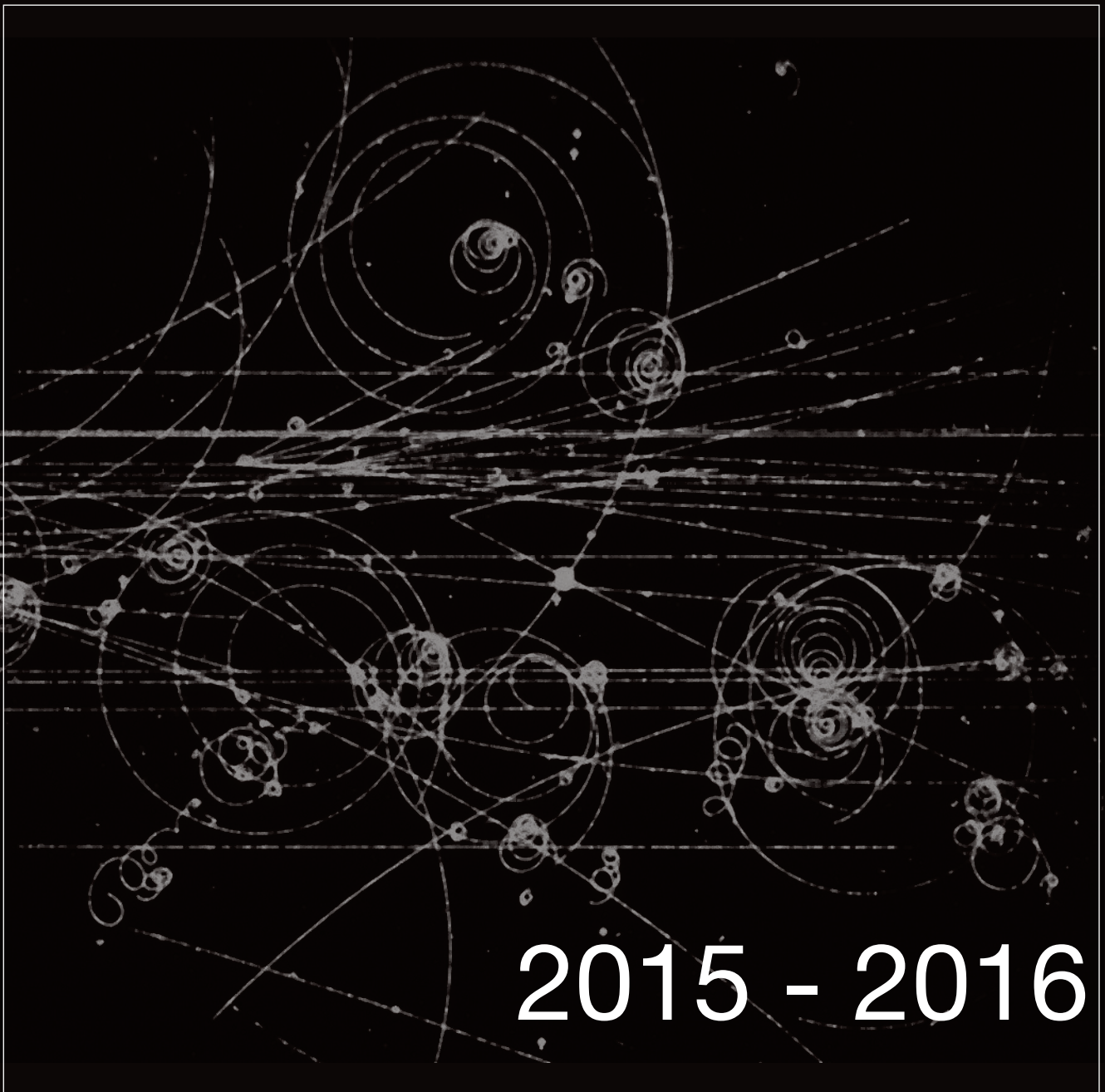


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2015 - 2016

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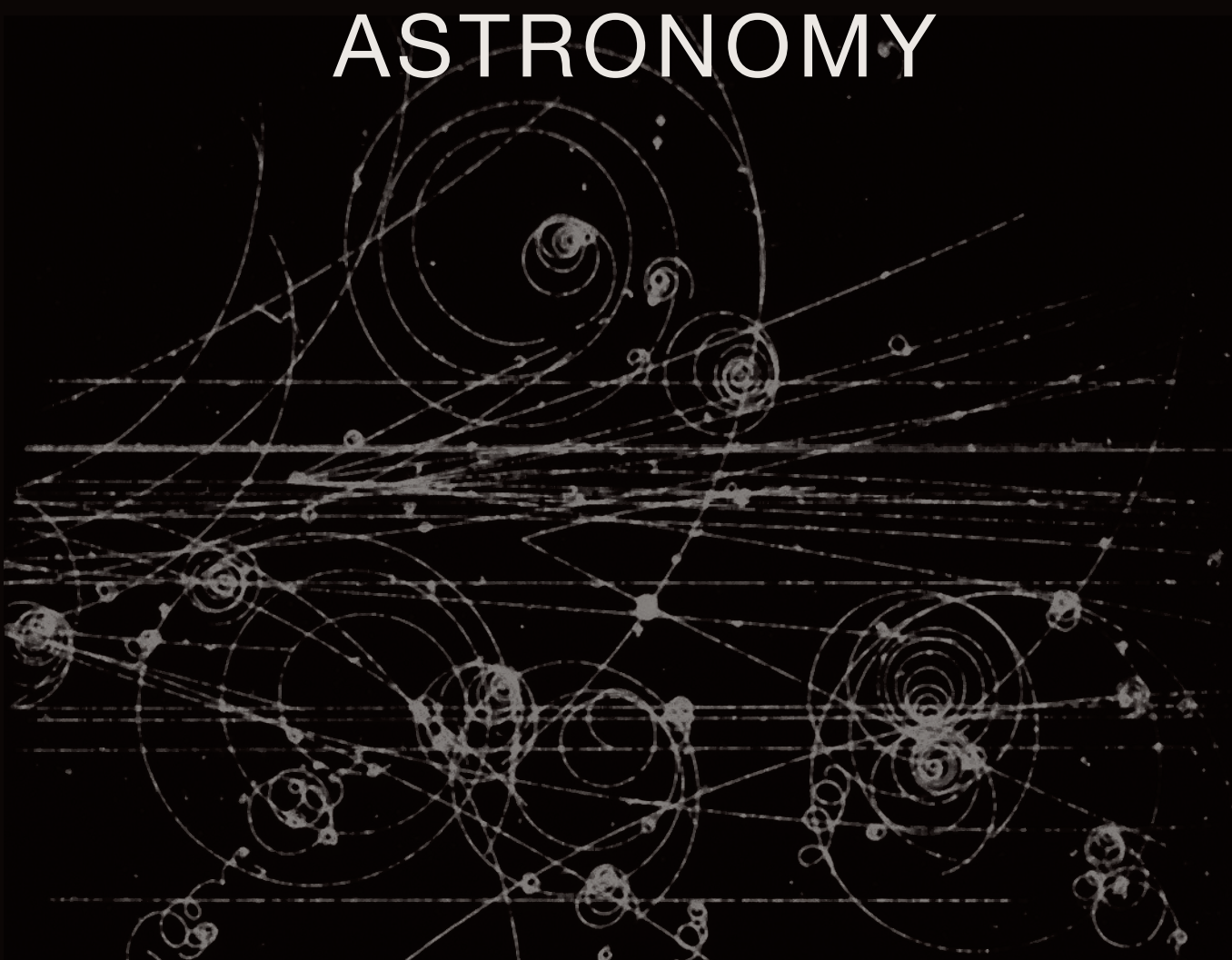
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DEPARTMENT OF PHYSICS & ASTRONOMY



