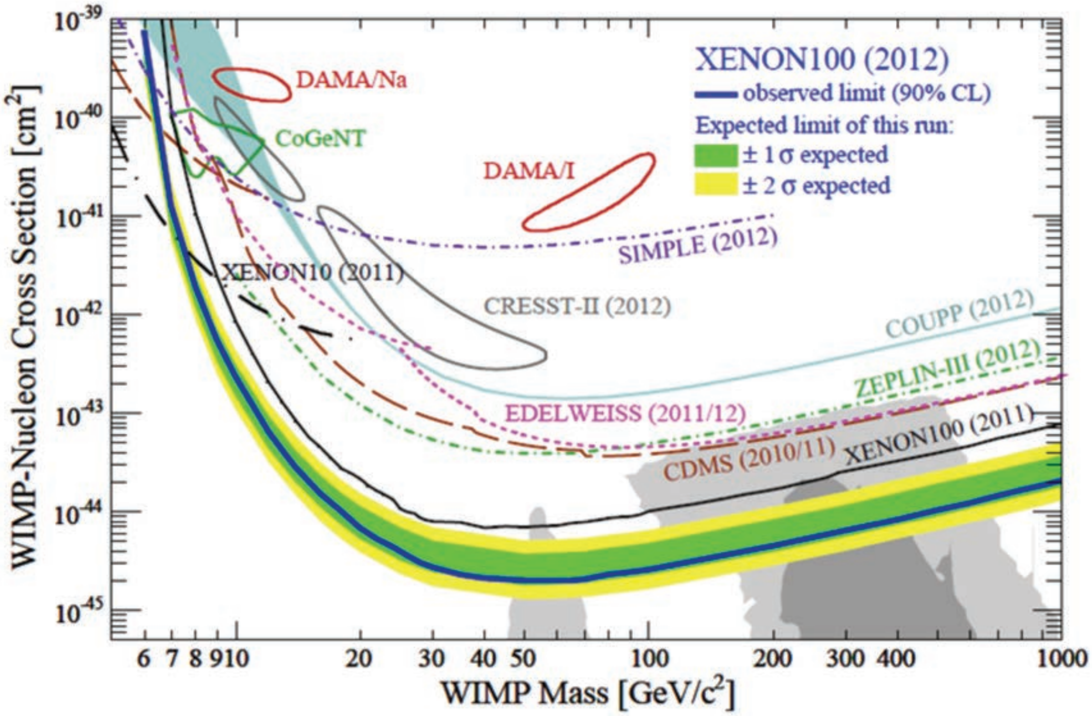
The nature of astrophysical dark matter is one of the most compelling mysteries facing physics and astronomy today. There are strong arguments that a new particle (or particles) comprises the bulk of the dark matter. One highly motivated candidate is the weakly interacting massive particle (WIMP). Many experiments worldwide are searching for WIMPs utilizing various techniques, among which a unique signature for WIMP annihilation could come from the detection of anti-deuteron particles in the cosmic rays. Astrophysical anti-deuterons have never been detected but UCLA is working with the other groups to develop the first dedicated search experiment, called the General AntiParticle Spectrometer (GAPS). In the GAPS instrument, an anti-deuteron would be detected through its interaction in lithium-drifted silicon detectors (Si(Li)). The GAPS team developed a prototype instrument that had a successful flight in June 2012 from the Taiki launch facility of the Japanese Aerospace Exploration Agency (JAXA) in Hokkaido, Japan. The team is now proposing to build a science payload that would fly on a long-duration balloon around the Antarctic.

Currently the VHE astrophysics group consists of Professors Rene Ong and Vladimir Vassiliev, postdoctoral researchers Taylor Aune, Issac Mognet and Julien Rousselle, and graduate students Timothy Arlen, Matt Buchovecky, and Alexis Popkow.

ASTROPARTICLE PHYSICS DARK MATTER GROUP

The Search for Dark Matter with Noble Gas Liquid Detectors

Katsushi Arisaka, David Cline, Hanguo Wang



The direct search for Dark Matter particles has reached a critical stage. The Large Hadron Collider CMS project, of which UCLA is a member, has put lower limits on the mass of supersymmetric states. That, in turn, suggests a limit of one half TeV for the mass of dark matter particles. Currently the best limit on the dark matter search is held by the XENON 100 detector. UCLA is also a member of this team. In the 1990s these methods to search for dark matter were invented at UCLA.

Currently the UCLA groups work on two future detectors: XENON 1 Ton and DarkSide 5 Ton. These detectors are supported by the NSF and DOE. Below we show the current limits from XENON 100 that are the best in the world. Several UCLA Ph.D. students are currently working on this project.

We also operate the most respected dark matter conference in the world every two years, "The UCLA Dark Matter Symposium". All dark matter detection searches worldwide are discussed at this meeting.

Katsushi Arisaka Group

The Arisaka Lab has continued to advance dark matter research in both ongoing and future experiments. Following the world's best sensitivity achieved by XENON100, we proposed the second generation (G2) experiment called XENON1T (shown in Figure 1). It was fully funded by a NSF grant in 2012 and the construction began in early 2013 and is expected to be complete in 2015. The Arisaka group is in charge of the heart of the detector, the photomultiplier arrays and its support stucture (Figure 1, right). It is notably the world's first detector with one ton target mass with a great discovery potential, covering the entire signal

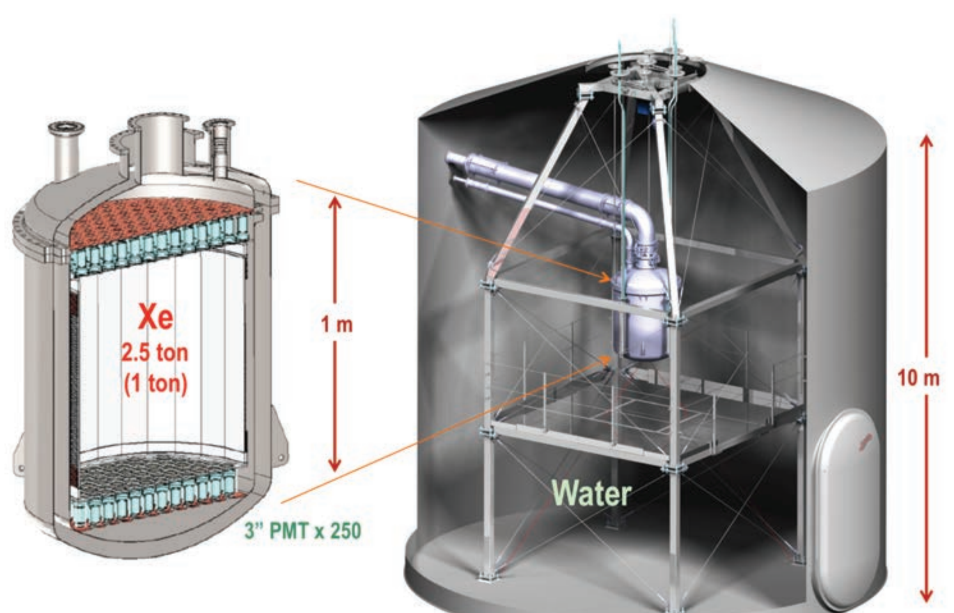


Figure 1. Conceptual 3D drawing of the XENON 1Ton detector, now under construction at Gran Sasso National Lab in Italy. The internal detector (Left) has been designed by Alexey Lyashenko.

region predicted by the super symmetry models (shown in Figure 2 as G2).

In addition, the Arisaka group has invented new data analysis methods and new detector concepts in three key areas:

We invented a new data analysis method based on the ionization signal as the energy estimator, and proved that xenon detectors are far more sensive to low mass WIMP tan previously conceived (*Astropart. Phys.* 37 (2012) 51).

We advanced the study of two target detection systems (XAX) to the ultimate size and sensitivities (G3 in Figure 2). The proposed multi-ton xenon detector has a great potential to observe other important signals such as pp-chain solar neutrinos, supernova neurinos and neutrinoless double beta decays (*Astropart. Phys.* 36 (2012) 93).

Together with Roberto Peccei we demonstrated that liquid xenon detectors are also sensitive to axions and axion-like bosonic dark matters (*Astropart. Phys.* 44 (2013) 59).

The Arisaka Lab has been also active in photon detector R&D. Following a succesful development of QUPID (QUartz Photon Intensifying Detector), we continue to work on evaluation on low radioactive photon detectors for the future G2 and G3 experiments. The Advanced Photon Detector Lab is equipped with various state-of-the-art systems to characterize photon detectors, including the vacuum UV cryogenic spectrometer to measure Quantum Effiency down to 150 nm and -185oC (shown in Figure 3), which only exists internationally in the Arisaka Lab.

The lab members include four researchers: Chamkaur Ghag (now at University College London), Paolo Beltrame (now at Edinburgh), Alexey Lyashenko (in XENON), and Nicola Canci (in DarkSide). Four graduate students have completed their Ph.D. from their works in XENON100: Ethan Brown, Chi Wai (Michael) Lam, Artin Teymourian, and Kevin Lung. More details of the Arisala Lab can be found at the Lab homepage: http://home.physics.ucla.edu/~arisaka/home/.

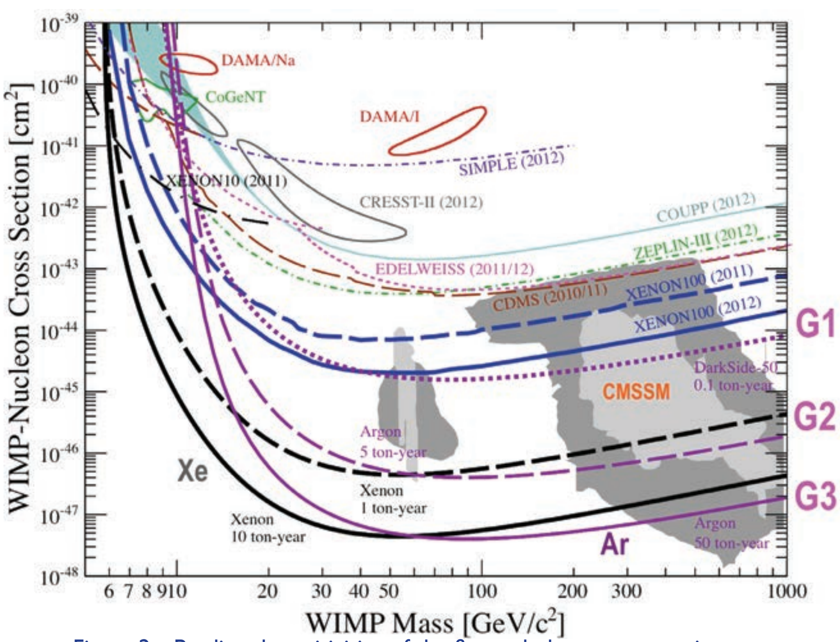


Figure 2. Predicted sensitivities of the figure dark matter experiments in both liquid xenon and argon at the first, second and the third generations (G1, G2 and G3) respectively, studied by Paolo Beltrame and Kevin Lung.

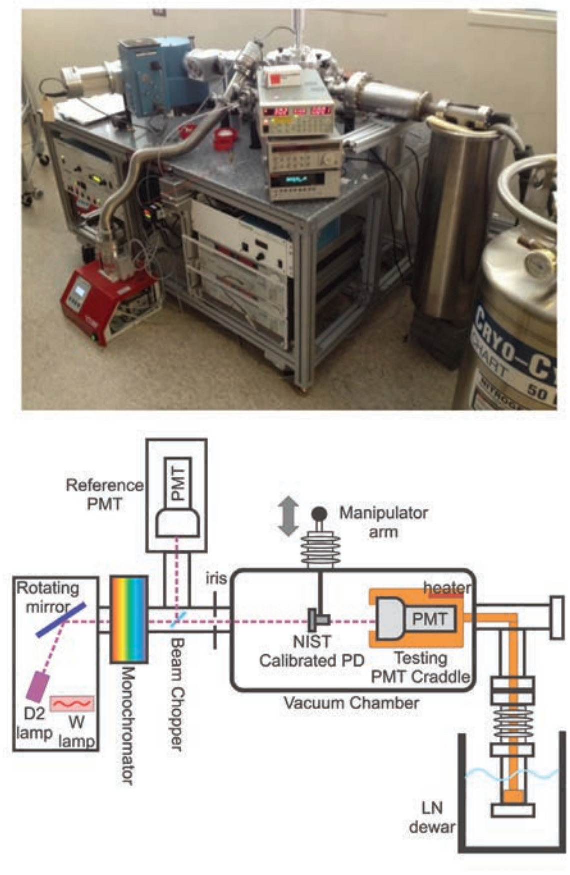


Figure 3. The vacuum UV cryogenic spectrometer to measure Quantum Effiency down to 150 nm and -185 °C, developped and constucted by Alexey Lyashenko. This is the very first system internationally for simultaneous operation under vacuum UV and low temperature.

Hanguo Wang group
Noble liquid detector lab for rare event searches

Dark matter makes up some 27 percent of our universe, according to the latest astrophysics findings, but it has proven very difficult to find. Dr. Hanguo Wang and his team of graduate students and postdoctoral fellows are on a quest for a dark matter particle candidate using noble liquid large-scale detectors.

The team is a part of the XENON and DarkSide international dark matter search programs, which utilize dual-phase (liquid-gas) noble liquid time projection chambers (TPCs). A particle interaction in the TPC induces scintillation light, which is detected by photodetectors, and an ionization charge, which is converted into proportional scintillation light in the gas phase and is also detected by photodetectors.

The XENON collaboration currently operates XENON100, a 60kg dual-phase liquid xenon TPC, which obtained the world's most sensitive limits over the last five years. The next step is the XENON1T detector, presently under construction, with more than 1 ton of target material and increased sensitivity by two orders of magnitude.

The DarkSide collaboration is presently commissioning DarkSide-50, a 150kg dual-phase liquid argon TPC with a dual-active veto system, which is unique in the world. It will have sensitivity similar to XENON100. DarkSide is planning to expand to a 5-ton underground liquid argon detector within the existing veto system to achieve sensitivity similar to XENON1T. Engineering physicist Dr. Yury Suvorov is the on-site expert responsible for commissioning of the whole DarkSide-50 detector system with a focus on the liquid scintillator veto and inner detector. Postdocs Artin Teymourian and assistant researcher Emilija Pantic are responsible for testing up to 200kV high-voltage distribution systems for the XENON, DarkSide, and two other experiments: LBNE and CAPTAIN.

LBNE (Long Baseline Neutrino Experiment) is a multi-kiloton liquid argon TPC for exploration of many key questions, one of which is asymmetry between neutrinos and antineutrinos. The CAPTAIN program (Cryogenic Apparatus for Precision Tests of Argon Interactions with Neutrinos) aims to make measurements important for the development of LBNE. Graduate students Yixiong Meng and Alden Fan are building small scale TPCs together with dedicated cryogenic systems to measure intrinsic properties of liquid xenon and liquid argon at UCLA and within the ScENE project. The ScENE program (Scintillation Efficiency of Nuclear recoils in Noble Elements) will perform measurements of the scintillation efficiency and associated electric field quenching in noble liquids.

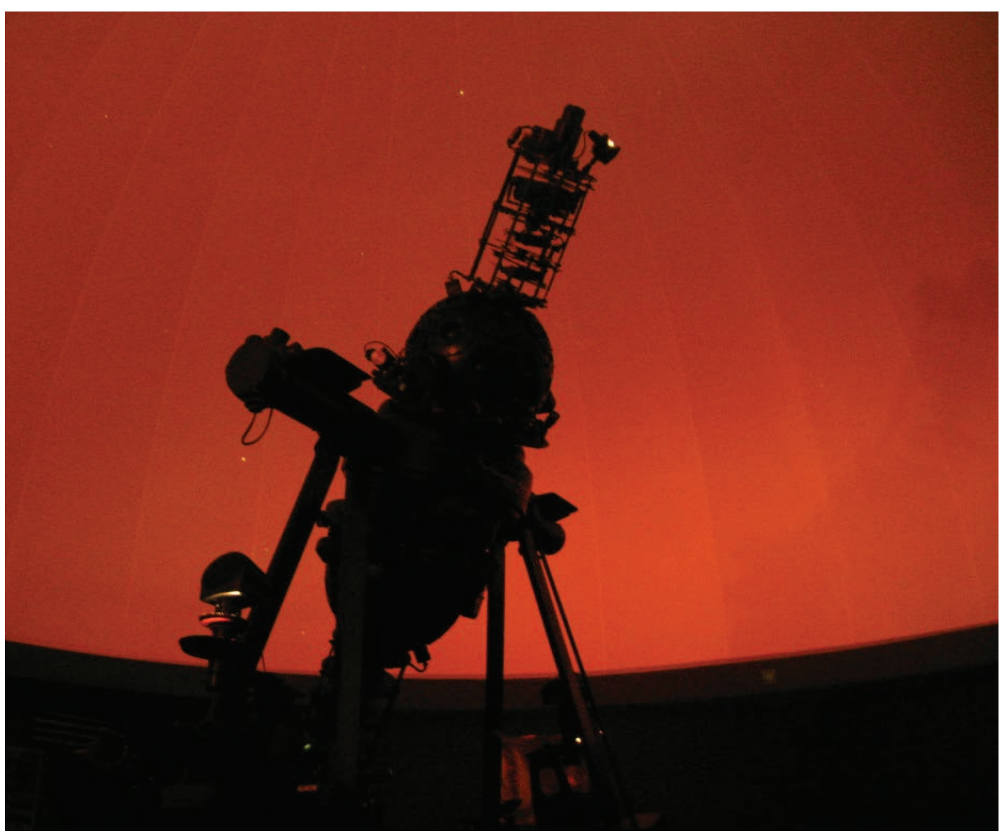
Figure 1. XENON100 detector in its shielding; (middle left): SiGHT conceptual drawing and detector structure; (middle right): Dr. Hanguo Wang in front of the UCLA lab with one of the HVFT prototypes. (right) DarkSide-50 detector inside the neutron veto.