ANNUAL REPORT

2015 - 2016

UNIVERSITY OF CALIFORNIA, LOS ANGELES

FEATURE ARTICLE:

Mani L. Bhaumik Institute For Theoretical Physics Department of Physics & Astronomy starts New Theoretical Physics Institute	6
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DONORS AND ALUMNI:

Donor Impact Story: Arthur Levine and Lauren Leichtman	12
List of Donors	13

ASTRONOMY

INFRARED LABORATORY GROUP: Ian McLean, James Larkin, Michael Fitzgerald	17
ASTRONOMY & ASTROPHYSICS RESEARCH HIGHLIGHTS	20

PHYSICS RESEARCH HIGHLIGHTS

NATIONAL SCIENCE FOUNDATION SCIENCE AND TECHNOLOGY CENTER Deputy Director: Jianwei (John) Miao	29
PHYSICS RESEARCH HIGHLIGHTS	31

FACULTY

NEW FACULTY: Professor Michail Bachtis	57
LIST OF FACULTY/RESEARCHERS/PROJECT SCIENTISTS	58

IN MEMORIAM

Maha Ashour-Abdalla	59
Michael Jura	60

OUTREACH

Astronomy Live!	61
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NEWS

Physics & Astronomy News	62
2016 GRADUATION KEYNOTE SPEAKER: Charles Woo	63
Research Experience for Undergraduates (REU)	63

Chair's Message

The 2015-16 academic year was a period of great change for the Department of Physics and Astronomy, led by events featured in this annual report. The path forward is a promising one, thanks to the efforts of our faculty, staff, and students and the generosity of our many friends and donors.



Jean Turner, Chair

The leading event of the past year was the establishment of the Mani L. Bhaumik Institute for Theoretical Physics. We are enormously grateful to Dr. Bhaumik for his generous gift, and to the many people on campus who helped to realize the new center on campus. The Bhaumik gift, largest to date in the Division of Physical Sciences, will enable sponsorship of visiting scholars, seminars, and postdoctoral fellows. It will fund outreach efforts, such as the highly successful Exploring Your Universe. Professor Zvi Bern is the first Director of the Bhaumik Institute and Emeritus Professor Joe Rudnick chairs the first Board of Advisors.

The Department is grateful to Lauren Leichtman and Arthur Levine for their continuing support of the research of Professor Andrea Ghez in her Galactic Center research. We also thank the Arman family for sponsoring the Moossa J. Arman colloquium series, which brought University of California Observatories Director Claire Max to lecture on campus in May.

The Eight-Year Review of the department took place this past March. The external review panel noted the tremendous growth in the number of undergraduate degrees, a factor of three over the past 15 years. It has been a challenge to handle this growth, although our current seniors seem very satisfied with the program. The panel also noted our success in generating research funding, reflecting a vibrant research program. The success continues, as it was announced in September that the department is involved in two of the four NSF Science and Technology Centers, the STROBE imaging center, of which John Miao serves as co-PI and Deputy Director, and the Center for Bright Beams.

Among the personnel changes of the past year, we are greatly saddened by the loss of Professors Maha Ashour-Abdalla and Michael Jura. Their obituaries are reproduced in this report. Professors Joe Rudnick and Ned Wright retired this summer. Since Joe is also retiring as Senior Dean for Physical Sciences, we are hoping to see more of him now. We are delighted that Ned was elected to the National Academy of Sciences this year.

Two assistant professors joined the faculty this year. Michalis Bachtis (Experimental Elementary Particle Physics) came to UCLA from a position at CERN. He plans to continue working on the LHC. Zhongbo Kang (Nuclear Physics) recently relocated to UCLA from Los Alamos. His research centers on development of QCD framework and applications in nuclear physics.



James Larkin
Vice Chair Astronomy

Finishing out the academic year, we were greatly honored to have friend and alumnus Charlie Woo as the featured speaker at the 2016 commencement celebration in June. Charlie's inspiring life story and message that "with physics, you can do anything" was well received by students and relatives and an excellent lesson for all.

A handwritten signature in black ink, appearing to read "Jean Turner".

MANI L. BHAUMIK INSTITUTE FOR THEORETICAL PHYSICS

Message from Mani L. Bhaumik



I wish to express my deepest appreciation to UCLA for establishing the Mani L. Bhaumik Institute for Theoretical Physics, fulfilling my long cherished vision. Theoretical physics is at the basis of all fundamental sciences including physics itself. Every great physics department needs to be strong in theoretical physics.

The intuition of giants like Einstein and many others has changed the course of human history. Technology spawned by science has already given us material abundance that our forefathers could only dream of. I believe science, especially theoretical physics, is capable of bringing a greater transformation by enormously broadening our mental horizon. The much anticipated discovery of unification of all forces and matter in the universe at its deepest level would surely have a profound impact in this regard. I am exceptionally happy knowing this is one of the foremost goals of the Institute.

I realize that my modest donation is just seed funding for starting a superb Institute. I hope very much that in the future other like-minded people will see the wisdom of having a theoretical physics institute and help contribute to its expansion into other areas of theoretical physics. I look forward to the day when the Institute will be able to fully support many areas of theoretical physics, including newly emergent ones.

I wish the Institute the best of luck in this glorious endeavor and look forward to great achievements in the coming years.

An \$11 million gift to UCLA from physicist and philanthropist Mani Bhaumik will establish a center devoted to advancing knowledge of the basic laws of nature.



DEPARTMENT OF PHYSICS & ASTRONOMY STARTS NEW THEORETICAL PHYSICS INSTITUTE

The recent formation of the Mani L. Bhaumik Institute for Theoretical Physics at UCLA is a landmark event in the Department of Physics and Astronomy.

In today's environment, with tight funding in fundamental theoretical research, only those universities that have institutes can attract the best minds and most exciting theory research. The top ranked physics departments have theory institutes. The Bhaumik Institute will help us stay competitive.

We are deeply indebted to Dr. Bhaumik for his vision and understanding of the importance of theoretical physics, not only to UCLA, but more generally for all of humanity. While Dr. Bhaumik made his mark on experimental laser physics, his love and appreciation of theoretical physics began long ago, after studying under the renowned theoretical physicist S.N. Bose of "Bose-Einstein" fame. He hopes that his gift will allow others to follow a research path that he was unable to follow.

Theoretical physicists determine the laws of nature and their consequences by constructing mathematical models of physical systems and solving the equations that underlie those models, sometimes aided by computers. This is in contrast to another primary branch of physics, experimental physics, in which scientists use tools and instruments to perform measurements and uncover the behavior of natural systems. At the deepest level, theoretical physicists formulate the laws that govern the world in which we live, providing a basis for the technology, and perhaps even more importantly to satisfy the human thirst for knowledge about the universe we live in.

In the modern era, with instantaneous global communication one might think that a gathering place for theorists to meet and discuss the latest ideas is a thing of the past, replaced by tweets, blogs, e-mails and teleconferences. In fact, it is just as true today that the life-blood of theoretical physics is face-to-face interactions. Institutes for Theoretical Physics have played and will continue to play a crucial role. Nothing is more important than intense face-to-face discussions for spreading and exchanging new cutting-edge ideas. It is the way new advances are made.

In this regard, a primary goal of the Bhaumik Institute is to provide an exceptional environment for theoretical physics research. The Institute provides support for postdoctoral researchers and graduate students. The Institute will also run a robust visitor program, and will host workshops, conferences and public lectures on cutting-edge topics.

In addition, it will host a Bhaumik Lecture series, constructing a library of lectures on a variety of topics from distinguished leaders. The Institute will bring the latest theoretical physics research from around the world to UCLA. It will also promote outreach to the general community via public lectures and other activities.