Students are also validating various TPC designs by performing dedicated electric-field simulations, and are also part of the data processing and analysis efforts. Dr. Wang's team has also just begun developing a novel hybrid photodetector, SiGHT (Silicon Geiger Hybrid Tube), with ultra-low radioactivity to match the requirements of rare event searches.

Figure 2. (left): Yury Suvorov and Hanguo Wang working on the DarkSide-50 inner detector in the radon-free clean room at the Gran Sasso underground laboratory (Italy); (middle): Alden Fan, Artin Teymourian, and Emilija Pantic in front of the new dedicated cryogenic system; (right): graduate student Yixiong Meng testing the idea of calibration system at the UCLA lab.

UCLA Planetarium Shows

Public planetarium shows (suitable for all ages) are given by current astronomy and astrophysics graduate students. Content varies with presenters, but commonly includes discussion about the current night sky, constellations, astronomical phenomena, and more! See website at:
http://www.astro.ucla.edu/planetarium/shows.shtml



Star projector silhouetted against "twilight."

Condensed Matter

CONDENSED MATTER THEORY

Elihu Abrahams

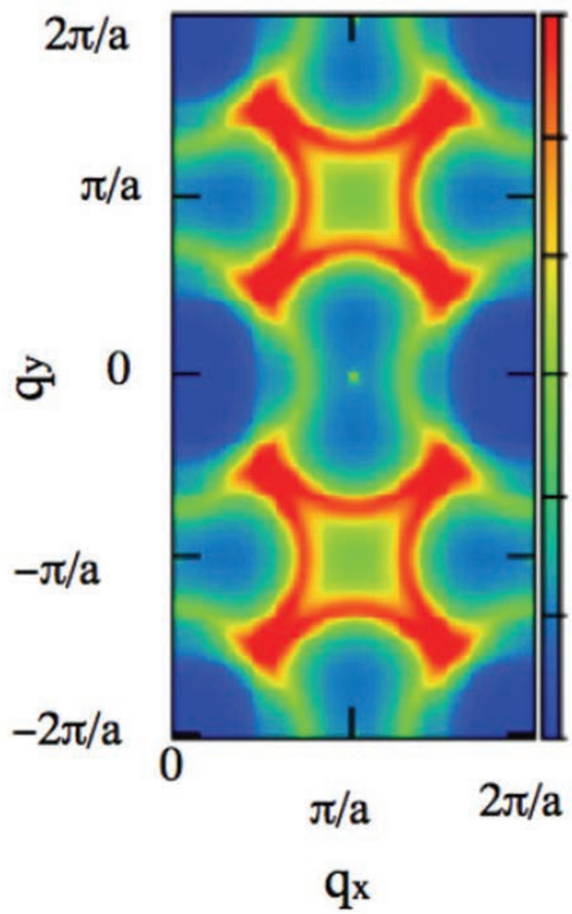
Elihu Abrahams came to UCLA from Rutgers University at the end of 2009. He is a member of the National Academy of Sciences and the American Academy of Arts and Sciences. He is a Fellow of the American Association for the Advancement of Science and of the American Physical Society.

Elihu Abrahams' research is on the application of quantum many-body theory to understanding the physical properties of strongly-correlated systems. These are often realized in compounds whose behavior is primarily determined by strong electron-electron interactions that dominate the various contributions to the energy of the system. The consequence is the emergence of unexpected phenomena and phase transitions.

Abrahams' most recent research is on the phenomenon of quantum criticality, which is associated with the transformation from one phase to another at the zero of temperature. It is found in many rare-earth and actinide based heavy-fermion metals and is at the forefront of condensed matter research.

Abrahams has collaborated with Peter Wolfe (Karlsruhe) in developing a new theory of how quantum critical fluctuations in these materials affect the electronic properties. It is an extension of the traditional Landau Fermi liquid picture that goes beyond the usual theory of weakly-coupled critical fluctuations. This critical quasiparticle theory was used to calculate a number of the observed properties of the prototypical heavy-fermion metal, $Yb_2Rh_2Si_2$. The agreement with experiment is remarkable and is described in *Proc. Nat. Aca. Sci.* 109, 3238 (2012).

In 2010-2011, Abrahams and coworker Qimiao Si (Rice University) showed that the properties of the normal state of the newly discovered iron pnictide superconductors are well explained within an approach based on the observation that they are proximate to an insulating ("Mott") state due to strong electronic correlations and that their magnetic properties are therefore best understood as arising from interacting localized spins. Important support for this approach is obtained by comparing the theory to experiment. Now, with coworkers from Rice and Florida State Universities, Abrahams has shown how the dynamical structure factor (see Figure, right) and spin-wave dispersion observed in inelastic neutron scattering experiments are naturally explained by the theory, published in *Phys. Rev. B* 86, 085148 (2012).



Theoretical structure factor in the Brillouin zone of a typical iron arsenide. The color code is red = high intensity, blue = low intensity. This is in good agreement with neutron scattering on $BaFe_2As_2$.

EXPERIMENTAL CONDENSED MATTER

HongWen Jiang

The research of Professor HongWen Jiang's group continues to focus on two areas: coherent control of quantum bits (qubits) in semiconductor quantum dots and high-frequency dynamics of spintronics devices. The Hidden Markov Model (HMM) is a well-developed statistical method that has been applied to data analysis problems in a variety of other fields, including automatic speech recognition, financial modeling, and a number of biological applications, but has not been used in a quantum physics context.

Graduate student Matt House and others demonstrated that HMM theory can be useful to recover quantum spin-dependent information in the random telegraph signal, collected in the presence of strong thermal excitations.[1] Professor Jiang has directed a project in the University of Science and Technology of China to demonstrate ultrafast control of a quantum dot charge qubit, on the picosecond scale.[2] The coherent qubit manipulation uses the Landau–Zener–Stuckelberg interference, a textbook model for quantum phenomena. Postdoc fellow Zhongming Zeng has led an interdisciplinary effort that leads to the observation of low-current-density and bias-magnetic-field-free spin-torque-transfer in a new type of nano-oscillator containing a planar polarizer and a perpendicular free layer.[3]

[1] M. G. House, M Xiao, G. Guo, H. Li, G. Cao, M. M. Rosenthal, and H. W. Jiang, *Phys. Rev. Lett.* 111,126803 (2013).

[2] G. Cao, H. Li, T. Tu, L. Wang, C. Zhou, M. Xiao, G.C. Guo, H. W. Jiang, G. P. Guo, *Nature Communications,* 4, 1401 (2013).

[3] Z. M. Zeng, G. Finocchio, B. S. Zhang, J. A. Katine, I. Krivorotov, Y. Huai, J. Langer, B. Azzerboni, K. L. Wang, and H. W. Jiang, *NPG Scientific Report* 3, 1426 (2013).

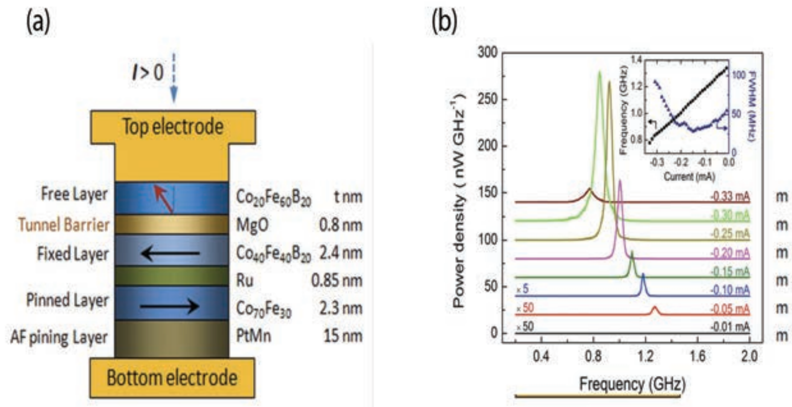


Fig. (a) Schematic of a nano-oscillator layer structure consisting of an in-plane magnetized fixed (polarizer) layer and an out-of-plane magnetized free layer. (b) Emitted microwave spectra as a function of DC current bias, all at zero applied magnetic field.

Rahul Roy

Most of the observed phases of electronic matter can be understood in terms of patterns of symmetry and symmetry breaking. Since the 1980s a number of new types of phases, best described as "topological," have been discovered. These include the integer and fractional quantum Hall effects discovered in the 1980s as well as the more recently discovered topological insulators.

The organization of the electrons in these systems is not conventionally ordered according to some symmetry such as translation. Rather they seem to display a more subtle kind of order, which leads nonetheless to dramatic effects such as the quantization of the Hall conductance and presence of robust edge states.

One direction of my research over the last year has involved exploring the connections between commensurability, space group symmetries, topological order, and ground state degeneracies in many body systems. In interacting systems invariant under non-symmorphic space group symmetries, I showed that the ground state on tori for the smallest commensurable fillings were necessarily degenerate. Ground state degeneracies on non simply connected manifolds are a signature of topological order.

With Dr. Suk Bum Chung, a post-doctoral fellow in my group, I have also been studying the Hall conductance of topological superconducting phases. Our calculations may provide a way of testing the onset of topological order in these systems.

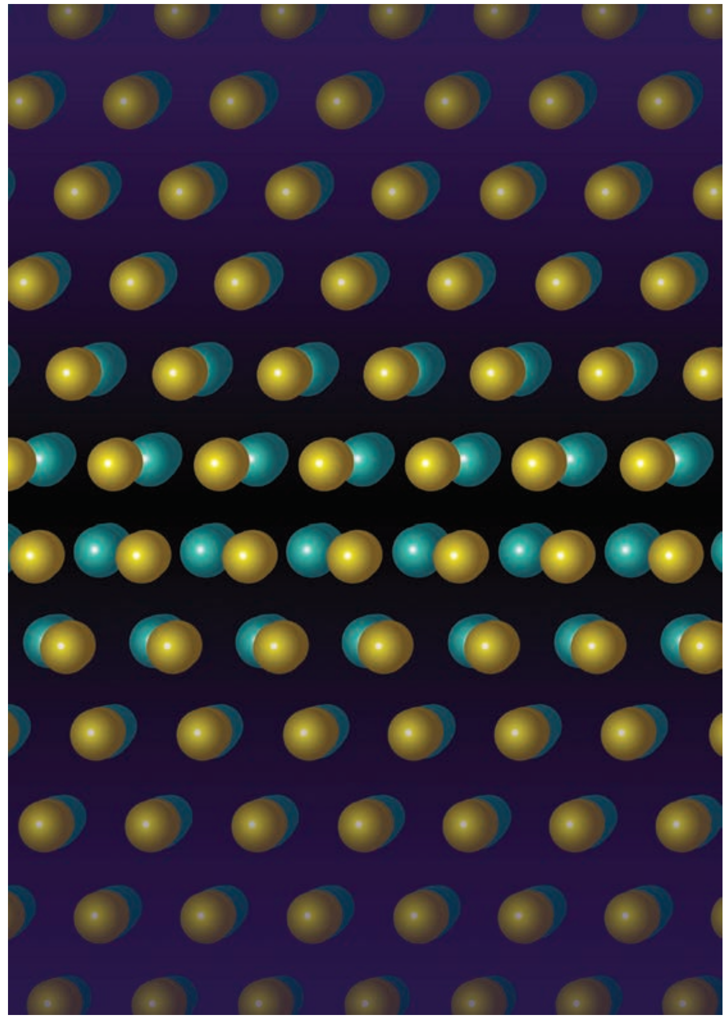
A third direction of my research has been focused on understanding the connections between the quantum geometry of flat bands and the stability of fractionally filled topologically ordered states in these bands (such as the fractional quantum Hall states in the lowest Landau level). Dr. Thomas Jackson, a post-doctoral fellow in my group, has been working on various tests to probe these connection for the past few months.

Biophysics

COHERENT IMAGING GROUP

Jianwei (John) Miao

Dislocations and their interactions strongly influence many of the properties of materials, ranging from the strength of metals and alloys to the efficiency of light-emitting diodes and laser diodes. Although various experimental methods have been used to image dislocations since 1956, a 3D technique for visualizing dislocations at atomic resolution has not previously been demonstrated. John Miao and collaborators have recently achieved, for the first time, 3D imaging of dislocation core structures of a Pt nanoparticle at atomic resolution, and obtain textbook-like images of edge and screw dislocations. The ability to image 3D disordered structures such as dislocations at atomic resolution is expected to find application in materials sciences, nanoscience, solid state physics and chemistry. (Although 3D atomic resolution images of dislocations have been widely shown in materials science and solid state physics textbooks, to our knowledge these images are not directly obtained from experiments, but inferred from 2D TEM images or computer simulations.) This work is published in *Nature* [C. C. Chen, C. Zhu, E. R. White, C.-Y. Chiu, M. C. Scott, B. C. Regan, L. D. Marks, Y. Huang & J. Miao. Three-dimensional imaging of dislocations in a nanoparticle at atomic resolution. *Nature* 496, 74–77 (2013)], accompanied by a "News & Views" article [P. J. McNally. 3D imaging of crystal defects. *Nature* 496, 37-38 (2013)]. *Nature* also produced a video for this work which has been viewed for >236,000 times on YouTube since March 27, 2013. Postdoc Chien-Chun Chen and graduate student Chun Zhu are co-first authors of this paper. Chen, recently receiving his Ph. D. after four years of graduate study at UCLA, has published fifteen peer-reviewed papers (including two in *Nature*) and became a Postdoctoral Scholar in the Miao group.



Three-Dimensional Atom Dislocations. A representation of a 3D atomic-resolution screw dislocation in a Pt nanoparticle. (Illustration: Chien-Chun Chen & I-Sheng Chou)

In addition to 3D atomic resolution imaging of dislocations, Miao has recently led an international team that reports quantitative 3D coherent X-ray diffraction imaging of a molten Fe-rich alloy and crystalline olivine sample, synthesized at 6 GPa and 1800°C, with nanoscale resolution. The 3D mass density map is determined and the 3D distribution of the Fe-rich and Fe-S phases in the olivine-Fe-S sample is observed. These results indicate that the Fe-rich melt exhibits varied 3D shapes and sizes in the olivine matrix. This work has potential for not only improving our understanding of the complex interactions between Fe-rich core-forming melts and mantle silicate phases, but also paves the way for quantitative 3D imaging of materials at nanoscale resolution under extreme pressures and temperatures. The paper is published in *Phys. Rev. Lett.* [H. Jiang, R. Xu, C.-C. Chen, W. Yang, J. Fan, X. Tao, C. Song, Y. Kohmura, T. Xiao, Y. Wang, Y. Fei, T. Ishikawa, W. L. Mao & J. Miao. Three-Dimensional Coherent X-Ray Diffraction Imaging of Molten Iron in Mantle Olivine at Nanoscale Resolution. *Phys. Rev. Lett.* 110, 205501 (2013)]. Finally, Miao and Dr. Ilme Schlichting of Max-Planck-Institut für medizinische Forschung wrote a review paper on emerging opportunities in structural biology with X-ray free-electron lasers [*Curr. Opin. Struct. Biol.* 22, 613–626 (2012)]. In this article, they review the current status and future prospects of this emerging field – structural biology with X-FELs. They mainly focus on two research areas: serial femtosecond crystallography and single-particle coherent diffraction imaging (CDI).

MOLECULAR BIOPHYSICS LAB
Giovanni Zocchi

Enzymes are deformable molecules; often the catalytic cycle is associated with large conformational motion of the enzyme, itself responsible for virtually all aspects of the molecular machinery of the cell. Research in the Zocchi Lab is focused on probing this mechano-chemical coupling, using forces and elastic energies to control chemical reactions ("mechano-chemistry"). Thus we are generally interested in molecules under stress.

Mechanical control of Renilla Luciferase

We developed a new set of enzyme–DNA chimeras, where a DNA molecular spring exerts a mechanical stress on the enzyme leading to a modulation of enzymatic activity (Fig. 1). The new chimeras are built with the enzyme Luciferase from Renilla Reniformis (Rluc), which catalyzes a bioluminescent reaction. Since the measurement of enzymatic activity is simply by light detection, these molecules allow for very precise measurements of the effect of mechanical stress on the enzyme, and are unique tools to study mechanochemistry (Fig. 2).

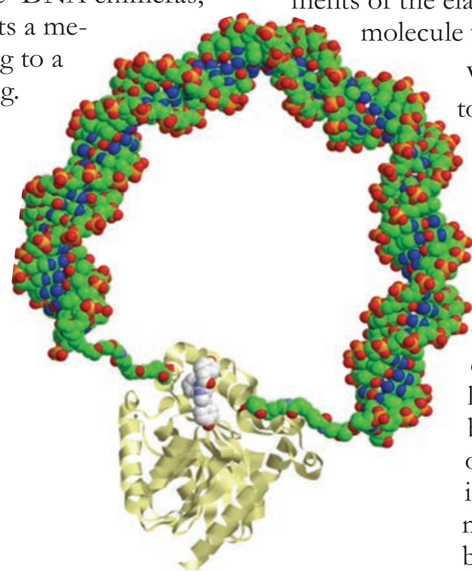


Fig. 1 Cartoon of the RLuc-DNA chimera with the DNA spring attached to sites 161/188. The RLuc structure is from PDB 2PSJ and DNA is from the nucleosome structure 1KX5. The protein, DNA, and cross-linkers are drawn approximately to scale.

Since the structure and function of this enzyme is completely unrelated to the previously investigated Kinases, these results show that mechanical control through the DNA springs in indeed general, i.e. applicable to virtually any enzyme [C.Y. Tseng and G. Zocchi, *J. Am. Chem. Soc.* 135, 11879 (2013)].

The new Rluc-DNA chimeras also constitute a practical molecular probe which can detect, for example, femto-moles of a specific DNA sequence in a one-step homogeneous assay.

Nonlinear bending elasticity of DNA

We continued to quantitatively characterize the nonlinear bending elasticity of DNA through unique measurements of the elastic energy of short (~10 nm) DNA molecule with built in stress (Fig. 3).

We found that the critical bending torque τ_c which characterizes the softening transition at which the molecule develops a kink is essentially temperature-independent [D. Sanchez, H. Qu, D. Bulla and G. Zocchi, Phys. Rev. E 87, 022710 (2013)]. This rules out the existence of a ss bubble at the kink, contrary to present lore. We also found that τ_c is essentially sequence-independent; cumulatively, these results establish the critical bending torque as a materials parameter of DNA mechanics on the same footing as the persistence length or bending modulus. While the latter describes linear bending elasticity, the critical bending torque τ_c describes nonlinear bending elasticity of DNA.

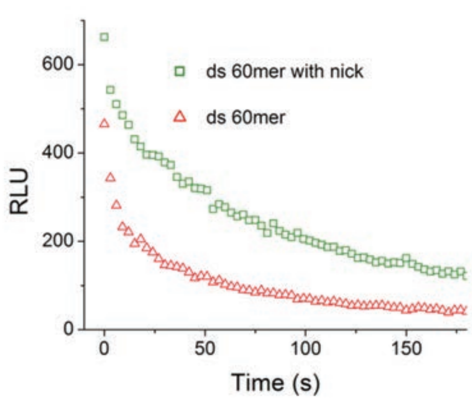


Fig. 2 Emitted light intensity in the course of time for the RLuc chimera subjected to a small (squares) and larger (triangles) mechanical stress. The figure shows how enzymatic activity is modulated by the applied mechanical stress.

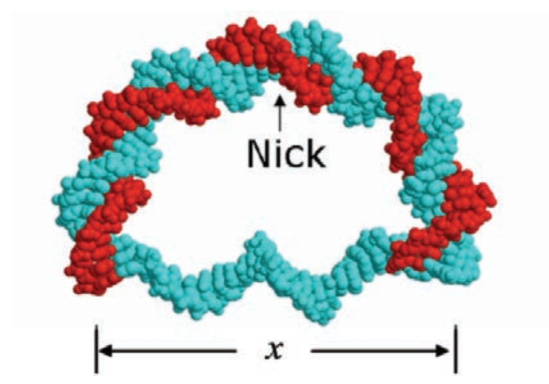


Fig. 3 We use these stressed DNA molecules to measure the nonlinear bending elasticity of short ds DNA.

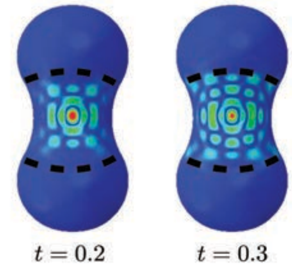
THE GEOMETRIC OPTICS OF GEOMETRY: REFLECTION AND REFRACTION OF UNDULATORY WAVES BY CHANGES IN LOCAL CURVATURE

Alex Levine

Elastic shells abound in nature, from ice sheets spanning continents to airplane wings on a scale of meters, to cell membranes that are only billionths of meter thick and millionths of a meter in lateral extent. These surfaces support elastic waves or ripples.

This year Professor Alex Levine and Art Evans developed a new theory for the transport of undulatory waves on curved elastic surfaces. They showed that changes in the local geometry of the undeformed shell can reflect and refract such waves, and they developed a type of geometric optics where geometry plays the role of the index of refraction.

Among the resulting surprises was the finding that regions of negative Gaussian curvature (e.g. surface of a donut when viewed from in the donut's hole) can trap undulations by total internal reflection. Applications may include new methods to use surface geometry to guide and isolate vibrations, and a new understanding of the spatial distribution of the thermal undulations of red blood cells. Theoretical issues regarding the localization of undulatory waves in random geometries and understanding the (slow) equilibration undulatory waves in parts of a shell separated by a region of negative Gaussian curvature remain to be studied.



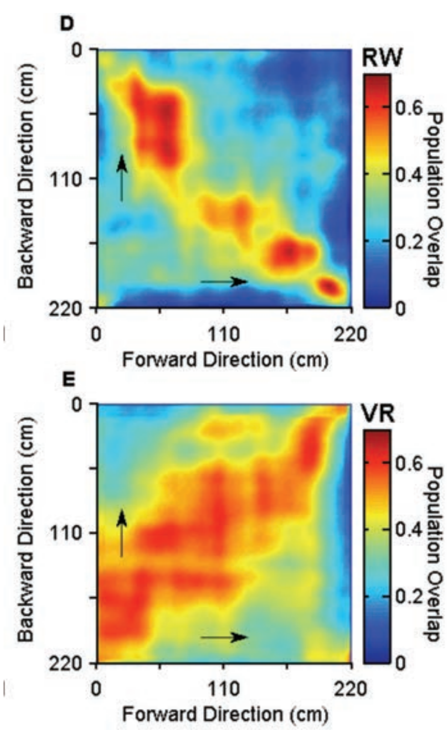
An example of the trapping of undulatory waves by a region of negative Gaussian curvature on a peanut shaped shell. In a test of the calculation, waves were (numerically) excited in the central section having negative Guassian curvature. These waves are trapped by the interface with positive Gaussian curvature shown by the black dashed lines. The result is a standing wave pattern between two totally internally reflecting boundaries. From A.A. Evans and A.J. Levine, *Physical Review Letters* 111, 038101 (2013).

NEUROPHYSICS GROUP

Mayank Mehta

Several experimental and theoretical manuscripts were published during 2012-2013. The key significant findings were about how neurons generate a mental representation of space. This is a fundamental question that all animals must solve, quickly, based on partial, conflicting and constantly changing information. Unlike other stimuli that can be touched, seen, smelled etc., a point in space is an abstract concept that must be created internally based on the configuration of multisensory stimuli.

Previous studies have shown that, in a part of the brain called the hippocampus, neurons change their activity as a function of the position of a subject but the underlying mechanism remain a mystery. A key problem is that it is difficult to measure, let alone control, a subject as it moves through space. To overcome this, we developed a virtual reality system where only visual stimuli provide information about the position of the subject in a virtual room. The visual scene is projected nearly all around, above and below the subject and the change in visual scene is governed by the subject's movements, thus creating an immersive illusion of space.



The pattern of activity across a matrix of ~400 neurons in two movement directions (black arrows. x-axis: Forward direction, y-axis: Backward direction) on a one- dimensional track was quantified by the population vector overlap (color bar) in the real world (RW, top) and virtual reality (VR, bottom). Neurons in the real world showed similar activity around the same absolute position, indicated by high correlations (-45o line). In contrast, neurons in the virtual world showed similar activity around the same relative distance (+45o line).

We then measured the activity of neurons in this virtual reality (VR) and compared it to their activity in real world (RW) with identical visual stimuli, while subjects walked back and forth on a simple, one-dimensional track. While neurons in RW were active at the same position in both movement directions, thus representing absolute position, this never happened in the virtual world. Instead neurons in VR were active at the same relative distance along the two movement directions (see figure). We hypothesize that the uncontrolled stimuli on the track in the real world, such as scent marks that are localized in absolute position, are responsible for generating a representation absolute position. These uncontrolled stimuli are eliminated in the virtual world, which reveals the true, relative distance encoding of space based on visual landmarks and self-movement cues. This marks a significant shift in our understanding of mental representation of space: from absolute space to relative space. These findings were published in: Pascal Ravassard, Ashley Kees, Bernard Willers, David Ho, Daniel A. Ahroni, Jesse Cushman, Zahra M. Aghajan, Mayank R. Mehta, Multisensory Control of Hippocampal Spatiotemporal Selectivity, *Science* 340: 1342-1346 (2013).

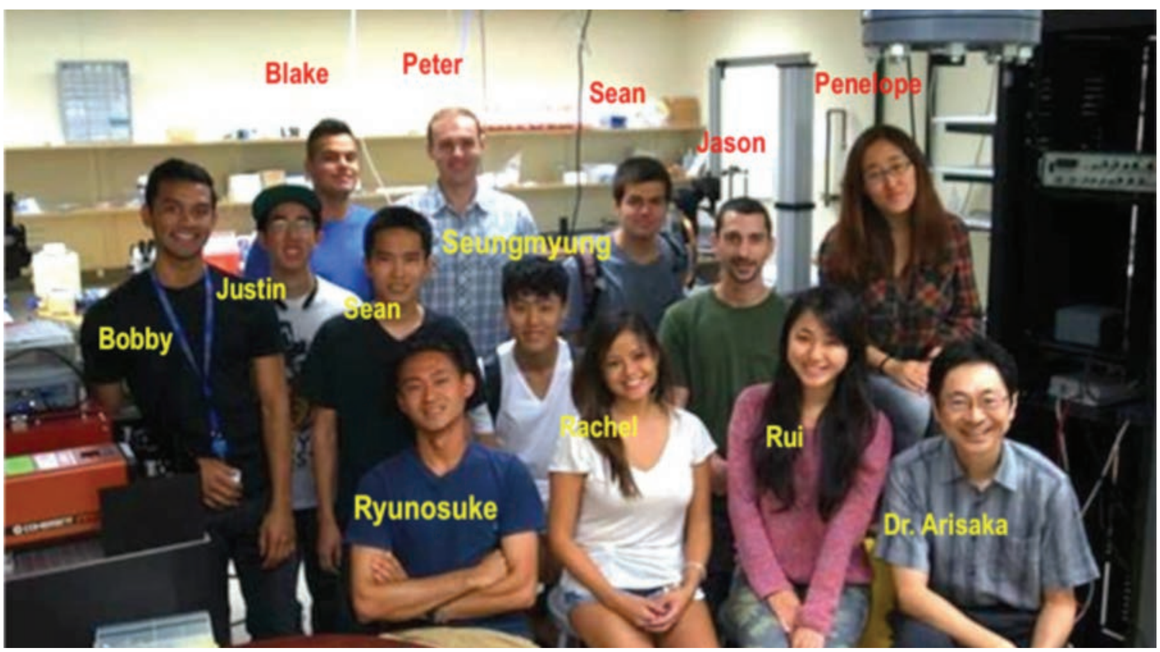
ARISAKA NEUROPHYSICS GROUP

Katsushi Arisaka

The Arisaka research group began investigating the biphysical principles behind sensory integration and directed behavior through study of the model organism, *Caenorhabditis elegans*. This is a 1 mm long transparent nematode with only 302 neurons. However it has a mapped connectome and is currently the only model organism amenable to complete systems-level analysis. In the laboratory research is focused on the visualization and analysis of the organism in response to modulation of its physical environment.

Starting in Spring 2013 Professor Arisaka assembled a team of fifteen undergraduate students who have constructed unique experimental devices, exposing *C. elegans* to electric and magnetic fields, temperature, and UV photon stimulation. Significantly this research effort will be integrated into a novel laboratory course, enabling undergraduates to learn fundamental physics through their direct application of lecture-acquired knowledge of biophysical research. The course will debut in Winter 2014 as the culminating lab and coupled honors section for the Physics 6 lab series at UCLA.

Moreover a special imaging system is planned, enabling the recording of the development and function of the neural circuits in *C. elegans*, from embryo to adult. This system is a radical, high-speed, super-resolution 3D microscope utilizing self-reconstructing Bessel beams. The ultimate goal is the primary observation of an entire functioning neural system: 302 neurons in real time.



A part of the UCLA *C. elegans* team, working on individual experiments to modulate the physical environment of *C. elegans* over the summer of 2013. Their work will result in a new Physics 6C lab course debuting in Winter 2014.

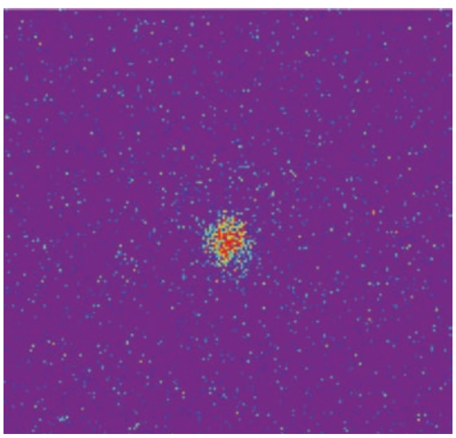
Atomic Molecular Optical Physics

Atomic Molecular Optical (AMO) Physics is highlighted this year as the Annual Report 2013 Feature Article. For in-depth history and research of AMO and the groups of Eric Hudson and Wes Campbell please go to pages 7-14.

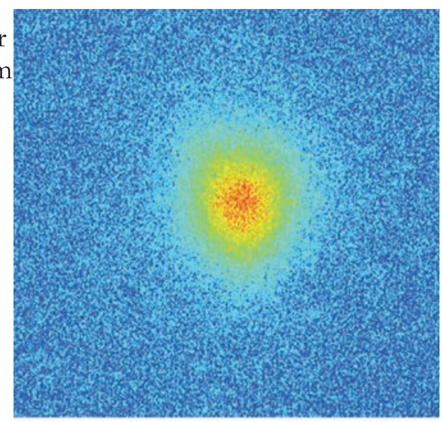
QUANTUM PHYSICS WITH ATOMS AND MOLECULES

Wes Campbell

As one of the new research groups just starting this year, our group has been focused on building our experimental infrastructure and assembling the equipment necessary for producing isolated quantum systems in the form of trapped atoms and molecules. This has involved the construction and stabilization of numerous lasers, each of which must produce light of a specific color to an accuracy of about 0.00001%. We have used these lasers to cool and trap neutral atoms using a technique called a magneto-optic trap and to trap single atomic ions in a radio-frequency Paul trap, both at temperatures of about 1/1000 of a degree above absolute zero. The neutral atoms will be used as a target for short pulses from an ultrafast laser, which will accelerate them to high speed in a vacuum chamber to allow us to benchmark a molecular deceleration process based on the same principle. We hope to use this process to produce "ultracold" samples of diverse species of polar molecules, which is a far more challenging task than laser cooling atoms and remains an outstanding problem in physics. Samples of such cold molecules are a highly-anticipated platform for building a large quantum information processor. For our atomic ion work, the atoms will also be used as quantum bits (called "qubits") in a quantum information processor. This device will be capable of simulating other quantum systems faster than a conventional supercomputer, allowing us to look for solutions to outstanding problems such as the nature of high-temperature superconductivity. We hope to use both the ultracold molecules and trapped atomic ions to investigate the crossover region between quantum mechanics and classical thermodynamics, where we often do not know the appropriate way to describe and predict the behavior of systems stretched to this limit.



False-color image of a single atom, levitated in a vacuum chamber in the Campbell lab.



False-color image of a cloud of ultracold atoms, each of which is less than 1/1000 of a degree above absolute zero.

Experimental Elementary Particles and Nuclear Experimental Physics

NUCLEAR PHYSICS GROUP

Huan Zhong Huang et al

The UCLA nuclear physics group includes research programs focusing on studies of Quantum Chromo-Dynamics (QCD) in the extremely high temperature and density environment at the Relativistic Heavy Ion Collider (RHIC), and on neutrino physics to search for neutrinoless double beta decays. Our QCD program centers on the STAR (Solenoidal Tracker at RHIC) experiment at Brookhaven National Laboratory and our neutrino program centers on the CUORE (Cryogenic Underground Observatory for Rate Events) at the Underground Laboratory in Gran Sasso, Italy. We have made major advances in all these research frontiers.

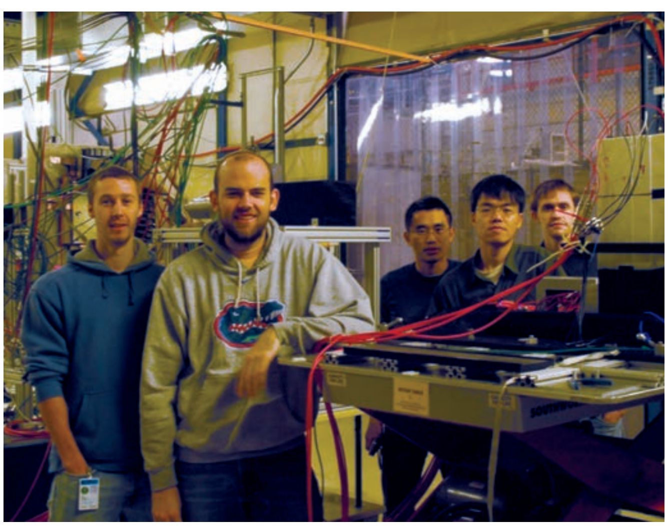
In this report we only highlight a detector R&D project that we have been carrying out at UCLA to develop new techniques for calorimeter constructions. Calorimeter is an essential component of the modern high energy particle and nuclear physics detector system. ElectroMagnetic Calorimeter (EMCal) measures energy showers from photons and electrons; Hadronic Calorimeter (HCal) measures hadronic showers which tend to be much broader transversely and longitudinally.