The Mani L. Bhaumik Institute will be financially stable thanks to an endowment. This will not only provide a stable source of funding, but because of its unrestricted nature allow us to bring cutting-edge programs to UCLA that would not be possible with conventional grants.

The Institute starts from a solid foundation in the Department of Physics and Astronomy. A primary goal is to maintain and expand this excellence. The Institute will initially focus on theoretical particle physics and issues related to the long-standing quest to unify forces and matter. As funding resources are extended, there are plans to expand its programs into a wider variety of cutting-edge areas of theoretical physics, especially to support the research of junior faculty. Membership in the Mani L Bhaumik Institute is open to any person in the theoretical physics community at UCLA.

The Institute will be an exciting place for our students, faculty and postdocs and we can expect it to help the Department recruit the most talented junior faculty to join the UCLA family.

The future has never been brighter.

MANI L. BHAUMIK INSTITUTE FOR THEORETICAL PHYSICS

DIRECTORSHIP



ZVI BERN, Director

The founding director of the Institute is Zvi Bern, who has been a faculty member since 1992. Professor Bern is internationally renowned for his development of innovative approaches to the calculation of fundamental quantities relevant to the interpretation of scattering processes at the subnuclear level. He has also received widespread attention for recent advances in understanding the ultra-high energy properties of gravity theories. His work is characterized by inspired utilization of the most advanced theoretical methods to carry out complex computations of physical importance. He has also worked on developing and applying new ideas for computing and understanding scattering amplitudes to physics at the Large Hadron Colliders.

In 2014, Professor Bern was co-winner of the J.J. Sakurai Prize from the American Physical Society, the highest honor that society bestows for theoretical work in elementary particle physics.



PER KRAUS, Associate Director

Per Kraus joined the faculty as assistant professor in elementary particle theory in 2001. His particular research interest is in string theory as a theory of quantum gravity. Per Kraus comes to UCLA from the University of Chicago where he was a research associate. His educational background includes a doctoral degree in physics from Princeton University, followed by three years as the Lee DuBridge Prize fellow at the California Institute of Technology.

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MANI L BHAUMIK HONORS AND AWARDS

- Sloan Foundation Fellow, 1959.
- Elected fellow of the American Physical Society, 1976.
- Elected fellow of the Institute of Electrical and Electronics Engineers for development of high power lasers and new laser systems, 1982.
- Received honorary D.Sc. for lifetime academic achievement in 1995 from Indian Institute of Technology Kharagpur.
- Received Mahatma Gandhi Humanitarian Award, 2005, from the Indian American Heritage Foundation.
- Received Pravasi Bharatiya Samman Award, one of the most prestigious civilian awards given by the Government of India to honor an exceptionally successful and meritorious Indian residing abroad for his extraordinary contribution, 2010.
- Received the prestigious Padma Shri Award 2011 from Government of India for distinguished service in science and engineering.
- Received Chaudhuri Award for extraordinary achievements in science by California Institute of Integral Studies, San Francisco, May 4, 2013.
- UCLA Established Mani L. Bhaumik Institute for Theoretical Physics in 2016.

Joseph Rudnick, former Dean of Physical Sciences, expresses gratitude to Mani Bhaumik for his remarkable generosity for the establishment of The Mani L. Bhaumik Institute for Theoretical Physics.



Joseph Rudnick and Mani L. Bhaumik attend Lusk Lecture 2014

I have been at UCLA since 1984, and it has been my privilege to serve as Chair of the Department of Physics, then later Chair of the merged Department of Physics and Astronomy and most recently as Dean of the Division of Physical Sciences. All of this has been deeply gratifying, and the founding of the Mani L. Bhaumik Institute of Theoretical Physics in the course of my final year as Dean was to me a capstone, and I believe a harbinger of wonderful things to come in this department, and indeed this great institution.

Theoretical physics has led to profound advances in our understanding of the world in which we live, and fundamental discoveries in physics have impacted both our view of the world and the quality of our lives.

However, for all the importance of the field, philanthropic support of theoretical physics remains a difficult project. Dr. Bhaumik's commitment to fund the Mani L. Bhaumik Institute for Theoretical Physics is remarkable, not only for its generosity, but also for the vision and the depth of understanding that underlies it. Rarely are we given the opportunity to witness such a transformative act, or one with the prospect of such far-reaching import. As Dean of Physical Sciences, it was my pleasure and my privilege to collaborate with Dr. Bhaumik in seeing to it that the Institute will have access to a permanent source of operating funds, and that there will be resources in place at the outset that will allow it to initiate its operations at an appropriate level. Additionally, I am deeply grateful to have been given the opportunity to assist in the work of the Institute through participation in the Advisory Board. Private funding at the level afforded through Dr. Bhaumik's support will allow a scope of action and a freedom to initiate bold and innovative projects that can lead to new insights and unexpected progress in the most challenging and exciting areas of research.

Finally, I want to express my deep appreciation to everyone at UCLA whose efforts have made the founding of the Institute possible, especially founding Director Zvi Bern, Brooke Sanders and the entire Physical Sciences Development team, Physics and Astronomy Chair Jean Turner, and indeed the entire Physics and Astronomy faculty, whose involvement, support and guidance have been essential to the successful establishment of the Institute, and our campus leadership, particularly Chancellor Gene Block and Executive Vice Chancellor and Provost, Scott Waugh. I join them all, and you, the supporters of Physics and Astronomy, in anticipation of an even greater future.



Left to Right: Mani Bhaumik Miguel Garcia-Garibay, Dean of Physical Science and Jean Turner, Chair, Department of Physics and Astronomy at Exploring Your Universe, November 2016

MANI L. BHAUMIK STORY

Mani L. Bhaumik was born in 1931 in a small village in Siuri, Medinipore, West Bengal, India and attended the Krishnaganang krishi silpa vidyalaya school. As a teenager, Bhaumik spent some time with Mahatma Gandhi in his Mahisadal camp. He received a Bachelor of Science degree from Scottish Church College and an M. Sc. from the University of Calcutta. He won the attention of Satyendra Nath Bose (creator of the Bose–Einstein statistics) who encouraged his prodigious curiosity. Bhaumik became the first student to receive Ph.D. degree from the Indian Institute of Technology Kharagpur in history when he received his Ph.D. in quantum physics in 1958. His thesis was on Resonant Electronic Energy Transfers, a subject he would have cause to use in his work with lasers.

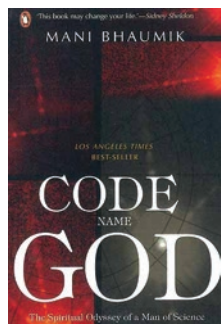
Receiving a Sloan Foundation Fellowship in 1959, Dr. Bhaumik came to the University of California Los Angeles (UCLA) for post doctoral studies. In 1961, he joined the Quantum Electronics Division at Xerox Electro-Optical Systems in Pasadena and began his career as a laser scientist. Concurrently, he taught Quantum physics and Astronomy at the California State University at Long Beach. In 1968, he was enlisted by the Northrop Corporate Research Laboratory, where he rose to become the director of the Laser Technology Laboratory and led a team that made contributions in research on excimer laser technology. One of the papers on this research was presented at the Denver, Colorado meeting of the Optical Society of America in May 1973. At this meeting, Dr. Bhaumik presented substantial evidence to demonstrate for the first time that an excimer laser could be efficient and powerful enough for practical utilization. The application of excimer lasers in Lasik eye surgery has resulted in vision correction in many cases. His significant contributions to the development of new and high power lasers merited his election by his peers to be a fellow of both the American Physical Society and the Institute of Electrical and Electronics Engineers.