Undergraduate students Alex Ruckel (UCLA) and Adam Lamson (RPI) working on the SiPMT testing.

We proposed a Research & Development project to develop a cost-effective technique to build compact, fine grained calorimeters with good energy resolution, hermeticity, homogeneity, timing and energy resolution. We constructed an EMCal prototype using Tungsten powder and scintillator fibers using a novel technique and tested the prototype in a Fermilab beam. Satisfactory calorimeter performance for electron energy resolution was achieved.

We are currently constructing an array of 7x7 tower HCal prototype and are developing read-out scheme using Silicon APD based photon sensors. Many graduate students and undergraduate students from UCLA are involved in the R&D project under the supervision of staff member Oleg Tsai. The R&D project is supported by the BNL generic Electron-Ion Collider (EIC) detector R&D initiative and the STAR future upgrade R&D funds.

Undergraduate student Maria Sergeeva (UCLA) working on light collection scheme for HCal design.



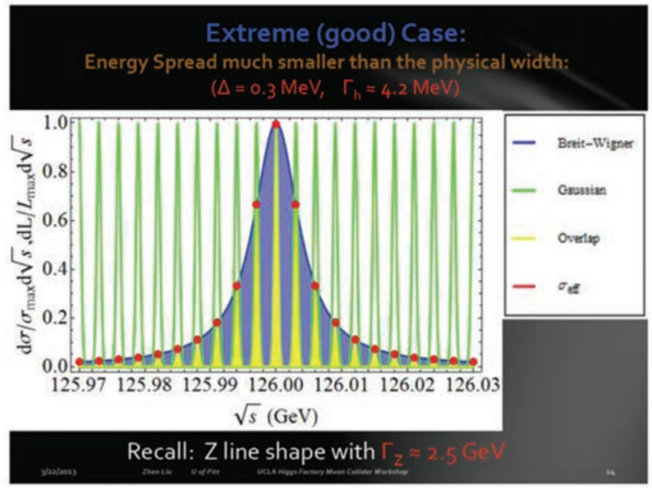
(Left to right) Keith Landry, Jay Dunkelberger, Qingxian Zhang, Yuxi Pan (all UCLA) and Chris Dilks (Penn State) with the UCLA testing table at the FNAL testing beam facility.

COMPACT MUON SOLENOID (CMS) EXPERIMENT

Particle Physics (Higgs Boson) Higgs Factories in the Future

David B. Cline

The discovery of the Higgs Boson in 2012 is a major advance. This is the first fundamental scalar particle discovered, and it could be responsible for inflation in the early universe. In March 2013 UCLA hosted a workshop on Higgs factories, which are special colliders designed to produce 100,000 or more "clean" Higgs particles. There are several candidate machines in the United States, and Europe, China, and Japan are considering a Higgs Factory project. UCLA's specific project is a muon collider that would produce the Higgs particle in the S channel, allowing a direct measurement of the 4-MeV width of the particle, detailed in the figure top page right. There is a robust program supported by the DOE to study muon colliders and neutrino factories. David Cline, Xiaoping Ding, and Ph.D. student Jon Lederman are UCLA members of this program.



UCLA Undergraduates play a role in the Large Hadron Collider and the discovery of the Higgs Boson

Robert Cousins, Jay Hauser, David Saltzberg
Researcher: Mikhail Ignatenko

Cutting-edge physics research is traditionally the domain of graduate students, postdocs, and faculty. But at UCLA undergraduates have played a key role in the experimental work that allowed the construction of detectors necessary for the recent discovery and elucidation of the Higgs Boson and - with luck - of even bigger surprises to come.

For over twenty years UCLA physicists have designed, built, operated, and analyzed data from the Compact Muon Solenoid (CMS) experiment. CMS is one of the two detectors at the Large Hadron Collider (LHC) hosted by CERN in Geneva, Switzerland that last year announced the discovery of a new particle, remarkably similar to the anticipated Higgs Boson. Further data-taking and analysis show that these Higgs Boson candidates look remarkably like what was predicted over fifty years ago. This appears to serve as a capstone of the understanding of elementary particle physics.

A large fraction of the muon detectors for both endcaps of the CMS detector came through UCLA for their final assembly and testing. These detectors cover a large area and detect the passage of a muon particle by its tiny amount of ionization in a gas. Many UCLA undergraduate students helped the effort and learned detection principles at the same time.

Meanwhile such detectors cannot work without electronics to find the muon particles and record them. Over the years UCLA configured thousands of custom-built trigger and data acquisition electronics. In just a few microseconds these boards find and record the presence of muon particles from the decays of Higgs Bosons and other interesting processes in the CMS detector. Such boards need to be tested before deployment and must be repaired when they fail.

Most recently UCLA undergraduate physics majors Alan Tran and Shayan Rastegari have served at the front line of this work, testing and repairing boards under tight deadlines and rigorous specifications. Over the last decade ten other undergraduates have worked in that capacity as well: Jacob Beres, Alex Perloff, Nick Lytal, Rina Kakimi, Paul Cubre, Kainoa Wright, Daniel Maronde, Alan Eramya, Mihajlo Tomic, and Kristjan Stone.

UCLA undergraduate Jacob Beres works at CERN preparing copper-clad panels for building new muon detectors. UCLA is helping build the upgrade of the Compact Muon Solenoid Experiment for the higher energy and higher luminosity running of the Large Hadron Collider scheduled to begin in 2015.

Day-to-day operations are overseen by a recently graduated UCLA physics major, Andrew Peck, who is now a full-time UCLA employee for our CMS work.

Despite its successes the CMS detector's muon system was never fully constructed according to our original vision. With the expected increase in beam intensity the remaining gaps had to be filled. UCLA undergraduates made quality assurance measurements at a local Southern California aerospace industry location, where the large 12 foot by 5 foot copper-clad sheets, the first step in building a muon chamber, were being stamped out. UCLA undergraduate Jacob Beres relocated to CERN for a summer to work on the project, where he glued, wound wires, cleaned, and tested high voltages for the new muon detectors under construction. He was followed the following year by Andrew Peck, who upon graduation with his UCLA physics degree spent six months living at CERN and building muon chambers.

Detectors are built with known technology, but we must always be looking for ways to improve them. The exquisite particle-tracking abilities of the CMS detector are conducted with fragile silicon detectors, which degrade in the high local radiation environment. UCLA undergraduates Charlie Schrupp and Taylor Barrella went to CERN to be part of a team that placed diamonds in a test beam of charged particles, to test whether these manufactured gems could better survive and track particles, perhaps becoming one of the detectors of the future.

Being on the cutting edge of science, CERN andits CMS experiment is a popular educational destination for UCLA undergraduates, and not just physics majors. We have given tours of the underground facilities to numbers of visitors including a large group of UCLA political science majors.

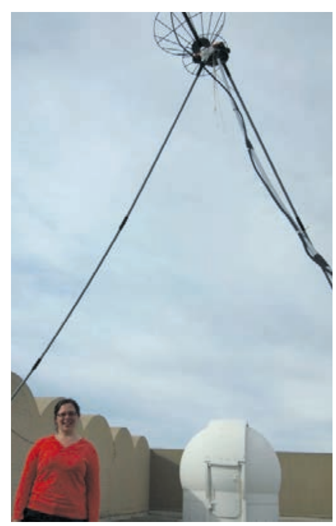
But the Higgs Boson is just a capstone for the last fifty years of understanding all the particles and fields we know about. There are good reasons to believe our understanding is not complete and that there will be new particles and new fundamental interactions. The CMS detector and LHC are undergoing radical upgrades to double the energy and increase the intensity of the beams. We hope this new data ushers in a new era of the next fifty years of particle physics, a foundation built, in part, on the work of UCLA undergraduates.

RADIO DETECTION OF HIGH-ENERGY PARTICLES

David Saltzberg

Professor David Saltzberg (shown) helped out his former Ph.D. student, Professor Abigail Vieregg, at the NSF Summit Research Station on the central Greenland ice sheet. Professor Vieregg has led exploratory work for a new site for a glacial neutrino detection, which heretofore has been conducted in Antarctica.

This year Stephanie Wissel arrived from Princeton as a new postdoc in David Saltzberg's research group, which specializes in searches for ultra-high energy neutrinos and cosmic rays in the polar regions. Dr. Wissel and several undergraduates are building a new 30-80 mHz horizontally-polarized but azimuthally-symmetric antenna that will descend from our Antarctic balloon payload. This new frequency capability will allow us to characterize the bulk of the emission from EeV cosmic rays in the next flight of the ANITA balloon experiment in Antarctica. Dr. Wissel is also collaborating with Dr. Andres Romero-Wolf from NASA/JPL to extend the detection technique from a balloon-borne receiver to an envisaged satellite mission called SWORD.

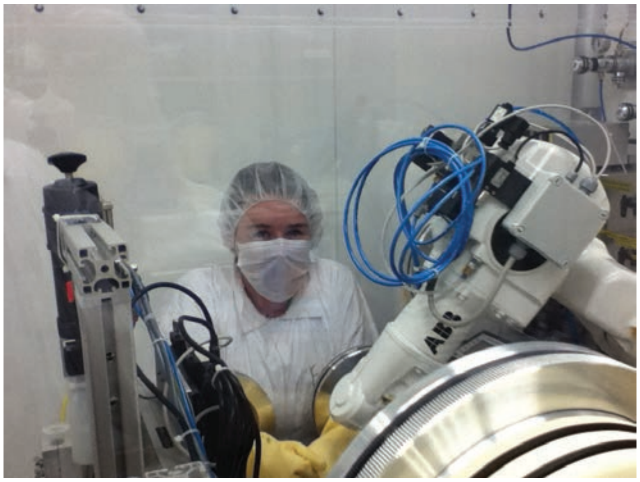


Dr. Stephanie Wissel puts the roof of Knudsen Hall to good use, shown with her receiver for an impromptu UHF antenna calibration.

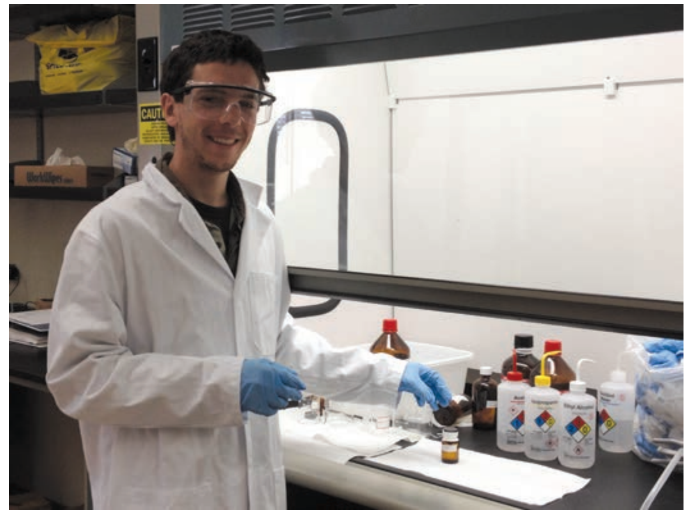
NEUTRINOS@UCLA - THE WINSLOW GROUP

Lindley Winslow

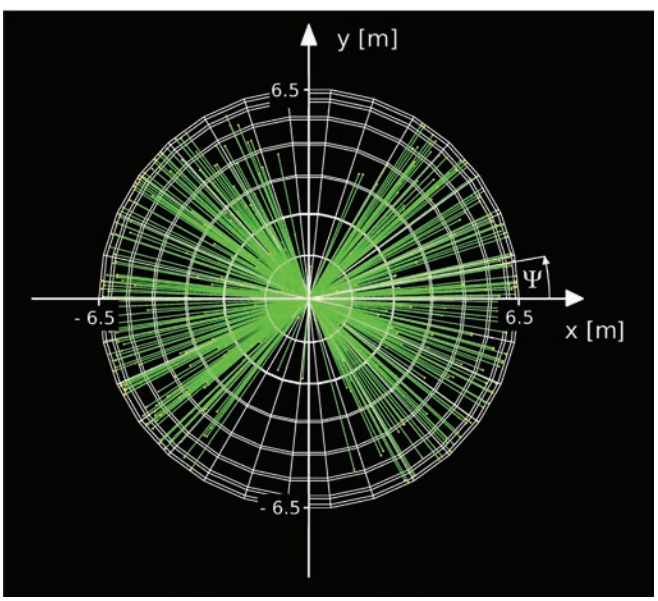
The Winslow Group has had an exciting first year getting started at UCLA. We study the boundary between nuclear, particle and astrophysics by focusing on one particle the neutrino. The central question we are trying to answer is whether the neutrino is its own antiparticle, a Majorana particle. If it is, this would have profound implications for particle physics and could also provide an explanation of the matter antimatter asymmetry in the universe. The only feasible experiments to determine the Majorana nature of the neutrino are searches for a yet-unobserved nuclear process neutrinoless double-beta decay. In this process, a nucleus decays while emitting two electrons simultaneously, but no neutrinos.



Erin Hansen is shown gluing very sensitive thermometers to the CUORE crystals.



Timothée de Guillebon, a visting student from ENS Cachan working on the quantum dot scintillator.



A pretty simulation of the Cerenkov light from two electrons from double-beta decay.

The group is working on two different experiments using two very different techniques to search for this process. The first, CUORE, is an Italian-American collaboration. It uses TeO_2 crystals operated as bolometers so the signal is a rise in the crystal temperature due the decay electrons. When completed next year, CUORE will be the coldest $1m^3$ in the universe. Incoming UCLA graduate students Erin Hansen and Agnieska Wergieluk were at the Laboratori Nationali del Gran Sasso this summer helping with construction. The CUORE group at UCLA includes both the Winslow and Huang group and their main responsibilities are the electronics and other infrastructure for monitoring the health of the experiment.

To improve this type of experiment we will need to become larger. For this reason, the Winslow group is pursuing an R&D program in liquid scintillator detectors, a type of detector that scales well to large volume. A liquid scintillator is a fluid that gives off light when charged particles go through it. This light is isotropic, but at the same time some Cherenkov light is made and retains the direction information of the particle. For the first time the group was able to show that, with novel photodetectors, reconstruction of the direction of the electrons is possible in this kind of detector. The group is also developing novel scintillators based on nanocrystals to improve this reconstruction. A $1m^3$ prototype detector has been proposed to test these ideas over the next few years.

Theoretical Particle Physics And Mathematical Physics

Eric D'Hoker, Vice-Chair for Academic Affairs

Over the past year, my research has focused on three topics in string theory. In collaboration with Michael Green (Lucasian Professor at Cambridge University), I have studied string theory induced corrections to Einstein's equations of gravity. We were able to understand the hidden symmetry properties of some of these corrections, and related them to so-called Zhang-Kawazumi invariants which were introduced in mathematics just a few years ago. Using string theory, we went on to propose an infinite family of new invariants which systematically generalize the original Zhang-Kawazumi invariant.

In collaboration with D.H. Phong (Professor of Mathematics at Columbia University), I have evaluated the first non-zero contribution, at two-loop order, to the vacuum energy produced by supersymmetry breaking in certain Calabi-Yau orbifold models for the Heterotic string. This subtle calculation combines methods introduced by Phong and myself more than 10 years ago for two-loop superstring amplitudes, with a recent general prescription in terms of integration over cycles in supermoduli space, due to Edward Witten.

Finally, in collaboration with Constantin Bachas (Professor Ecole Normale Superieure, Paris), John Estes (Research Associate Imperial College, London), and Darya Krym (Assistant Professor CUNY), I have made serious progress in understanding the near-horizon limit of the intersection of M2 and M5 branes in M-theory (the non-perturbative extension of superstring theory). These two types of branes are the fundamental building blocks of the theory, and the near-horizon limit of their intersection produces a uniquely interesting conformal field theory whose symmetry is governed by the unique simple superalgebra D(2,1;a) which depends on a free continuous parameter. Through large families of new solutions that we have found, this conformal field theory can now be much better understood.

John M. Cornwall

John Cornwall helped to organize the third annual QCD Workshop held at the European Center for Theoretical Studies of Nuclear Physics and Related Areas, Trento, Italy in September 2013. He gave an invited talk on "The running charge and the Pinch Technique" at the Symposium "Quantum Chromodynamics: History and Prospects," Oberwoelz, Austria, September 2012, showing how the well-known running charge of QCD is actually a part of a much more comprehensive construct that is, in principle, more accurate and useful. He is finishing an invited review paper for *Mod. Phys. Lett. A* entitled "Positivity Violations in QCD," showing how unnatural signs in quantum electrodynamics (QED), a fundamentally-flawed theory at enormous energy, are actually natural in QCD because of the so-called "wrong" sign of QCD's beta-function. Recent research shows how 40-year-old work of Cornwall and Tiktopoulos yields powerful alternative tools for string-theory-inspired QCD calculations.

Christian Fronsdal

Christian Fronsdal has been pursuing his project that consists of producing a fairly radical book on thermodynamics. To this end he has continued his travels, following a quarter at the Yukawa Institute in Kyoto last year with a quarter at Norway's Technical University in Trondheim during the spring of 2013. He enjoyed interesting discussions with physicists, chemists and engineers. As a direct result of this visit we shall have a visitor to the department for about six months, Professor Tore Haug-Warberg from NTU in Trondheim. Plans are under way to spend the next spring in Moscow.