As a quantum physicist, Dr. Bhaumik is a co-inventor of excimer laser that made possible the highly popular LASIK eye surgery for 15 million people worldwide. He is an international best selling author. Two of his books, *Code Name God* dealing with science and spirituality and *The Cosmic Detective*--a primer on cosmology for everyone, have been translated into eight different languages. Dr. Mani Bhaumik is the creator and co-executive producer of the award winning animated TV Series, *Cosmic Quantum Ray*. The TV series intended to spark children's interest in quantum physics and cosmology, has been selected as a special public outreach program by IYA2009 declared by UN General Assembly and partially administered by UNESCO.

Dr. Bhaumik has published over fifty papers in various professional journals and is a holder of a dozen laser-related U.S. patents. He has been invited to lecture all over the world, at forums including: Summer School on High-Power Gas Lasers, Capri, Italy 1975; International Symposium on Gas-Flow and Chemical Lasers, Belgium 1978; International Symposium on Gas Discharge Lasers, Grenoble, France 1979; Asoke Sarkar Memorial Lecture, Calcutta International Book Fair 2001; Institute of Culture, Calcutta, India 2006; Kolkata Society for Asian Studies, Kolkata, India 2015.



Mani Bhaumik at UCLA's Exploring Your Universe science festival, an annual outreach event sponsored by the Bhaumik Institute.



DONOR IMPACT STORY: ARTHUR LEVINE AND LAUREN LEICHTMAN

I am thrilled to announce a generous gift from Lauren Leichtman and Arthur Levine which will have a profound impact on my research and the UCLA Galactic Center Group. Lauren and Arthur have pledged additional funding for the Lauren B. Leichtman and Arthur E. Levine Astrophysics Chair, originally established in 2006. I am honored to hold this chair, which will become the first centennial chair in the Division of Physical Sciences.

This gift comes at a critical time for our research group, as we prepare to track star S0-2's closest approach to the supermassive black hole in the Milky Way.

I first met Lauren and Arthur in 2005, not long after I came to UCLA. They have a long history with UCLA, and Arthur is a double Bruin (Philosophy '73, MBA '76). Together, they founded Levine Leichtman Capital Partners (LLCP), a private investment firm. I am forever grateful to them both for transforming what was possible for me to do at UCLA. From day one, they have believed in me and in the importance of my work. Lauren and Arthur are true leaders, and they have consistently encouraged me to think on a completely different scale, to dream big and bold

Andrea Ghez,
Lauren B. Leichtman and Arthur E. Levine Astrophysics Chair
and Professor of Physics and Astronomy



Professor Andrea Ghez with Lauren Leichtman and Arthur Levine.

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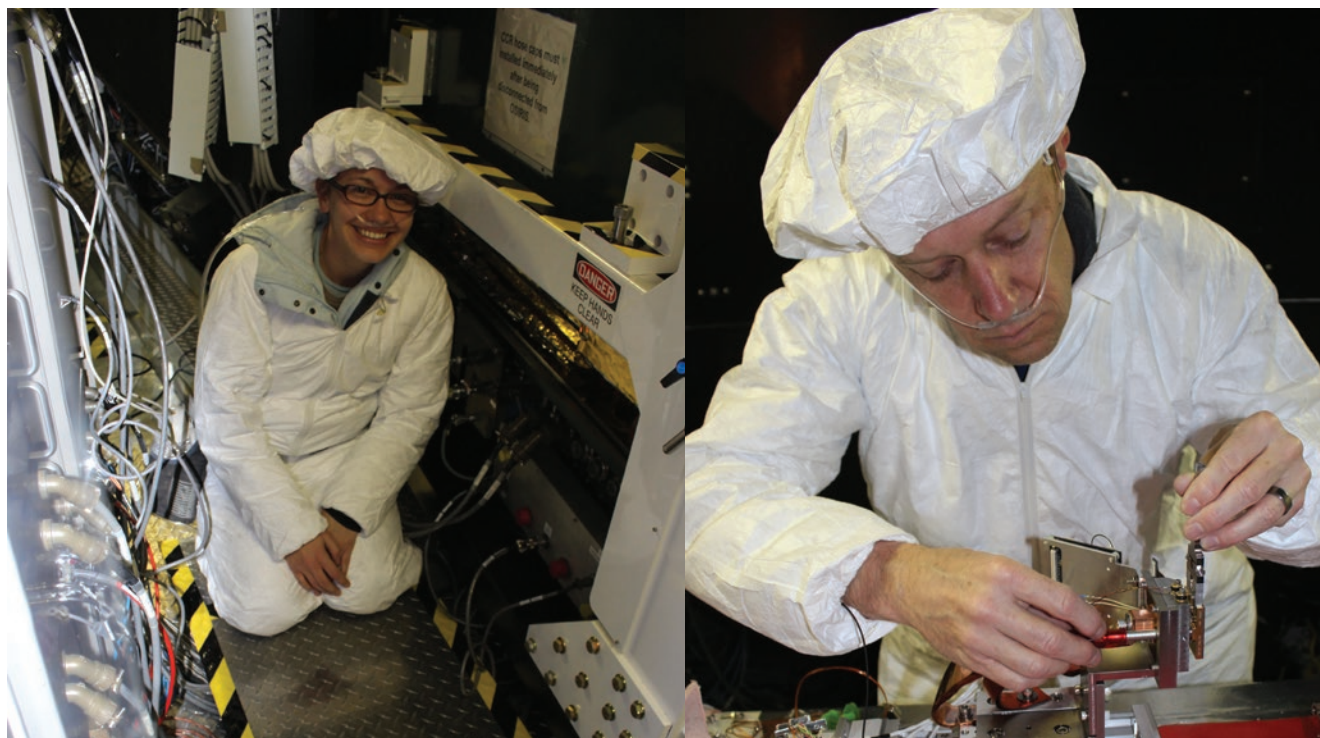
Ian McLean, James Larkin and Mike Fitzgerald

Since its inception, the UCLA Infrared Laboratory for Astrophysics (IR Lab) group has developed and supplied state-of-the-art infrared cameras and spectrometers to many observatories, most especially the twin 10-meter telescopes of the W. M. Keck Observatory on Mauna Kea, Hawaii. UCLA led or contributed to all four of the infrared instruments in current use at the Keck Observatory (NIRSPEC, NIRC2, OSIRIS, and MOSFIRE). NIRSPEC was delivered in 1999, while the most recent addition to the group, MOSFIRE, began operations in 2012. These innovative devices have facilitated numerous discoveries, and resulted in many hundreds of research papers from the entire Keck community. Each instrument is developed for open use in order to maximize scientific return. This approach means that although the work of the instrument builders is well recognized, they are not always coauthors on each research paper.

During the current reporting period the IR Lab performed a major task for the Keck Observatory, the upgrade of the detector for the OSIRIS spectrograph. The principal investigator (PI) for this project is Professor James Larkin, who

also delivered the original instrument in 2005. OSIRIS is a unique and powerful scientific tool in a class known as integral field spectrometers. Operating in conjunction with the observatory's adaptive optics (AO) system to compensate for atmospheric turbulence, OSIRIS provides both images and spectra over the diffraction-limited field of view. Since 2005, better infrared detectors have become available. The new system was delivered in January 2016. This project was supported by the National Science Foundation (NSF). The figure below shows UCLA graduate student Anna Boehle and Professor James Larkin working on the installation of the new detector at the observatory on the 14,000 ft summit of Mauna Kea, Hawaii. Both are wearing O₂ nasal tubes to compensate for the oxygen deficit at high altitude, which can impair thinking, especially for precision work!