Christian Fronsdal is engaged in writing a book on Thermodynamics. This work has some controversial elements and departs from traditional views and methods in many ways. For example, he emphasizes the lagrangian approach, which is a very strong constraint since, for a given system, one lagrangian density has to be effective in all contexts. He proposes an improvement of Landau's two-fluid theory of superfluids and takes a controversial approach to (mixed) atmospheres. For mixtures he recognizes all the natural degrees of freedom but do not use molar fractions. Entropy is very central to his approach. Most radical is the explicit modeling of the entropy of a mixture as a linear function of the densities. There is no concept of 'entropy of mixing'. The central problem is to determine the entropy functional. The Gibbs-Dalton hypothesis, valid for ideal gases, is generalized to the case of mixtures defined by their constituents and by their mutual interaction. In the case of chemical interactions the explicit modeling of the entropy appears to be a tool towards a more complete theory that actually makes predictions beyond the mass action law. A full integration of thermodynamics with General Relativity is proposed and now included in the book, a significant improvement over the much used method of Tolman. There is a chapter on phase transitions and another on mixtures, including some chemical reactions. Fronsdal moved away from elementary particles and from pure mathematics to take up work in astrophysics, about five years ago. He was very unhappy with the method invented by Tolman and thinks that he has improved on it. But to justify his suggestions with respect to this topic he has had to make a strong effort to learn thermodynamics; the book is the result. A working and preliminary copy of the book can be seen at *fronsdal.physics.ucla.edu* Comments are received with thanks.

Sergio Ferrara

The focus of the research of Sergio Ferrara over the last and present year is on two main topical arguments in the physics of elementary particles and quantum gravity. The first topic is the study of properties of black holes, in particular extremal zero temperature) black holes, peculiar objects which appear as basic ingredients in modern theories of quantum gravity, such as supergravity and superstrings.

The other topic, which is becoming more fashionable in view of the results from LHC and from Planck Satellite experiment, is the nature of supersymmetry breaking, which seems to prefer fundamental (relatively light) scalars as well as the dynamics of the other fundamental scalar, the inflaton.

The inflaton is a pure cosmological particle needed to explain inflation. The Planck data seem to support the identification of the "inflaton" with the "scalaron," a pure gravitational degree of freedom which emerges in gravity theories with higher (scalar) curvature terms.

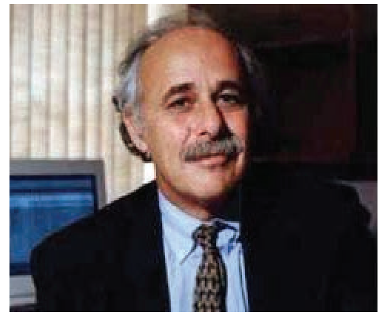
The supergravity origin of the scalaron was obtained in a work done in 1988 with a UCLA team also including a UCLA postdoc (M. Porrati, now a distinguished faculty member at NYU), a UCLA student (S. Sabharwal), and a UCLA visitor (S. Cecotti, now a faculty at SISSA, Trieste, Italy). The dynamics of the scalaron as a minimal inflaton scenario was recently suggested and investigated in collaboration with Porrati and two Stanford faculty members, Renata Kallosh and Andrei Linde. The minimal inflaton scenario tends to identify the inflaton as a Higgs-like particle of a "massive vector multiplet," similar in spirit to the MSSM, where, in the supersymmetric limit, the two Higgs doublets are partners of the massive weak vector bosons. Further study along these lines is in progress.

References:
S. Cecotti, S. Ferrara, M. Porrati, S. Sabharwal, *Nucl.Phys. B* 306(1988)160 "New Minimal Higher Derivative Supergravity Coupled to Matter."

S. Ferrara, R. Kallosh, A. Linde, M. Porrati, *arXiv:*1307.7696 "Minimal Supergravity Models of Inflation."

Sergio Ferrara is a distinguished professor, TEP High Energy Theory Group, Department of Physics and Astronomy,UCLA and Senior Scientist,Theory Unit, Physics Department, CERN, Geneva, Switzerland

Roberto Peccei


Roberto Peccei

Roberto Peccei was awarded the 2013 J.J. Sakurai Prize for Theoretical Particle Physics, shared with Helen Quinn of SLAC. Roberto was honored "for the proposal of the elegant mechanism to resolve the famous problem of strong-CP violation which, in turn, led to the invention of axions, a subject of intense experimental and theoretical investigation for more than three decades".

Alexander Kusenko

UCLA high-energy physicists have contributed to the Community Summer Study 2013 conducted by the American Physical Society's Division of Particles and Fields to develop a long-term plan for the future directions of high-energy physics research. Alexander Kusenko has served as a co-convener of one of the subgroups focusing on dark matter. The outcomes of this study will be used by the U. S. Department of Energy Particle Physics Projects Prioritization Panel (P5) that will advise the DOE on the priorities for future funding. Physics & Astronomy professor Robert Cousins is among the members of P5.

Inspired by the discovery of the Higgs boson at Large Hadron Collider, UCLA graduate student Lauren Pearce, in collaboration with her thesis advisor Alexander Kusenko as well as John M. Cornwall and Roberto Peccei, has pursued a novel framework in which supersymmetry can be realized in nature. In an unusual strongly coupled phase, supersymmetry can evade detection at the LHC, while providing a new possibility for generation of matter-antimatter asymmetry in the early universe. Lauren Pearce has been awarded a Dissertation Year Fellowship.

In a paper published in *Physical Review Letters* in 2010, Alexander Kusenko and collaborators, which included then-graduate student Warren Essey, predicted that a neutrino spectrum peaked at a PeV could arise from interactions of cosmic rays with photon backgrounds. The existence of such line-of-sight interactions was inferred from the hard observed gamma-ray spectra of distant blazars. Now the IceCube experiment at the South Pole has detected some PeV neutrinos. In a new paper published this year, also in *Phys. Rev. Letters*, the authors show that the observed signal is in agreement with the prediction based on the blazar spectra. The connection between cosmic rays and gamma rays from distant blazars allows one, in particular, to measure magnetic fields deep in the voids between clusters of galaxies. These magnetic fields are the closest measure of primordial fields, whose understanding opens a new window on the physics of the early universe.

Plasma and Beam Physics

THEORETICAL PLASMA PHYSICS

George Morales

" Permutation entropy analysis of temperature fluctuations"

In a recent publication [*Plasma Phys. Control. Fusion* 55, 085015 (2013)], by Dr. James Maggs and Professor George Morales, the concept of amplitude permutation probability introduced by Bandt and Pompe [*Phys. Rev. Lett.* 88, 174102 (2002)] is used to compute the entropy and statistical complexity for time signals obtained from experimental data obtained in the Large Plasma Device (LAPD) at UCLA. The associated "CH plane," which displays Jensen-Shannon complexity vs. normalized Shannon entropy as introduced by Rosso et al [*Phys. Rev. Lett.* 99, 154102 (2007)], is used to determine the statistical nature of the dynamics associated with temperature fluctuations measured in a basic experiment that probes the nonlocal heat transport that arises when a small heat source, akin to a candle, is applied to a large and cold magnetized plasma [*Phys. Plasmas* 15, 122304 (2008)]. The advantage of this modern signal analysis technique is that is permits the identification of the underlying dynamics that generates the time series without any a priori assumptions about the behavior of the signal. An example of a CH display is given in Fig. 1. For reference, note that, in a "CH display," the lower right corner corresponds to white noise, while the lower left corner represents constant signals. The central top region is where pure deterministic chaos appears, e.g. signals generated by the logistic map. The path delineated by the green line in Fig. 1 represents the stochastic process of fractional Brownian motion (fBm) for a range of Hurst exponents between .025 and .975. The quantity "d" is the embedding dimension used in the analysis. The results shown in Fig. 1 identify that the underlying dynamics responsible for nonlocal transport in the temperature filament is deterministic chaos, and not a stochastic process as would correspond to local transport described by Fick's law. This conclusion is arrived at independently of any statement about the shape of the frequency spectrum.

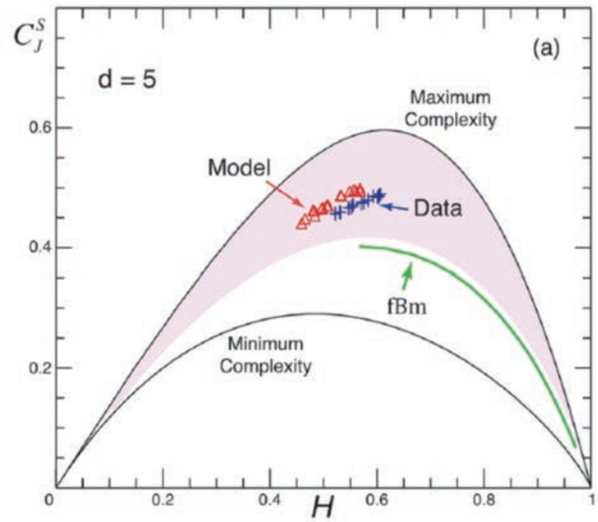


Fig. 1. Locations in the CH plane of temperature filament data (blue crosses), and numerical output of chaotic advection model (red triangles). The shaded region delineates the region of chaotic behavior. The stochastic process of fractional Brownian motion (fBm) is also shown for comparison.

"Uphill fractional transport"

As part of his Ph. D. dissertation Adam Kullberg, a graduate student supervised by Professor Morales, extended the mathematical description of fractional transport (i.e. the flux is proportional to a fractional derivative of order between 1 and 2) to two-dimensional bounded domains [*Phys. Rev. E* 87, 052115 (2013)]. These mathematical and computational improvements allow more realistic comparisons with experiments that exhibit nonlocal transport. A striking prediction from this model is that "uphill transport" arises when a source is applied off-axis. "Uphill" refers to the heat flux being in the same direction as the gradient of the temperature, instead of the usual prediction made by Fick's law, in which the flux is opposite to the gradient direction. An important consequence is that off-axis sources result in profiles that are hollow at the center. This model has been recently compared to experimental results obtained in the RTP tokamak [*Phys. Rev. Lett.* 82, 5048 (1999)], as shown in Fig. 2.

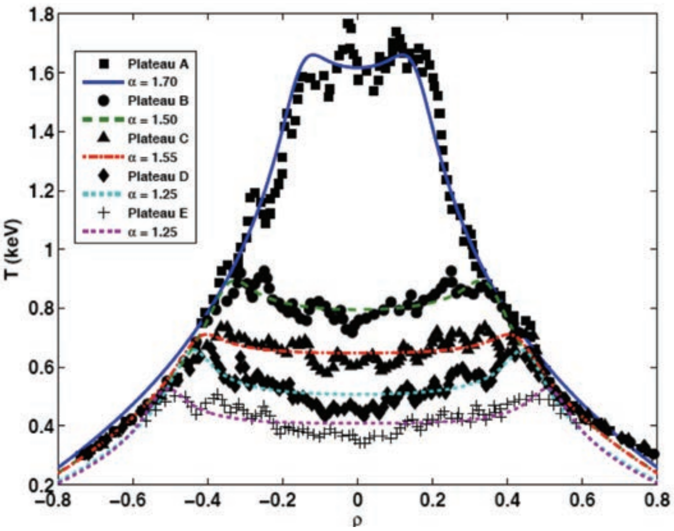


Fig. 2. Steady state temperature profiles measured (black symbols) in the RTP tokamak when heating is applied off-axis. Color curves are predictions of 2D fractional model for heating source applied at different radial positions.

THE COMPUTER SIMULATIONS OF PLASMA GROUP

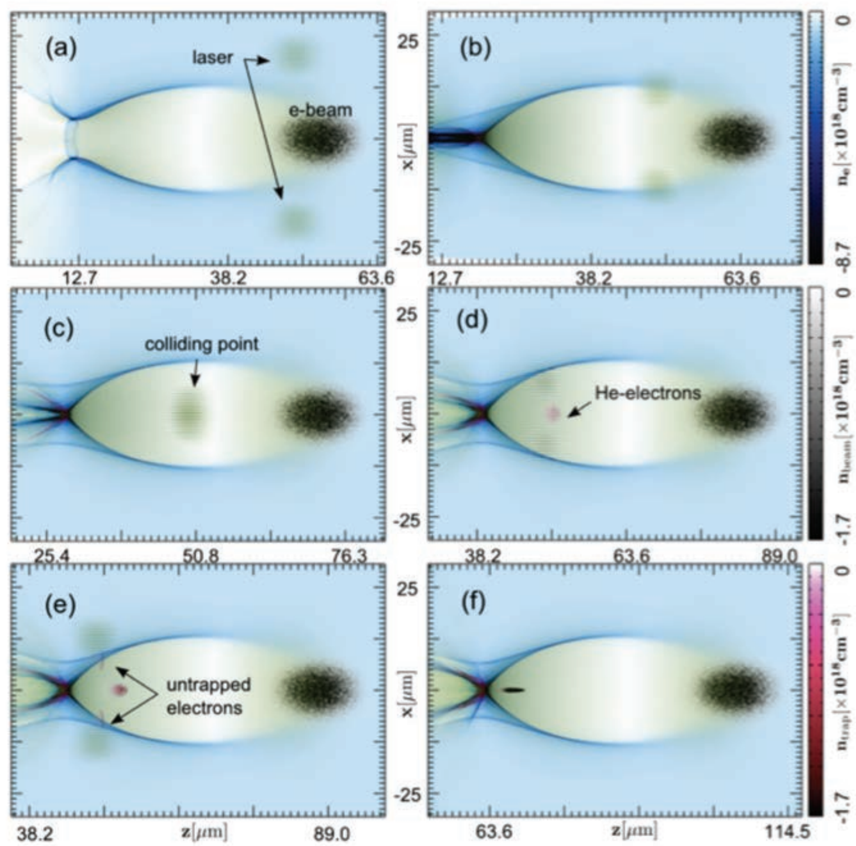
Warren Mori

The Computer Simulations of Plasma Group (http://plasmasim.physics.ucla.edu) under the leadership of Professor Warren B. Mori and Adjunct Professors Viktor Decyk and Phil Pritchett, continues to do pioneering work in high-performance computing of complex plasma phenomena. During the past year, the group also included four research physicists (Drs. Tsung, Tzoufras, Lu, and Tonge), a post-doctoral researcher, and six Ph.D. students. Its research remained focused on the use of fully parallelized particle based simulation models to study laser and beam plasma interactions, plasma based accelerator and light sources, space plasmas, Alfvénic plasmas, inertial fusion energy plasmas, and high-energy density science.

The group specializes in fully kinetic simulation of plasmas using particle-in-cell (PIC) and Vlasov Fokker Planck (VFP) techniques. Its codes are used throughout the world and are run on some of world's fastest computers. Earlier this year the group's code OSIRIS was run on the over 1,600,000 cores on the Sequoia computer and Lawrence Livermore National Laboratory (https://www.llnl.gov/news/newsreleases/2013/Mar/NR-13-03-05.html). The group is also home to the DAWSON2 computer, which has 1152 CPUs and 288 General Purpose Graphics Processing (GPGPU) units. This was funded through a National Science Foundation (NSF) Major Research Instrumentation (MRI) Award. It is a leader in developing algorithms for kinetic simulation codes to run a GPU and other many core systems.

In recognition of its state-of-the-art plasma simulation software, the group was awarded a grant from the National Science Foundation Office of Cyberinfrastructure to create the particle-in-cell and kinetic simulation software center (PICKSC). Our group mission will be to significantly broaden the impact of PIC simulations by documenting and making available several tools: illustrative software programs for different computing hardware, a flexible framework for rapid construction of parallelized PIC programs, and several production codes. We will also document best practices and develop educational software for classroom instruction.

Besides developing state-of-the-art simulation tools, the group also uses these simulation tools to find solutions for several grand challenge research topics. These include attempting to design next generation accelerators at the energy frontier and for x-ray free electron lasers based on particles surfing on plasma waves. Recently the group has been discovering new methods for generating electron beams with unprecedented brightnesses and emittances, understanding the evolution of the six dimensional phase space of electrons accelerated in plasma waves, and studying how to effectively load electrons and positrons into plasma wakes.



Results from a three-dimensional OSIRIS simulation. A particle beam moving from left to right creates a nonlinear plasmas wave and to side injected lasers cross the middle of the first wavelength of the wave. These lasers ionize gas which injects electrons into the wake which are then trapped and accelerated creating a beam with potentially unprecedented emittance and brightness.

We have also been studying how lasers evolve as they propagate through mm to cm scale plasmas at the National Ignition Facility (NIF). NIF is the world's largest and most powerful laser. A grand challenge in NIF and IFE research is to unravel the complicated physics behind how a multitude of overlapping high-power laser beams are absorbed, scattered, and deflected as they propagate through centimeters of high-energy density plasmas. Our group's codes can be used to understand some of this complicated physics.

Our group is part of several interdisciplinary research teams. One such team was recently funded by the Scientific Discovery through Advanced Computing (SciDAC) program within the Department of Energy (DOE). We are also part of the DOE High Energy Density Laboratory Plasmas to study laser and electron beam transport in high energy density plasmas that are found in inertial fusion energy experiments and the joint NSF/DOE basic plasma science program to study how intense lasers and particle beams propagate in tenuous plasmas.

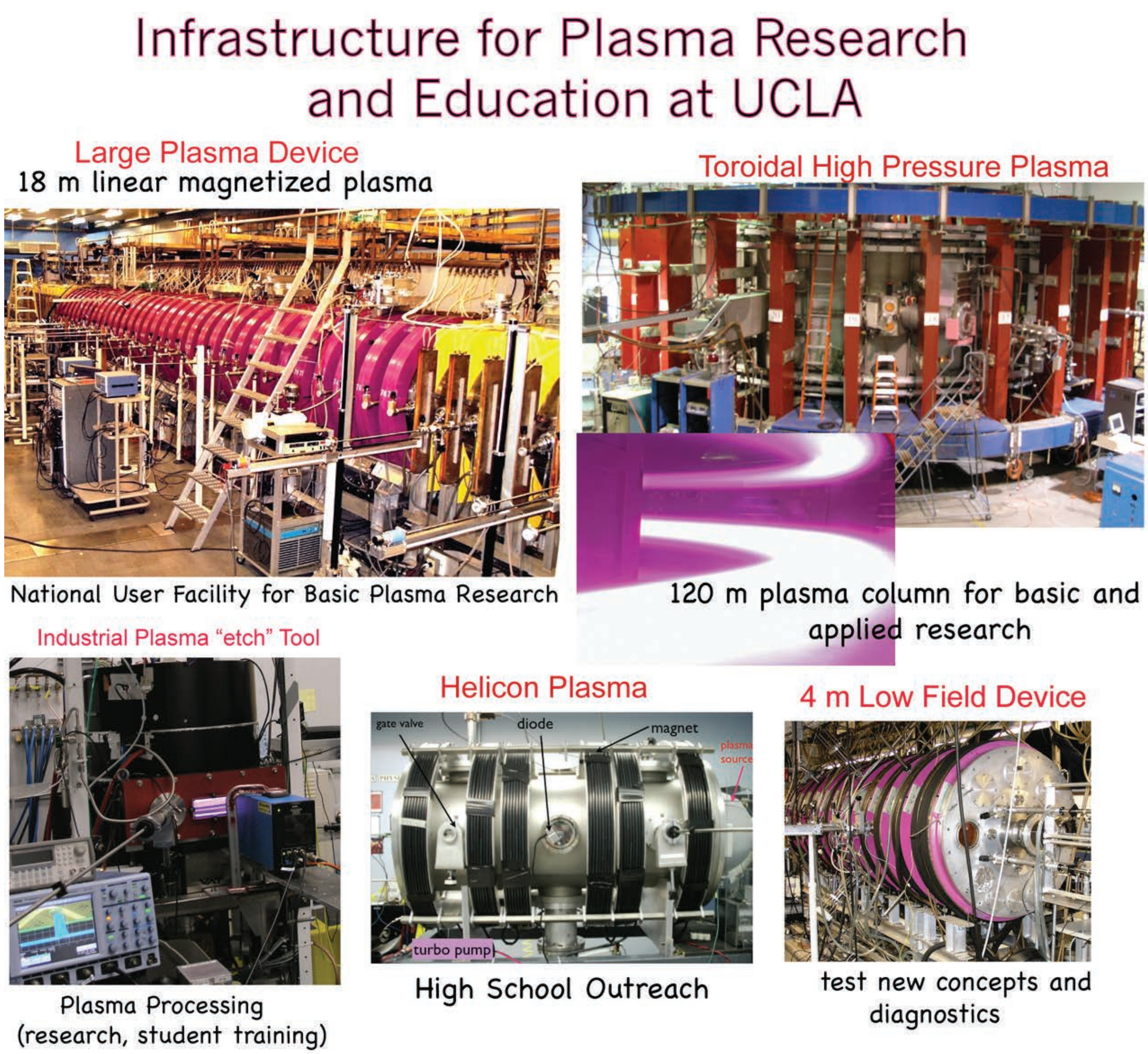
The group continues to be part of Innovative and Novel Computational Impact on Theory and Experiment (INCITE) Awards that provides access to the largest computers managed by the Department of Energy (DOE). We also continue to be affiliated with a DOE Fusion Science Center (FSC) on "Extreme states of matter and fast ignition physics."

For information on its recent publications and results go to its webpage. (http://plasmasim.physics.ucla.edu). Sample results are shown in Li, F.,et al., *Physical Review Letters,* Vol. 111, No. 1, pp. 015003/1-4 (July 2013).

BASIC PLASMA SCIENCE FACILITY(BaPSF)

INFRASTRUCTURE FOR PLASMA RESEARCH AND EDUCATION AT UCLA

UCLA is the home of the Basic Plasma Science Facility. BaPSF provides national and international scientists access to unique research devices and diagnostic tools that permit the exploration of a wide range of fundamental plasma problems that impact topics at the frontiers of fusion, space science and plasma technology. The broad parameter ranges accessible in the plasma devices operated at BaPSF allow studies that span microscopic phenomena on the fast electron time scales (e.g., electron plasma waves, cyclotron radiation) to the slow time scales characteristic of plasma transport driven by drift-wave turbulence and long wavelength magnetic fluctuations. The BaPSF plasma devices provide effective platforms for the training of graduate students because of their optimum, mid-scale size. The devices (below) and diagnostic tools available at the BaPSF are sufficiently large and sophisticated so as to provide exposure to frontier developments that require learning to work in a team environment. Faculty directly involved with the BaPSF are Walter Gekelman, George Morales, and Troy Carter. There are five full time research scientists involved as well as four engineers and technicians. At any one time the group supports of order 15 graduate students. Undergraduates find projects at BaPSF and there is a high school outreach program. The following are a sample of what we did this year.

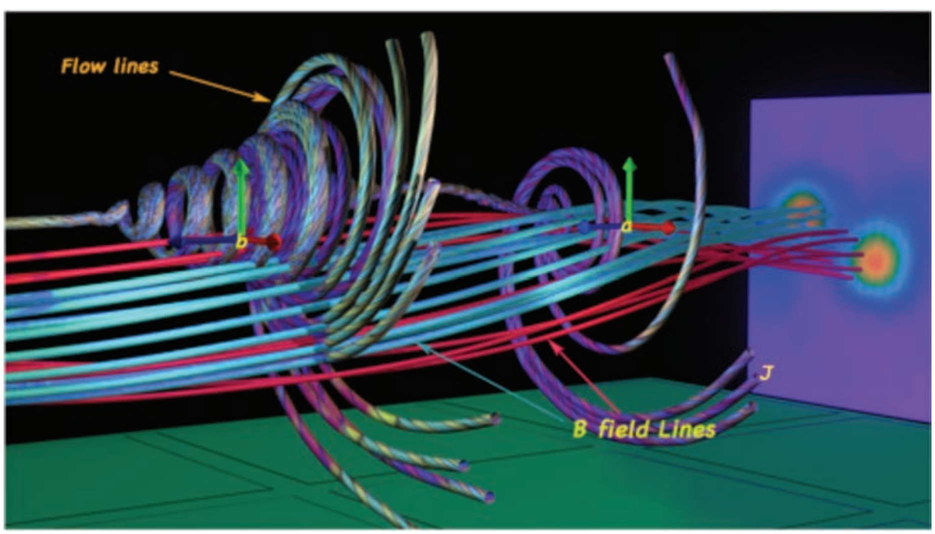


MAGNETIC FLUX ROPES

W. Gekelman, B. Van Compernolle, Tim DeHaas

A series of experiments has been undertaken at UCLA to study magnetic flux ropes. These are objects which routinely occur near the surface of the sun and every other star. Sometime large magnetic ropes are ejected from the sun and come all the way to the earth. They have been seen by satellites that photograph the sun in UV and X-ray light as well as detected by magnetic probes on satellites closer to the earth. The source of instability responsible for the eruption is a topic of current research in solar physics. Current sheets, which can be considered to be slab ropes such as those observed in the earth's magnetotail, can become unstable and tear into a series of nearly linear ropes which can interact and braid with one another. Under the right conditions the individual ropes can be subject to the kink instability. The resulting motion can be violent enough to make them collide and produce bursts of magnetic field line reconnection. The study of these objects is so rich that it has involved solar and space plasma physicists, experimentalists, those doing simulations, and mathematicians working in topology. They have been studied in unprecedented detail at the BaPSF. No other experiment comes close.The series of experiment has provided a strong link between the laboratory plasma physics community and solar physicists as well as astrophysicists. A number of invited talks to these communities have been given as a result of this work and a paper published in the Astrophysical Journal as well as in *Physics of Plasmas and Solar Physics*. The work shows that astrophysics can be studied in laboratory devices provided that the problem is carefully selected and the experiment well planned.

Flux ropes are twisted bundles of electrical current and magnetic field. There are quite a few situations where multiple flux ropes exist simultaneously. If the magnetic ropes have strong enough magnetic fields they can mutually interact. The interaction results in the ropes twisting about each other, colliding and sometimes merging. In instances when they do collide magnetic field can be destroyed. Magnetic fields carry energy (proportional to B^2) and total energy is conserved. When the magnetic field energy decreases new forms of energy such as plasma heating, flows, and a variety of plasma waves appear. This exotic process is called magnetic field line reconnection and the UCLA experiments have explored it in full three dimensions by acquiring volumetric data sets. The experiments were done in the LArge Plasma Device (LAPD) at UCLA. This machine has a 18m long, 60 cm diameter magnetized plasma which is pulsed on once a second and runs 24 hours a day. Its reproducible plasma allows experiments such as this to be done (there is no other machine like it in the world). These experiments have allowed the identification of Quasi Seperatrix Layers (QSLs) for the first time in the laboratory, within the plasm Using these data sets we are studying the chaotic motion of the magnetic field lines in space and time. To do this we are using methods developed by mathematicians who study complex systems subject to deterministic chaos. The methodology is too complicated to explain in this short narrative but has been successfully used by our group for the first time in the study of an unstable temperature filament5. A paper on the complexity of fully three dimensional, kink unstable flux ropes will be submitted for publication in September 2014.



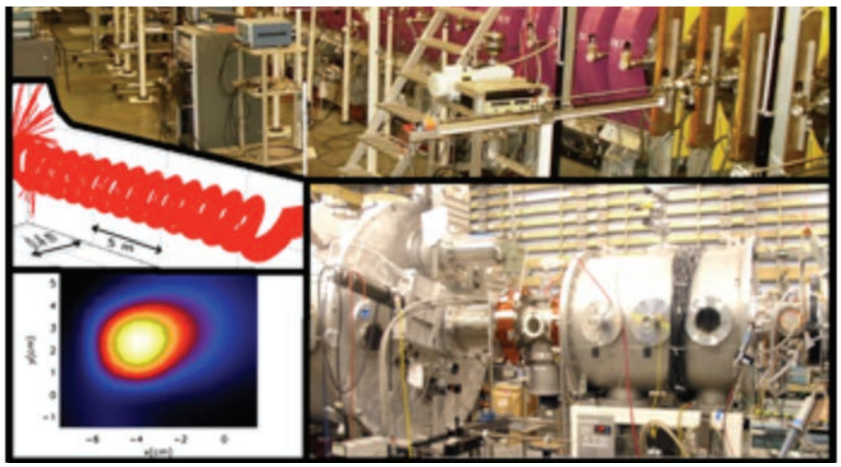
Flux ropes field lines, current and flows. The plane on the right (dz = 1.28 m, z=0 is on the LaB6 cathode) shows the plasma current density. The value in the center spot (orange) is 8.63 A/cm^2 and the average value 5.75 A/cm^2. Blue is zero. The flux cm^2 ropes field lines were started in the high current regions. Magnetic field lines are colored red and blue and the plasma flow, with a cross-hatched pattern is observed to snake between and around them. Three axis marker arrow a is located at dz = 5.28m and arrow b at dz = 8.28 m. The Background magnetic field (Boz = 330 G, Ar) is in the same direction as the blue marker arrow. The extent of the x and y planes is dx = dy = 16 cm. The data was acquired at t = 4.18 ms after the flux rope turn on.

INJECTION OF A SPIRALING ION BEAM IN THE LARGE PLASMA DEVICE

Shreekrishna Tripathi, Patrick Pribyl, Walter Gekelman, Bart Van Compernolle

Confinement properties of fusion-grade plasmas are greatly influenced by fusion-produced alpha particles and fast-ions from auxiliary heating. These energetic-particles excite numerous wave-modes with which they non-linearly interact, thereby affecting stability and energy transport. The fusion-campaign at the Large Plasma Device (LAPD) at UCLA addresses this important research area. A photo of the LAPD is displayed in the top panel of the graphic. LAPD is a highly-flexible linear magnetoplasma device operating at 1 Hz repetition rate with typical plasma parameters: $n \approx 10^{12}$ cm^{-3}, $T^e \approx 4.0$ eV, B =1.0 - 1.8 kG, 19 m length, and 0.6 m diameter.

The magnetic-field profiles and plasma parameters of the LAPD are adjustable, allowing for the study of a variety of fundamental processes relevant to fusion and space plasmas. The principal instrument for carrying out fast-ion studies on the LAPD is an ion beam source (25 kV, 10 A, bottom-right panel). The ion source uses a hot-cathode LaB^6 plasma source and a multi-aperture three-grid extractor to inject super-Alfvénic ions ($v^{beam} \leq 1.2\, v^{Alfven}$) from one end of the LAPD. The pitch-angle of the beam is varied from 0°-75° by changing the beam-injection angle. Interaction of the spiraling ion-beam with the LAPD magnetoplasma is diagnosed in great detail using fast-ion collectors and a variety of probes. Numerically calculated ion trajectories are compared with measurements from the fast-ion collectors. The trajectory of an 18 keV helium ion beam (injection angle = 4°, pitch angle ≈ 25°, B = 1 kG) and its profile ($j^{max} \approx 82$ mA/cm2, recorded in the LAPD plasma at a 12 m distance from the ion-source exit-grid) are depicted in the middle-left and bottom-left panels. Initial results include observations of beam-driven Alfvén waves and resonant-interaction of waves with fast-ions.



Photograph of the Large plasma device and ion beam source are displayed in the top and bottom-right panels, respectively. Typical profile of the ion beam is shown in the bottom-left panel and its trajectory is depicted in the middle-left panel.

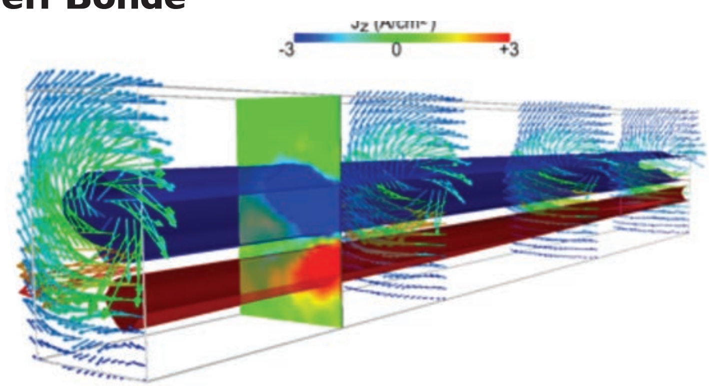
ELECTRON CURRENT SHEET DISRUPTION VIA FAST PARTICLE INJECTION.

Stephen Vincena, Walter Gekelman, Jeff Bonde

In work funded by the US DOE, experiments have recently begun to study the disruption of current sheets by the injection of fast particles. Dr. Frank Tsung is also conducting simulation efforts.

In nature, injection of particles can be driven by high-speed flows in the solar wind interacting with current sheets in the earth's magnetosphere. In fusion research, frozen pellets can be injected into tokamaks to both fuel the plasma and to disrupt the currents of localized wave modes; these modes, if left unchecked, could lead to a catastrophic loss of plasma confinement, damaging or destroying plasma-facing components.

In the Large Plasma Device, a current sheet is preformed in an existing, magnetized plasma and disrupted by the cross-field expansion of a laser-produced plasma (LPP) from a laser-target interaction. The peak of the



Volumetric measurements of the magnetic field (vectors) and derived axial current density (isosurfaces and cut-plane). The plane in the upper right is located at z=+160cm from the laser target. The largest magnetic field is 24 G (δB/B0z=3%).

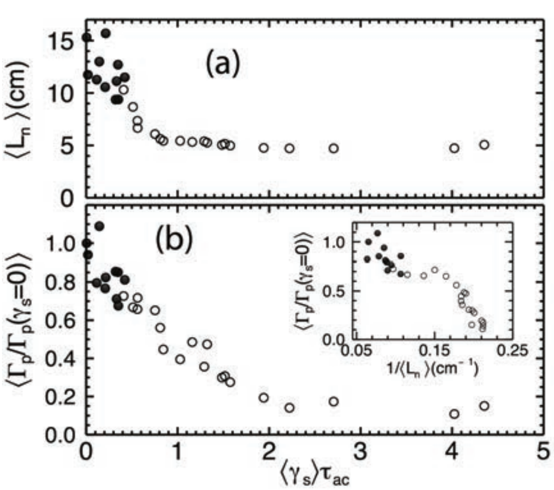
interaction is shown in Figure 1. Magnetic fields are shown as arrows and the corresponding current density as isosurfaces and a colored plane. Prior to the LPP, the electron current would be seen as a blue vertical sheet, measuring 10cm in y and 2cm in x. Exterior measurements show a 30% drop in net current, while Alfvén-wave-dominated currents in the diagnosed volume show the current can be completely shut off for an ion cyclotron period. The group is currently investigating whether the current disruption is driven by magnetic reconnection or by changes in the local plasma potential caused by the hot laser plasma.