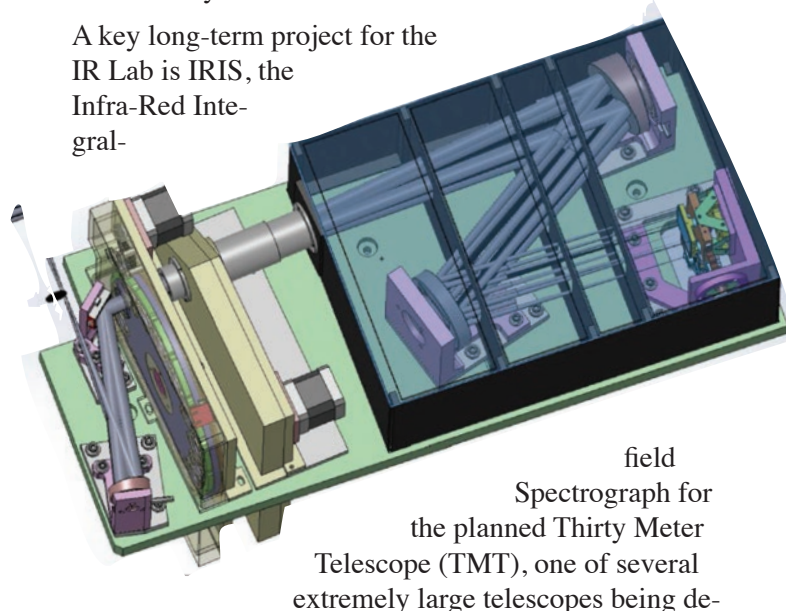
The new 4-megapixel infrared detector from Teledyne Imaging Sensors (Camarillo, CA) offers several important benefits including, lower dark current in the absence of light, no background glow from on-chip amplifiers, and less crosstalk between the 32 discrete output channels. The largest gain however, is a factor of two in sensitiv-



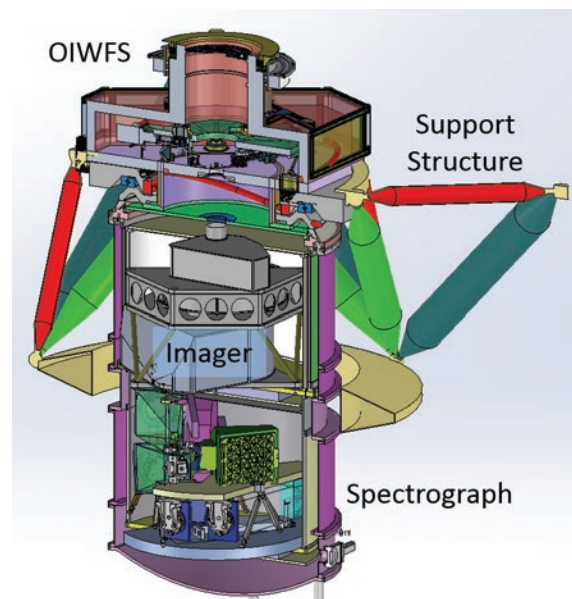
ity at short wavelengths ($\sim 1\mu\text{m}$) due to improvements in quantum efficiency. In February and March this year (2016), James, Anna, and UCLA electronics technician Ken Magnone installed the new system. Contributions to the upgrade were made by several members of our engineering team. Eric Wang designed the mechanical mounts and focus stage for the detector, Jason Weiss and Chris Johnson put together the computers and controllers, and adapted the MOSFIRE software system for the new OSIRIS detector. When combined with the successful upgrade of the spectrometer's diffraction grating two years ago, the raw sensitivity is now roughly 4 times better than at first light in 2005.

With funding from the Moore foundation, an additional modification to OSIRIS got under way. This second upgrade involves a major redesign of the camera (or imager) section of the OSIRIS instrument (PI: Michael Fitzgerald); this section is independent of the spectrograph. A top priority for this upgrade is to provide stable imaging over a $20'' \times 20''$ field of view, with fine sampling more suitable for astrometry – the accurate positional measurement of sources on the sky. Such an improvement will be important for many applications, including observations of stars orbiting the central black hole in the Milky Way galaxy. In addition, the new camera will finely sample image quality over the field and measure the Point Spread Function (PSF) for the spectrometer. The new design will improve sensitivity at the instrument's longer wavelengths (K-band) over the current performance, and also help support the development of the next generation of Adaptive Optics (AO) at the Keck Observatory. The picture below shows a model of the optical and mechanical layout of the new OSIRIS Imager section at the end of the design phase earlier this year.

A key long-term project for the IR Lab is IRIS, the Infra-Red Inte-



veloped within the next decade. Professor James Larkin is principal investigator of the international team tasked with building this huge instrument that will operate at the diffraction limit and provide unprecedented detail on objects ranging from the solar system to the galactic center to the high redshift universe. The primary goal of the current phase of development was to achieve preliminary design of all optical subsystems, all internal mechanisms, and the overall vacuum cryogenic system. However, with continued delays to the 30-m telescope construction effort, we have also been able to develop the software and electronics portions of the instrument to the same level; both of these activities are led by UCLA. The spectrograph has three tip/tilt probe arms that must interact in real time with the rest of the instrument, and with the TMT adaptive optics system. IRIS is therefore much more of an integrated piece of the telescope + AO + instrument system, than a stand-alone instrument. As a result, there are a myriad of software interfaces that must be understood and addressed. The current layout of the instrument is shown in the figure below.



IRIS covers the wavelength range 0.84-2.4 microns. Three on-instrument deployable wavefront sensors (OIWFS) work in the near-infrared to gain from the AO correction. The spectrograph section provides a base resolving power of $\sim 4,000$ (8,000 in some modes) and the Integral Field Spectrograph (IFS) comes with four plate scales (0.004, 0.009, 0.025, 0.050 arcsec per sample). The IRIS imager provides a 34 arcsec field of view using a 2×2 grid of $4K \times 4K$ (H4RG) HgCdTe detectors from Teledyne. The plate scale is 0.004 arcsec per pixel.

In late June of 2015 our FLITECAM instrument (PI: Ian McLean) was deployed to New Zealand on board NASA's

Stratospheric Observatory for Infrared Astronomy (SOFIA) to capture an occultation of a bright star by Pluto. This rare event happened just 14 days before the New Horizons spacecraft performed the first ever Pluto flyby, and provided advance evidence of a thin, hazy atmosphere. Additional flights were carried out in October 2015, and the FLITECAM instrument was formally accepted as a SOFIA facility by NASA, thus bringing this project to a successful conclusion. UCLA graduate student Sarah Logsdon was on both missions in 2015. Sarah is one of only a small number of graduate students to fly on SOFIA. To complete our guaranteed observing time, UCLA has six science flights planned for October 2016.

In collaboration with Keck Observatory, UCLA (PI: Michael Fitzgerald) submitted a proposal to the NSF in January 2015 for the upgrade of the NIRSPEC instrument at Keck Observatory. As mentioned, NIRSPEC was originally delivered by UCLA in 1999 (PI: Ian McLean). Funding was approved by NSF in October 2015. The project to replace the 1990s era detector systems is now well under way. Both

the spectrograph and the slit-viewing camera system will be upgraded. A prototype for the new spectrograph detector is currently under test, and the optical design for a new slit-viewing camera is being developed. UCLA graduate student Emily Martin is working on both of these aspects of the project.

The IR Lab also contributed software expertise to the Keck Cosmic Web Imager (KCWI) instrument, which is led by Caltech and due for delivery to Keck Observatory later this year. Professor Fitzgerald is also participating in the Heising-Simons Foundation funded effort (PI: Mawet, Caltech) to add a fiber optic interface to NIRSPEC from the adaptive optics bench, and a proposal from Caltech/JPL to add a laser comb to the NIRSPEC calibration unit. Finally, the UCLA IR Lab hosted the annual Keck Science Meeting at UCLA in September 2015.