TURBULENT TRANSPORT IN MAGNETIZED PLASMAS

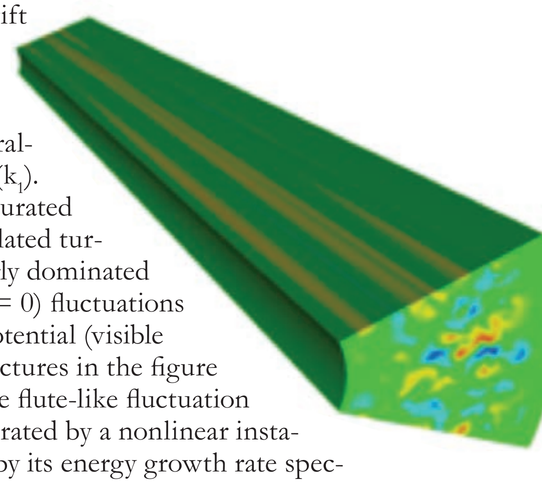
David Schaffner, Brett Friedman, Troy Carter, Giovanni Rossi, Danny Guice

Magnetically-confined plasmas in the laboratory generally suffer from instabilities driven by pressure gradients. These gradients are unavoidable as the goal of confinement is to maintain a high-temperature, high-pressure plasma away from nearby material walls near room-temperature. The instabilities that arise tend to drive flows that mix the high temperature plasma in the "core" of the plasma with lower temperature plasma nearer to the edge. This turbulent mixing leads to a leakage of heat and particles, making it difficult to maintain a confined, hot, dense plasma for applications such as fusion energy production. It has been known since the 80s that sheared (spatially varying) flows across the magnetic field can reduce turbulence and transport associated with pressure gradient instabilities. This phenomena is the basis for the so-called high-confinement or H-mode in tokamak fusion reactors, where a strong flow layer near the edge of the confined plasma reduces turbulent transport. While this turbulent transport reduction is critical to the success of current and future (e.g. ITER) fusion experiments, we still lack a complete first-principles understanding of the H-mode and the suppression of transport by shearing.

Graduate student David Schaffner led experiments on the Large Plasma Device in which the edge flow and flow shear was varied through external control and the modification of turbulence and turbulent transport in response to this shear flow was measured. The figure below shows the density gradient scale length (smaller scale length means steeper gradient and better confinement) and particle flux (outflow of particles due to turbulent mixing) versus the level of shearing in the applied flow (shearing rate normalized to the "eddy turnover time" of the turbulence). We find that confinement improves, and particle flux reduces, with increasing shearing. Near complete suppression of turbulent mixing occurs for shearing rates comparable to the eddy turnover time. This dataset is the most comprehensive to date on the effects of flow shear on turbulent transport; papers detailing this work have been published in *Physical Review Letters* and in *Physics of Plasmas*. Comparisons of these measurements to theory and simulation are underway.



Graduate student Brett Friedman has led an effort to simulate turbulence in LAPD using massively-parallel computation. A 3D fluid code, BOUT++, is used which was developed to simulate turbulence in tokamak plasmas. The figure to the right shows a snapshot of the simulated turbulence (colors represent electrostatic potential) in a section of the cylindrical LAPD plasma. An analysis of the energy dynamics of these simulations have been performed in order to understand the nature of turbulence in LAPD. The primary linear instability is the resistive drift wave which has a positive linear growth rate for low but finite parallel wavenumber (k_1). However, the saturated state of the simulated turbulence is strongly dominated by flute-like ($k1 = 0$) fluctuations in density and potential (visible as elongated structures in the figure to the right). The flute-like fluctuation spectrum is generated by a nonlinear instability, identified by its energy growth rate spectrum, which varies significantly from the linear growth rate spectrum. Nonlinear instabilities are not uncommon in physical systems, in fact turbulence in ordinary water pipes is explained by nonlinear instability (or subcritical instability). The presence of nonlinear instabilities calls into question the use of linear instability physics to explain turbulence and compute transport (e.g. via quasi-linear theory) in magnetized plasmas.

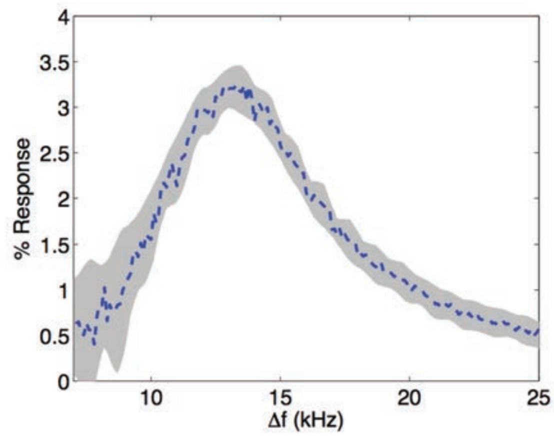


NONLINEAR PHYSICS OF ALFVÉN WAVES

Seth Dorfman, Troy Carter

Alfvén waves are low-frequency modes in magnetized plasmas which can play fundamentally important roles in laboratory, space and astrophysical plasmas. One important process, called the parametric decay instability, results from the decay of a large amplitude Alfvén wave into a daughter Alfvén wave and a sound wave. This process could play a role in heating the solar corona, which is observed to be as hot as three million degrees (compared to the 6000 degree solar surface). Postdoc Seth Dorfman has led a study of the nonlinear coupling between the Alfvén waves and sound waves in the Large Plasma Device (LAPD). Antennas are placed at both ends of the machine, each launch a high amplitude Alfvén wave and the resulting nonlinear interaction is observed. Probes placed between the antennas then look for signatures associated with the heavily damped sound wave expected from this three wave interaction process. To do this, the frequency of one antenna is held fixed while the frequency of the second antenna is varied between plasma discharges. As shown in the figure below, the amplitude of the response peaks where the interaction between the three modes is most efficient. Other observed features including the spacial pattern and frequency vs. wavelength relation are also consistent with the expected damped sound mode.

This work, which was recently published in *Physical Review Letters*, represents the first observation of this important interaction in a laboratory plasma.



PLASMA DIAGNOSTICS GROUP

Tony Peebles, Terry Rhodes, Troy Carter

Dr. Jon Hillesheim's paper on "Observation of a critical gradient threshold for electron temperature fluctuations in the DIII-D tokamak" [*Phys. Rev. Lett.* 110, 045003 (2013)] was published. Dr. Hillesheim is a recent UCLA graduate (Fall 2012) having worked on the DIII-D tokamak, a National Fusion Facility was published. This Letter presents the first direct, systematic evidence of a critical gradient threshold in locally measured turbulence characteristics in the core of a high temperature fusion research tokamak. It is an important step forward in establishing the physics basis for first principles simulations of transport in magnetic fusion plasmas. This paper is based upon Dr. Hillesheim's work while a graduate student at UCLA and utilizes results obtained from the Correlation Electron Cyclotron Emission (CECE) and Doppler backscattering (DBS) systems, which were both developed by the UCLA Plasma Diagnostic group. Dr. Hillesheim presented an Invited Talk on this topic at the 54th Annual Meeting of the APS Division of Plasma Physics, October 29th-November 2, 2012, in Providence, Rhode Island. The paper associated with this talk, "Experimental characterization of multiscale and multifield turbulence as a critical gradient threshold is surpassed in the DIII-D tokamak," was published [*Phys. Plasmas* 20, 056115 (2013)]. Figure 1 shows data from that work demonstrating the simultaneous increase in thermal flux and local turbulent temperature fluctuations with inverse electron temperature scale length. Dr. Hillesheim is currently a staff researcher at Culham Centre for Fusion Energy which is located just south of Oxford in the United Kingdom.

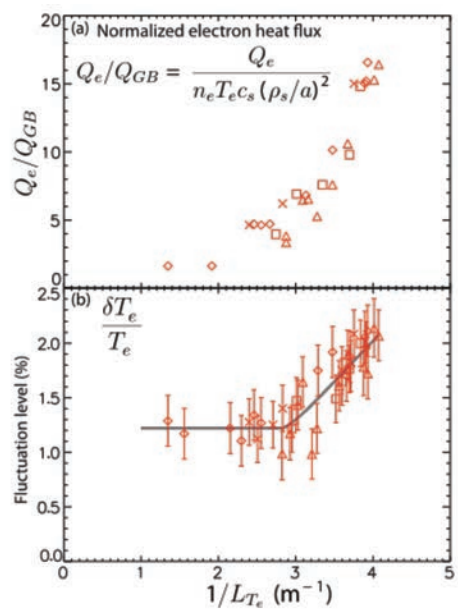


Fig 1. (a) Normalized electron heat flux, at radial location r/a-0.6 vs inverse electron temperature scale length. (b) Electron temperature fluctuation levels as a function of inverse electron temperature scale length.

Prior to this year, UCLA graduate student Jie Zhang successfully fabricated, tested, and installed a mm-wave (288 GHz) polarimeter on the DIII-D tokamak. This diagnostic measures steady state and fluctuating magnetic fields internal to the plasma. During this past year Mr. Zhang performed experiments and obtained final data for his dissertation topic using this diagnostic. During this time, Mr. Zhang also published a paper on "A sensitivity assessment of millimeter-wave polarimetry for measurement of magnetic fluctuations associated with microtearing modes in NSTX-U" [*Plasma Phys. Control. Fusion* 55 (2013) 045011]. In this paper, Mr. Zhang assessed whether a mm-wave polarimeter system will have sufficient sensitivity to observe microtearing modes in NSTX-U. He developed a synthetic diagnostic code to determine the expected phase fluctuation level. The fluctuating profiles for density and magnetic field generated by a non-linear gyrokinetic simulation were used as input to the code. Results indicate that the polarimeter phase fluctuation level due to the modeled microtearing modes is ≥2º. Utilizing the same model, it was also established that the calculated phase fluctuations are dominated by magnetic, not density fluctuations. These results indicate that the polarimeter planned for NSTX-U should have sufficient sensitivity to observe magnetic fluctuations associated with microtearing modes.

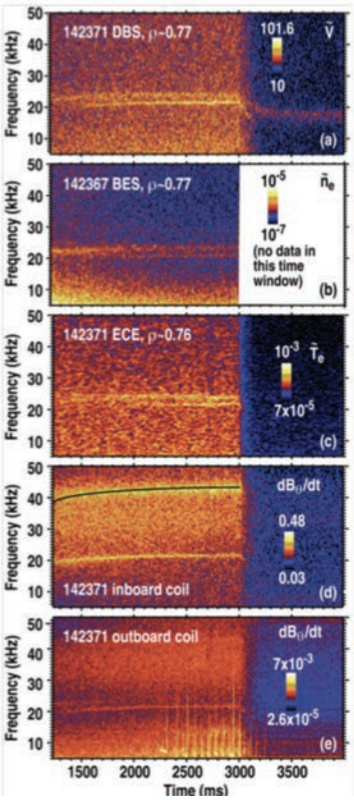


Fig 2. Power spectra vs frequency and time for (a) poloidal velocity fluctuation, (b) density fluctuations, (c) elecron temperature fluctuations, magnetic fluctuations at (d) inboard midplane, and (e) outboard midplane. The black curve in (d) stands for the calculated second harmonic of the GAM. The color map level units in (a)-(e) are in arbitrary units.

Two UCLA papers were presented at the 24th IAEA Fusion Energy Conference in San Diego in October 2012, and included in the proceedings: paper EX/P3-26 by UCLA researcher E.J. Doyle, et al., on "Particle transport results from collisionality scans and perturbative experiments on DIII-D," and paper EX/P7-17 by UCLA researcher L. Schmitz, et al., on "The Role of Zonal Flows and Predator-Prey Oscillations in the Formation of Core and Edge Transport Barriers."

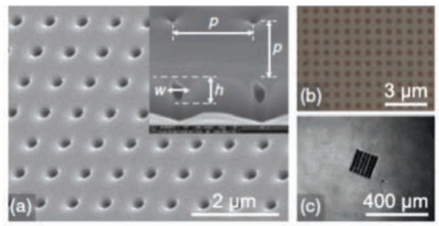
UCLA researcher Dr. Guiding Wang published new measurements on geodesic acoustic modes (GAMs) [*Phys. Plasmas* 20, 092501 (2013)]. GAMs are normal modes of the plasma that are thought to play an important role in regulation of turbulence and transport of heat and particles. In this paper he reports two distinct, simultaneous, radially-overlapping eigenmode GAMs (i.e. constant frequency vs. radius), observed in the poloidal ExB flow. The eigenmode GAMs occupy a normalized radial range of r/a=0.6-0.8 and 0.75-0.95 respectively. These oscillations at the GAM frequency were observed for the first time in multiple parameters (see Fig. 2), including n_e, T_e, and B_q. The magnitude of normalized Te fluctuations (comparable to ñ/n) and measured n_e-T_e cross-phase (~140º at the GAM frequency) together indicate that the GAM pressure perturbation is not determined solely by ñ. The magnetic GAM behavior, a feature only rarely reported, is significantly stronger (x18) on the high-field side of the tokamak, suggesting, for the first time, an anti-ballooning type nature. Finally, the GAM is also observed to directly modify intermediate-wavenumber ñ levels. These non-local eigenmode GAMs exist where first principles transport simulations have experienced difficulty reproducing measured fluctuations and transport.

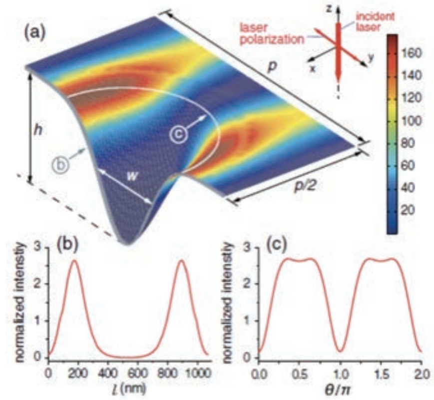
THE PEGASUS PHOTOINJECTOR LABORATORY

Pietro Musumeci

The UCLA Pegasus Laboratory led by Pietro Musumeci has pioneered the use of nano-engineered cathodes in an RF photoinjector. By applying nanoplasmonics concepts and using nanofabrication techniques to pattern a square array of nanoholes on the surface of a copper cathode, we demonstrated how it is possible to control and shape the optical response of a metal surface and signifcantly improve its photoemission properties.

A novel application enabled by the quality of the electron beams generated at Pegasus is ultrafast electron diffraction. A workshop was organized December 12-14th 2012 by UCLA by Pietro Musumeci in collaboration with X.J. Wang from Brookhaven National Laboratory on the topic of Ultrafast Electron Sources for Diffraction and Microscopy. A link to the workshop program, attendees list and to all the presentations can be found at *http://pbpl.physics.ucla.edu/UESDM_2012/*. This was the first international workshop on Ultrafast Electron Sources for Diffraction and Microscopy applications. The workshop objectives included informing the broad scientific communities – accelerator, electron scattering and ultrafast science, on the latest development in ultrafast electron sources, and to identify critical technologies and high impact scientific opportunities.





Left: (a) Scanning electron microscopy images of the nanohole array. Inset: Zoomed-in cut view of the nanoholes. (b) Nanohole array under an optical microscopy with off-resonance visible light. (c) A nanopattern consisting of 6-by-6 25 um square patches illuminated at resonant laser wavelength. Right: (a) Intensity distribution on the nanohole surface. The lineouts of I along the metal-vacuum boundaries in the x = 0 plane (curve b, gray line) and z = -14 nm plane (curve c, white line) are shown in (b) and (c), respectively, both normalized by the average intensity over the entire surface.

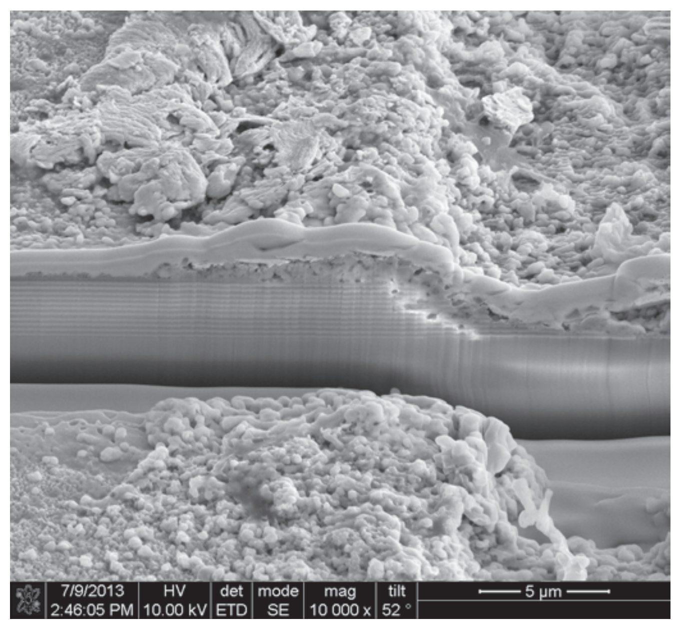
BEAM PHYSICS

Gil Travish

This past year the team has demonstrated preliminary acceleration in an optical scale structure. While this experimental result awaits validation, our collaborators at SLAC have detailed results on their Dielectric Laser Accelerator (DLA). The DLA promises to bring GeV/m gradients and wafer-scale particle accelerators. A publication in Nature has been accepted, with team members Esin Sozer, Josh McNeur and Gil Travish as co-authors.

This past year also witnessed the graduation of three undergraduate students: Nestor Carranza (industry); Alexander Lin (University of Arizona); and Josh Cutler (UC San Diego). The work has been supported by a fifth and final year of funding from the Defense Threat Reduction Agency (DTRA). The future of the program is uncertain as further funding is being sought. Strange memories on this nervous night in the accelerator lab. Five years later? Six? …And that, I think, was the handle – that sense of inevitable victory over the forces of nature and physics. We had all the momentum; we were riding the crest of a high and beautiful wave.…

So now, less than five years later, you can go up on a steep hill in Los Angeles and look west, and with the right kind of eyes you can almost see the high-laser-field mark – that place where the wave finally broke and rolled back.