IAN MCLEAN continued as Director of the Infrared Lab, and Associate Director for the University of California Observatories (UCO). He stepped down on September 30, 2015 as Vice Chair of Astronomy after six years in that role. He took over the role of Vice Chair for Academic Affairs on July 1, 2016. During this reporting period, McLean supported graduate students Sarah Logsdon and Emily Martin. 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. He uses the NIRSPEC and MOSFIRE instruments at the Keck Observatory, and the FLITECAM instrument on NASA's SOFIA. In June 2016 the Astronomical Society of the Pacific announced that professors Ian McLean (UCLA) and Chuck Steidel (Caltech) will receive the 2016 Maria and Eric Muhlmann Award for innovation in astronomical instrumentation for their work on MOSFIRE for the Keck Observatory.



JAMES LARKIN became Vice Chair for Astronomy on October 1, 2015, and continued as Deputy Director of the Infrared Lab. His research 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 California, San Diego) 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 also supports graduate student Anna Boehle, who worked on the OSIRIS upgrade as well as imaging spectroscopy of nearby active galaxies.



MICHAEL 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 current graduate students Li-Wei Hung, and Pauline Arriaga to develop and apply high-contrast imaging techniques to these systems. He is now applying these methods to observations with the Gemini Planet Imager, and received NSF funding to support this research. Meanwhile, he is also leading the upgrade of the OSIRIS imager for the Keck Observatory and the recently funded upgrade for NIRSPEC. He is also working with Professor Ghez's group to model the field-dependent aberrations in Keck AO imaging via the AO Optimization project.

OBSERVATIONAL COSMOLOGY, GALAXY FORMATION, AND SUPERMASSIVE BLACK HOLES

Tommaso Treu's group

Professor Treu's group has been continuing to pursue three major research areas. The first one is galaxy formation and evolution from first light to the present day universe. The second one is observational cosmology, i.e. the measurement of the fundamental constituents of the universe, from the properties of dark matter and dark energy to spatial curvature and neutrino content. The third one is supermassive black holes. Prof Treu's interests are mainly focused on their formation and evolution across cosmic time and the role they play in the evolution of galaxies.

In galaxy formation and evolution, the main results are in the context of the Grism Lens Amplified Survey from Space (GLASS; glass.astro.ucla.edu), led by Professor Treu, and including UCLA Professor Malkan, UCLA post-doc Louis Abramson, and UCLA graduate students Xin Wang, Charlotte Mason, and Takahiro Morishita. Mason was awarded a prestigious NASA Earth and Space Science Fellowship to support her work. Among the many highlights of this survey two were the subject of press releases. The first one was the successful prediction of the re-appearance of supernova Refsdal. Multiple images of the supernova were discovered in November 2014 in GLASS Hubble Space Telescope data. The multiple images are due to the presence of a foreground massive cluster of galaxies

that acts as a giant cosmic lens. Multiple team coordinated by Prof Treu predicted in October 2015 that an additional image of the supernova would appear towards the end of 2015. The supernova image appeared as predicted in December 2015. This is the first time ever that the timing and location of a supernova image has been predicted and it is a powerful test of general relativity (<https://www.spacetelescope.org/news/heic1525/>). The second highlight is the discovery of the faintest known galaxy at $z \sim 7$, again multiply imaged by a foreground cluster of galaxies http://www.keckobservatory.org/recent/entry/faintest_early_universe_galaxy_ever_detected_and_confirmed).

In observational cosmology, the group has been working on using gravitationally lensed quasars (instances where multiple images of a quasar are observed due to the lensing effect of an intervening quasar). The team includes UCLA graduate students Daniel Gilman, Peter Williams, Anowar Shajib and Xuheng Ding, undergraduate Cicero-Xinyu Lu as well as former UCLA postdoc Adriano Agnello. A major highlight of this work has been the determination of cosmological parameters from time delays with unprecedented accuracy, achieving a 3.8% precision on the expansion rate of the universe (the Hubble constant). This measurement is in mild tension with the

standard cosmological model as measurement by cosmic microwave background experiments, and if confirmed to greater accuracy it could lead to discovery of new physics. Another highlight has been the discovery of the first lensed quasars found in the Dark Energy Survey (strides.astro.ucla.edu).

In the field of supermassive black holes the two main highlights have been the undertaking of major campaign to measure masses of black holes in the local universe using the 3m Shane Telescope at the Lick Observatory, and the first measurement of a black hole mass using robotic telescopes. The team includes UCLA Professor Malkan and graduate students Xuheng Ding and Peter Williams.

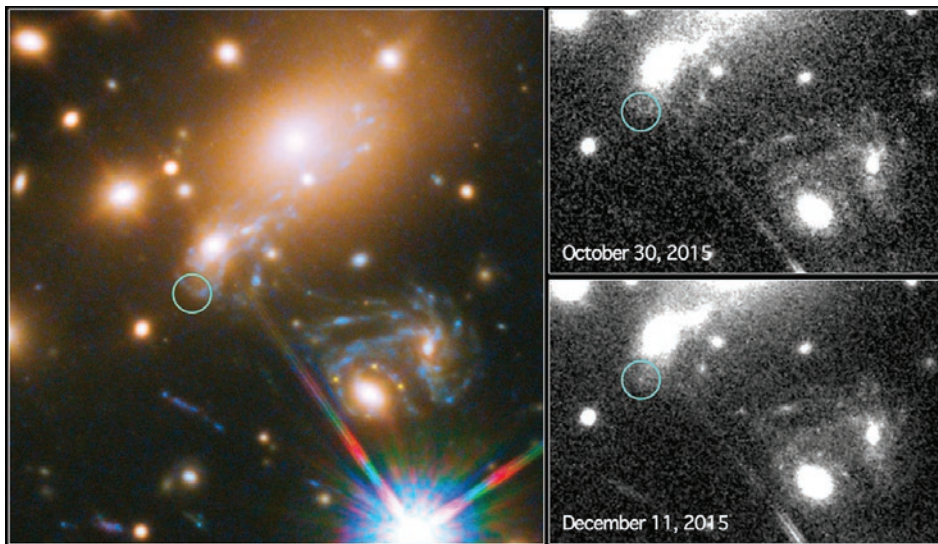


Figure 1: Images of supernova Refsdal, obtained by the NASA/ESA Hubble Space Telescope. The image to the left shows an image based on data taken prior to December 2015. The right panels zoom in the region where the supernova reappearance was successfully predicted.

Matt Malkan

The Universe Going Green

Galaxies in the young universe were forming stars at much higher rates (ten to a hundred times) than their modern-day counterparts such as our Milky Way. The interstellar gas that provided the raw material for this intense activity was much closer to primordial composition. This leads most researchers over the last few decades, including Malkan and his collaborators, to assume that the strongest spectral features in young galaxies--the key to finding and then analyzing them--were produced by hydrogen. That is by far the most abundant product of the Big Bang, and can easily be spotted by the pinkish glow it produces when irradiated by young stars (as in the Orion Nebula, left hand figure).



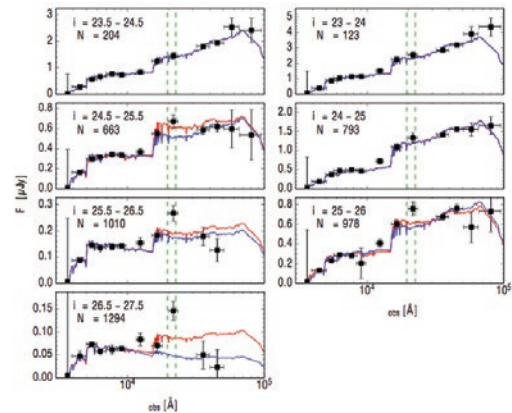
However, Malkan and several other researchers discovered a growing number of distant galaxies in which the strongest emission line is from doubly ionized oxygen, not hydrogen. Its wavelength, 500.7 nm, makes the striking green color that



is seen in so-called planetary nebulae (misnamed because their greenish color resembled that of planets Uranus and Neptune, for completely different reasons). It takes highly energetic photons (above 54 electron volts) to knock off (ionize) the second electron from oxygen. Very few such

photons are produced by the hot young stars seen today in the Milky Way. However, they ARE produced by much hotter stars such as those found in the center of planetary nebula. Although the explanation for WHY the universe was going green is still under intensive investigation, Malkan and colleagues suspect that it is because young stars were looking hotter in the earlier phases of galaxy evolution. More of them were--effectively--like the hot central stars in planetary nebulae (albeit with very different origins).

In 2016, an analysis of many thousands of distant galaxies in the Subaru Deep Field with graduate student Daniel Cohen found that **ALL** small galaxies are surprisingly strong emitters of the green 500.7nm oxygen emission line. The figure below shows an average of 1294 of these very faint galaxies at a redshift of $z=3$ (which are by far the most common in the young universe). The O++ line (which falls between the two vertical dashed lines) is so unexpectedly strong that it even distorts the overall broad-band spectrum.



Not only is the young universe 'going green'. The coming generation of space telescopes for cosmological surveys is also going for the green. In particular, the launch of NASA's James Webb Space Telescope in 2018, followed by their WFIRST in 2024, and the 2020 precursor from European Space Agency, EUCLID, are all designed to survey galaxies in the young universe though this green O++ emission line. Of course at the high redshifts of interest ($z=2-10!$), this 'green' line is shifted into the near-infrared wavelength range. The cold, dark environment of these telescopes, and their new detectors are highly optimized to provide unprecedented spectroscopic sensitivity to the strong O++ emission in the infrared. This one line will be the single most powerful probe of galaxy formation, as soon as they form their first stars and supernovae to produce oxygen atoms.

HIGH-REDSHIFT GALAXIES

Alice Shapley's Group

Alice Shapley and her group study key questions in the area of galaxy formation. Specifically, they use the Keck Observatory and space-based telescopes such as Hubble and Spitzer to collect spectra and images of very distant galaxies. These data provide a window ~ 10 billion years into the past, when the Universe was quite young and the galaxies we see around us today were actively forming. Along with her graduate students, Ryan Sanders, Xinnan Du, and Michael Topping, and collaborators around the University of California and beyond, Shapley is looking into the ways that gas cycles into and out of galaxies – one of the key processes governing galaxy growth and evolution. Shapley and her group also study the contribution of galaxies to the phenomenon of cosmic reionization – a major phase transition during the first billion years of cosmic time – and the growth of large-scale structure in the early universe.

In May 2016, Shapley and her collaborators completed 48.5 nights of observations on the Keck I telescope with the MOSFIRE instrument. This project, known as the MOSFIRE Deep Evolution Field (MOSDEF) Survey (<http://mosdef.astro.berkeley.edu/Home.html>), provides a census of the fundamental properties of galaxies during the first few billion years after the Big Bang. The basic data collected for the MOSDEF survey are near-infrared spectra that were emitted as optical radiation ~ 10 billion years ago. One particularly exciting MOSDEF discovery comes from UCLA graduate student, Ryan Sanders. Poring over the MOSDEF database, Ryan found a galaxy, COSMOS-1908 (see Figure 1), with a particularly unique spectrum of oxygen emission lines (Figure 2). This spectrum makes it possible to quantify the amount of oxygen present in the

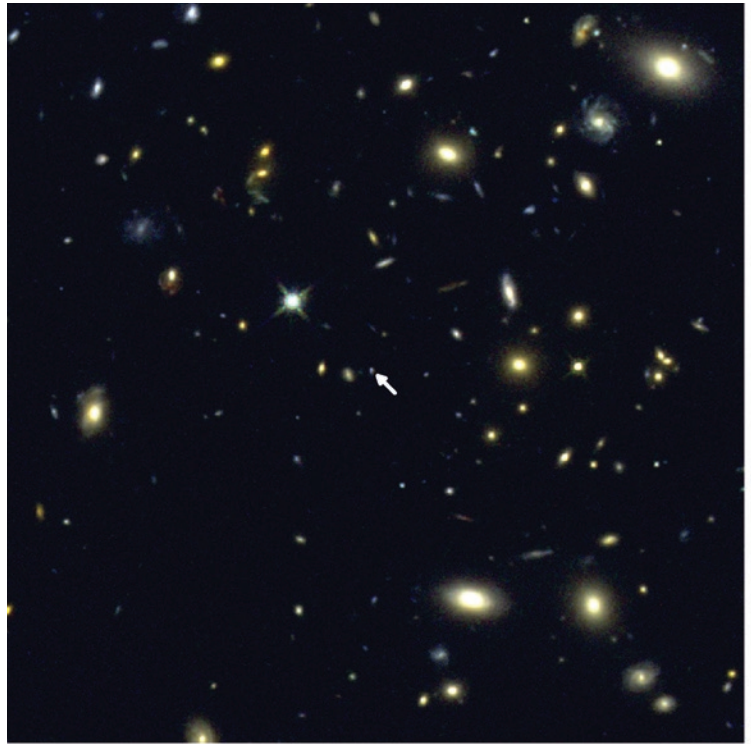


Figure 1: Hubble Space Telescope image of a portion of the COSMOS field, with an arrow pointing to the distant galaxy, COSMOS-1908. UCLA graduate student Ryan Sanders obtained an unprecedented measurement of the oxygen content of this galaxy, an important constraint on models of galaxy formation. (Image credit: Ryan Sanders / CANDELS team).

galaxy, observed ~ 12 billion light years away, as well as a path forward towards making similar measurements for a very large sample of galaxies. Measurements of oxygen in distant galaxies provide important constraints on the balance between the production of heavy elements inside of stars, the ejection of these heavy elements into the intergalactic medium, and the accretion of pristine hydrogen gas as the galaxy grows. A UCLA press release on this result can be found here:

<http://newsroom.ucla.edu/releases/ucla-astronomers-make-first-accurate-measurement-of-oxygen-in-distant-galaxy>

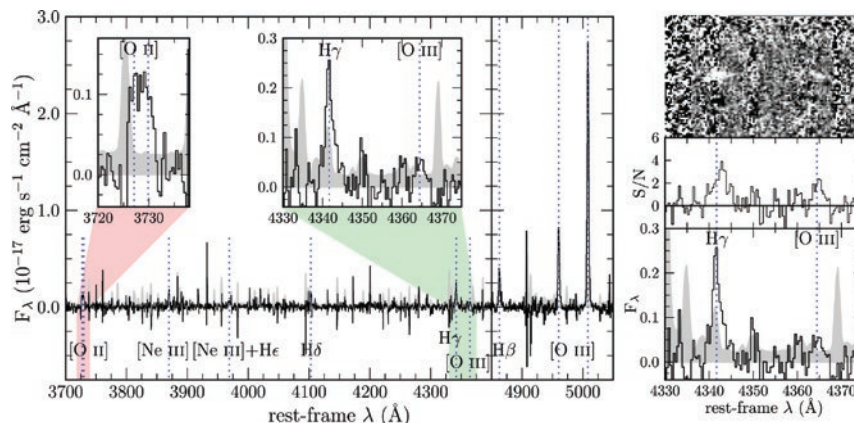


Figure 2: (From Sanders et al. 2016) MOSFIRE spectrum of COSMOS-1908. Left: The full MOSFIRE dataset of this galaxy, with emission lines from oxygen, neon, and hydrogen marked, respectively with "O", "Ne", and "H." The horizontal axis shows wavelength in angstroms, increasing from left to right, and the vertical axis shows intensity. The wavelength regions around key oxygen features are also highlighted. Right: Zoom-ins around the wavelength region around a particularly important oxygen feature at a rest wavelength of 4363 angstroms, showing the one-dimensional spectrum (bottom), signal-to-noise spectrum (middle), and two-dimensional spectrum (top). The measurement of this weak feature is crucial for determining the amount of oxygen in COSMOS-1908.