Fear and Loathing in Accelerator Land: an optical scale accelerating structure undergoes destructive damage threshold testing. The layers visible in this scanning electron microscope (SEM) image are the dielectric thin films that make up the accelerator. The pitted surface is a thin conducting layer of gold, which conforms to the surface profile. The ablated material is visible on the upper right portion of the image.

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So Takei
John Tonge
Michail Tzoufras
Bart Van Compernolle
Gang Wang
Jingwen Wu
Jeffrey Zweerink

New Faculty - Ni Ni

Ni Ni received her Ph.D. in physics from Iowa State University in 2009 for her work on structural/magnetic phase transitions and superconductivity in Ba(Fe1-xTMx)2As2 single crystals.

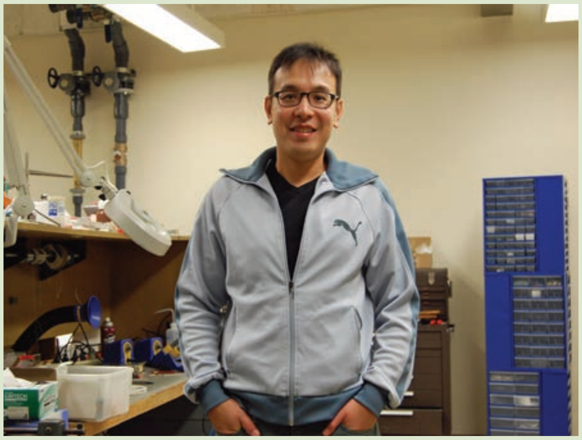
As a postdoc she moved to Princeton University to work with Robert. J. Cava in the Department of Chemistry where she identified and characterized two new high Tc Fe based superconductors. She was the first person to receive a Marie Curie distinguished postdoctoral fellowship at Los Alamos National Laboratory.

She joined our faculty this summer and is pursuing a program of synthesis and characterization of quantum materials.

New Electronics Shop

Electronics are the brains and on the front lines of many, if not all, physics experiments. So the department has launched an electronics shop, serving the entire experimental faculty of the Physical Science Division, led by Senior Development Engineer Peter Yu who arrived in July 2012.

Peter has carved out a large new space on the A-level floor of Knudsen Hall. He has already designed and built custom electronics for many areas of physics, astronomy and chemistry including complex high voltage controllers for the study molecules, fast triggering electronics for high-energy gamma-ray astrophysics and sensitive amplification of atomic-force microscope signals. Peter is often found advising graduate students and postdocs on their electronics questions. In addition he keeps the electronics of the teaching labs in good working order.

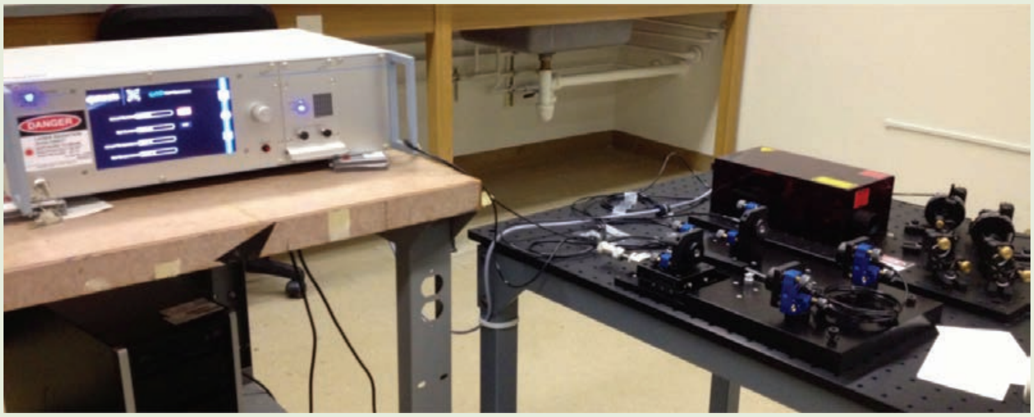


He has recently been joined by two work-study students who receive invaluable on-the-job training and benefit from Peter's deep knowledge while supporting experimental efforts in the department. We are working on expanding the shop with a full time junior development engineer in the new future.

Alumni and friends are invited to help develop the capabilities of the electronics shop, which has a broad impact across the department's teaching and research missions by contacting the chair's office.

A new quantum optics laboratory for undergraduates:

Getting an undergraduate degree in physics typically involves laboratory classes for everything from simple mechanics to electromagnetics, but when we cover, arguably, the most challenging material -- quantum mechanics -- we rely on (often) imprecise thought experiments. Therefore, last year UCLA developed, with a grant from the Cottrell Scholar foundation and a donation from Thor Labs, a new undergraduate laboratory on Quantum Optics (Phys 180Q). This class begins by teaching students practical skills for using modern optics (lasers, cavities, polarization optics, etc.) and culminates in two experiments – (see accompanying figure). Two-photon interference and a test of Bell's inequality -- experiments that can only be explained with quantum mechanics. The long term goal for this class is to continue its development over the next few years until there is sufficient material and equipment to offer it as an optional "lab course" to be taken with the standard quantum mechanics courses -- making UCLA the first institution to have a dedicated lab component for undergraduate quantum mechanics.



Bell's inequality violating machine: Parametric down-conversion of a blue laser beam produces pairs of entangled photons. Measurement of the polarization in non-commuting directions reveals the entanglement and resulting in a violation of Bell's inequality.

UCLA Physical Sciences rated 9th worldwide

The 2012 - 2013 Times Higher Education World University Rankings Physical Sciences judges world class universities across all of their core missions: teaching, research, knowledge transfer and international outlook. The ranking of the world's top 50 universities for physical sciences employs 13 carefully calibrated performance indicators to provide the most comprehensive and balanced comparisons available, trusted by students, academics, university leaders, industry and governments.The Times Higher Education World University Rankings for 2012 - 2013 has placed UCLA Physical Sciences at 9th worldwide (8th in the United States).

Professor Tserkovnyak awarded the Simons Fellowship

Professor Yaroslav Tserkovnyak has been awarded the prestigious Simons Fellowship for his work in theoretical physics. The Simons Graduate Fellowships will identify and support these stars.

Airforce Young Investigator Research Program grant

Wes Campbell has been awarded this prestigious Airforce Young Investigator Research Program grant for exceptional ability and promise in basic research. Professor Cambell's research uses ultra-cold atoms and molecules to learn about the physical processes that permeate our world.

First Moossa J. Arman Physics Colloquium: Science and Innovation

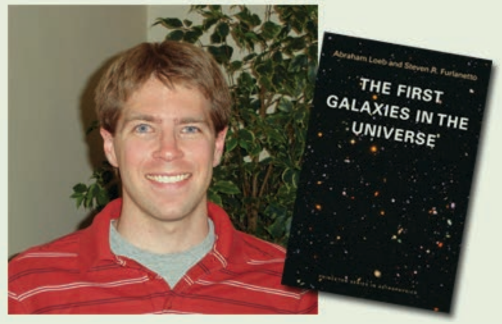
On May 29, 2013 we held the first Moossa J. Arman Physics Colloquium: Science and Innovation. This colloquium series was established by a generous gift in memory of Dr. Moossa J. Arman, an alumnus of our department, to highlight innovations in the area of physics and materials science, innovations that have a major impact to society. Stuart S. P. Parkin was invited to give the inaugural colloquium at CNSI. Dr. Parkin is an IBM Fellow (IBM's highest technical honor), Manager of the Magnetoelectronics group at the IBM Almaden Research Center, and a consulting professor in the Department of Applied Physics at Stanford University.

Asteroid is named for UCLA's Ian McLean

Ian McLean, director of UCLA's Infrared Laboratory for Astrophysics, has received many honors in his distinguished career. Now he has an asteroid named after him. McLean was chosen the namesake of Asteroid #249544 (2010 HQ44) at a recent Scientific Detector Workshop 2013.

"The First Galaxies in the Universe"

Astronomy professor Steven Furlanetto and colleague Abraham Loeb have written a new book, *The First Galaxies in the Universe*, now available



Professor wins prestigious Sloan Fellowship 2013

Rahul Roy, Assistant Professor of Physics, has been awarded the prestigious 2013 Sloan Research Fellowship for recognition of outstanding scholarship.

Professor Rene Ong and Vladimir Vassiliev win NSF grant

Rene Ong and Vladimir Vassiliev won a major NSF grant entitled "Development of a Novel Telescope for Very High-Energy Gamma-Ray Astrophysics." Although there are many collaborators on this project, UCLA is the lead and the telescope design comes from Vladimir's early pioneering efforts with this kind of optical design.

Andrea Ghez was named one the 25 most influential people in space by *Time* magazine http://issuu.com/bobjacobs/docs/timespace. Professor Ghez also received the University of Chicago's Distinguished Alumni Award (May 2013).

UCLA ASTRONOMY LIVE!

UCLA's astronomy outreach program, Astronomy Live!, has had a very successful fourth year of graduate student led community outreach, and our fifth year is continuing this success! During the 2012-2013 school year, we coordinated activities with seven different schools throughout Los Angeles county, visited a public library, had a star-gazing event with the Girl Scouts of Greater Los Angeles, and participated in the STAR Eco Station Earth Day. We also coordinated a visit to UCLA for ~100 students from Anatola Elementary in Van Nuys. These visits have been hugely successful, and we have a long list of schools that have requested visits in the future! Outreach events are initiated by requests from the teachers, through our webpage, and from our department staff directly.

On November 10th, 2012 and November 17, 2013, we hosted the fourth and fifth annual Exploring Your Universe events. These free public events included talks, demonstrations, exhibits, and hands-on activities from volunteers in over 18 deartments and student groups. This event has grown dramatically over the past few years and has tripled since it's inaugural year. Visitors come from all over the Los Angeles area, including many students, staff, and faculty of local schools and UCLA.

In addition, the UCLA Planetarium has had another very successful year. The graduate student-led planetarium saw 153 shows given over the 2012-2013 school year, with ovper 5,075 attendees and 27 different schools. It played a major role in two events--Observe the Moon Night, which was held in conjunction with the Institute for Planets and Exoplanets (iPLEX) on October 21, 2012, and UCLA Bruin Day for incoming undergraduates on April 13, 2013. Of special note, this was the first year that the planetarium exceeded 5,000 attendees since records started being kept in 2002.

REU 2013

Summer 2013 saw the 11th year of the NSF-sponsored Physics & Astronomy REU (Research Experience for Undergraduates) program at UCLA. Fourteen students, chosen out of 440 applications from every corner of the country, assembled for an intensive 10-week immersion in research, supervised by some of the best faculty in our department. To date UCLA has hosted 147 students through this program, many of whom are students from colleges which offer little or no research opportunities. Nearly all of these students have gone on to pursue graduate studies in STEM fields.

Each student worked on a different, well-defined science project, each overseen by a separate faculty mentor. All projects are meaningful and entail "real" frontier level research. The program also includes other academic and social activities, all in an effort to maximize the research experience and the amount of learning as well as to create a sense of community for the students.

The goals of the program are to give students a taste of what a research career might be and a sense of science as a community enterprise and thus to entice them to pursue graduate studies in physics or a related science field.

This program has been extremely successful and constitutes a major outreach effort on the part of the department. The REU program performs a real public service and demonstrates the commitment the department has shown in fostering a new generation of scientists in this country.

Physics & Astronomy Graduation Ceremony, June 15, Schoenberg Hall

Guest Speaker Raymond Orbach

"Enthusiasm for learning and discovery is a hallmark of the UCLA campus. The spirit and enjoyment of the UCLA experience make it a magnet for students and faculty. The quality of its academic programs set a high level of excellence that has inspired me throughout my research and service career." Ray Orbach

Respected theoretical physicist Raymond Orbach served as provost of the UCLA College of Letters and Science from 1982 to 1992, and is the former chancellor of UC Riverside (1992-2002). He is the founding director of the Energy Institute at the University of Texas at Austin (UT), and holds joint faculty appointments in UT's mechanical engineering department, physics department, and the Jackson School of Geosciences.

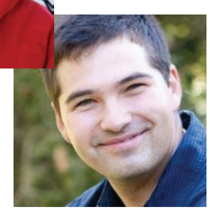
Orbach is the former head of the Office of Science at the Department of Energy (DOE), and was sworn in as the Department of Energy's first under secretary for science in June 2006. In this role he was responsible for implementing the President's American Competitiveness Initiative, designed to help drive continued economic growth in the United States. He spearheaded the DOE's efforts to transfer technologies from its national laboratories to the global marketplace.

He received a bachelor's degree in physics from the California Institute of Technology and a Ph.D. in physics from the University of California, Berkeley. Before joining the UCLA physics faculty in 1966, he was a postdoctoral fellow at Oxford University and assistant professor of applied physics at Harvard. His has published more than 240 scientific articles on theoretical and experimental physics. He is a fellow of the American Physical Society and the American Association for the Advancement of Science.

Ray Orbach

Physics and Astronomy alumni highlights

Abby Vieregg (formerly Goodhue) UCLA Graduate Student 2011 was recently hired for a tenure track position at the University of Chicago. Congratulations to Abby.



UCLA graduate student Cheyne Scoby has been hired by SpaceX. SpaceX designs, manufactures and launches advanced rockets and spacecraft. The company was founded in 2002 to revolutionize space technology, with the ultimate goal of enabling people to live on other planets. Another one of our graduates (Cheyne Scoby) is working at SpaceX.

Graduate Student News 2013-2014

During the application period for the 2013-2014 academic year, something unexpected happened. Physics & Astronomy successfully recruited 41 new graduate students — more than at any time since the 1980s.

You can enhance academic life for these talented individuals with your gift. Your donation can help with almost every part of their experience at UCLA, from advanced studies to research and scholarships.

Each gift, of any size, counts. You can make a difference in the professional lives of these new students. Express your commitment to academic excellence with your support.

Bachelor of Science in Physics

Antrim, Daniel
Bernal, Ivan
Brackbill, Nora
Bruitago, Jorge
Campbell, Jeffrey
Cassero, Sean
Cesar, David
Chu, Matthew
Coleman, Royce
Cutler, Joshua
Escobar, Erika
Fillingham, Sean
Fitzgerald, Mic
Frontiere, Nicolas
Gordon, Dante
Guice, Daniel
Hernandez, Julio
Hill, Daniel
Hsu, Henry
Huang, Andy
Kim, Byung
Kim, Joshua
Lee, Christopher R.
Lee, Christopher H.
Lim, David
Lin, Alexander
Lins-Odonnel, Nicholas
Mehta, Nikhil
Monroe-Martinez, Karina
Nakasawa, Raito
Nashelskiy, Oleg
Ng, Amos
Ourfalian, Armen
Peck, Andrew
Plumb-Reyes, Thomas
Roycroft, Rebecca
Ruiz, Harrison
Sanchez, Daniel
Snyder, Evan
Tran, Son
Taimourzadh, Sam
Threlkeld, Evan
Tran, Son
Vega, Ricardo
Wong, Vincent
Woodruff, Sam
Zhang, Tiany
Zhang, Zhuo

BA in Physics

McIntyre,Viviana
Maupin, Brandon
Pham, Vincent
Wukmer, Lucas

Biophysics

Cheng, Ya-Yun
Kirchhoff,Kevin
Le, Jenny
Madrid, Marinna
Sung, Lilly
Topchian, Marianna
Torres, Johnny
Yuan, Yuan

Astrophysics

Alcazar, Ronald
Ancheta, Agnes
Arulanatham, Nicole
Cheng, Carina
Hong, Sabrina
Hsyu, Tiffany
Jung, Chan Young
Lewis, John
Mileski, Dave
Nabeshima, Misaki
Pirez, Eylene
Schaul, Dylan
Sohn, Ji Man
Trujillo, Rafael

Awards for 2012-13

Rudnick-Abelmann Scholarship

Gavin Edward Carlson

Paokuan Chin

Jeffrey Schwartz

Li-Chia Tai

Winstein Award

Dante Rafael Gordon

Charles Geofffrey Hilton Award

Carina Cheng

E. Lee Kinsey Prize

Nora Brackbill

Nicholas Frontiere

Dante Gordon receiving Winstein Award from Professor David Saltzberg.

Doctor of Philosophy
Astronomy

Julia Fang
Advisor: *Jean-Luc Margot*

Kristin Kulas
Advisor: *Ian McLean*

Elisabeth Mills
Advisor: *Mark Morris*

Doctor of Philosophy
Physics

John Abraham
Advisor: *Gary Williams*

Daniel Aharoni
Advisor: *Katsushi Arisaka*

Timothy Arlen
Advisor: *Vladimir Vassiliev*

Brandon Buckley
Advisor: *Eric Hudson & Bahram Jalali (EE)*

Chien-Chun Chen
Advisor: *John Miao*

Kuang Chen
Advisor: *Eric Hudson*

Zhiping Chen
Advisor: *Mayank Mehta*

Keri Dixon
Advisor: *Steven Furlanetto*

Christopher Farrell
Advisor: *Jay Hauser*

Albert Kao
Advisor: *Dolores Bozovic*

Kevin Lung
Advisor: *Katsushi Arisaka*

Agostino Marinelli
Advisor: *James Rosenzweig*

Finn O'Shea
Advisor: *James Rosenzweig*

Hong Pan
Advisor: *Hongwen Jiang*

Koji Sato
Advisor: *Yaroslav Tsrkovnyak*

David Schaffner
Advisor: *Troy Carter*

Scott Singer
Advisor: *B. Chris Regan*

Bernard Willers
Advisor: *Katsushi Arisaka*

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