William Newman

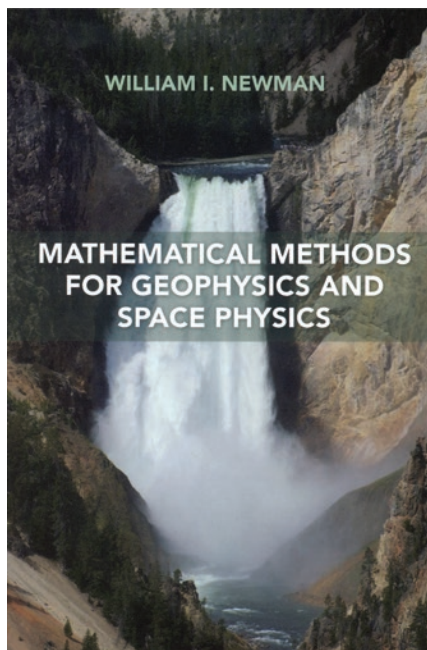
Professor Newman has been engaged in a number of research projects as well as the publication by Princeton University Press of a graduate textbook on mathematical methods applicable especially to classical physics. Entitled *Mathematical Methods for Geophysics and Space Physics*, this book is also beneficial to individuals in astrophysics, plasma physics, atmospheric physics, and related disciplines. While it does not address group theory, it is unique among mathematical methods for physics-related disciplines since it surveys chaos theory and fractals, nonlinear waves and turbulence as well as scaling phenomenon, inverse theory including the Abel and Radon transform and applications to astrophysical and geophysical tomography, as well as provide a brief survey of probabilistic/statistical issues and numerical methods.

Professor Newman spent the summer and fall on sabbatical, primarily in the Planetary Science and Physics Departments at the Weizmann Institute of Science in Israel, as well as in the Mathematics Department at the University of Auckland, New Zealand. His research overseas, as well as here at UCLA, has focused on problems relating to the origin, evolution, and dynamics of proto-planetary material in this as well as extrasolar planetary systems, performing simulations with his New Zealand and Jet Propulsion Laboratory collaborators, Philip Sharp and Bruce Bills. In addition, he has investi-

gated the statistical mechanical problem of random walks on a random ensemble of magnetic fields, as might occur in reconnection regions encountered in the intergalactic medium as well as the Earth's magnetosphere.

Culminating many years of development, he has developed a paper addressing spectral analysis challenges in radio, millimeter, and submillimeter astronomy as telescopes move away from century-old superheterodyne-based technologies towards ones exploiting semi-conductor/metal Schottky devices. These developments in instrumentation will extend the bandwidth over which observations are

conducted by orders of magnitude. In so doing, the computational challenges using conventional computers and Fast Fourier Transforms will become insuperable. By exploiting the architecture in massively parallel computers and the mathematics underlying spectral analysis, he has developed algorithms that will increase computational speeds many orders of magnitude, and make it possible to fully benefit from the increased bandwidths.



PLANETS AND EXOPLANETS

Jean-Luc Margot



Figure 1: Spring 2016 UCLA SETI class with guest lecturer Larry Lesyna

Our research group measures the spin states, shapes, gravity fields, and orbits of planets, satellites, and asteroids. This work allows us to quantify the interior structure of these bodies and the processes that affect them. The goal is to better understand the formation and evolution of habitable worlds.

Graduate student Adam Greenberg completed the characterization of the kilometer-sized asteroid 1566 Icarus. By obtaining a precise shape model of the asteroid using Arecibo radar data, Adam was able to estimate the range to the center of mass of the asteroid with a fractional precision of 1 part in 100 million! He then combined these measurements with decades of optical astrometry to measure a minuscule change in the orbit due to a radiative effect known as the Yarkovsky effect. This high-precision orbit determination software can be used for any asteroid for which sufficient optical and/or radar astrometry exists.

Postdoc Ashok Verma finalized his analysis of Mercury's gravity field using MESSENGER radio science data. In particular, Ashok measured tiny changes in the gravity field that occur as Mercury orbits the sun in a slightly eccentric orbit ($e=0.2$). These tidal variations inform us

about Mercury's interior structure. Ashok is now simulating the signal that will be measurable by NASA's much anticipated flagship mission to Europa. The tidal signal will (most likely) confirm or (less likely) disprove the presence of a subsurface ocean under Europa's icy shell.

Margot's new course titled "Search for Extraterrestrial Intelligence: Theory and Applications" was a great success. Nine undergraduate students and five graduate students (Figure 1) obtained data from the Arecibo and Green Bank telescopes, wrote an elaborate data processing pipeline, and searched terabytes of data for artificial signals. No evidence of ET has been detected so far, but many new marketable skills were acquired in the process. The course will be offered again in 2017.

In other news, Margot completed a review chapter titled "Asteroid Systems: Binaries, Triples, and Pairs" (in *Asteroids IV*, 2015). Margot's quantitative criterion for defining "planets" (AJ, 2015) was used in the context of Planet Nine. If Planet Nine is found with a mass and orbit similar to the predictions, it will qualify as a planet.

RESEARCH GROUP: GALACTIC CENTER GROUP

UCLA Faculty & Research Scientists: Andrea Ghez (Director), Tuan Do, Eric Becklin, Mark Morris, Shoko Sakai, Gunther Witzel, Smadar Naoz, Mike Fitzgerald

The mission of the Galactic Center Group is to transform our understanding of black holes and their role in the Universe with high-resolution observations of the center of our Galaxy. Due to its proximity, the Milky Way's central supermassive black hole and its environs affords us with the unique opportunity to study the fundamental physics of black holes - by opening up new probes of Einstein's Theory of General Relativity in regimes that have thus far never been explored - and the role that black holes play in the formation and evolution of galaxies.

With the closest approach of star S0-2 to the Milky Way's black hole just around the corner in 2018, preparation for this exciting occurrence (dubbed GR2018) is in full swing. The S0-2 periapse will mark the first test of Einstein's theory of General Relativity (GR) in an unexplored regime, 100 times closer to a black hole and on a mass scale that is 400,000 times larger than any previous test. The first step toward GR2018 is to obtain a better characterization of the black hole using multiple stars. Using a more sophisticated image reconstruction technique called speckle holography, data was published by Graduate Student Anna Boehle extracting the positional information for the star S0-38.

Combining this with new Adaptive Optics (AO) data, we have improved our measurement of the mass and distance of the black hole by over a factor of two.

We have also continued to explore the Galactic Center sources - G2 & G1, two puzzling objects that appear to be the first cases of objects caught in the act of being tidally disrupted by a central supermassive black hole. Both objects, with very eccentric orbits, have recently experienced their closest approach. They were the subject of Breann Sitarski's successfully defended Ph.D. thesis. G1 is 10 years ahead of G2 and has revealed an initially extended source (at closest approach) that has become compact and fainter over the course of two years. These observations support the idea that G1 and G2 may be binary star merger products that were driven to merge through gravitational interactions with the central black hole.

Gunther Witzel has been working on a project developing algorithms that improve the precision of measurements of stellar positions in AO images. This project has delivered a new software package: AIROPA (Anisoplanatic and Instrumental Reconstruction of Off-axis PSFs for AO),

which makes use of independently measured atmospheric data that describes the turbulence of the air, and predicts how the shape of stellar images in the field of view change for different field positions. It is a milestone on the way to the measurements of general relativistic effects on stellar orbits at the Galactic Center, and a result of the group's continuing investment into new technologies and methods.

Other highlights include: (1) Profs. Naoz and Ghez organized a successful scientific meeting (see photo) (2) GCG hosted a roundtable discussion on the future of AO at Keck Observatory with 5 philanthropic foundations (3) Graduate Student Abhimat Gautam searched for eclipsing binary stars to estimate the underlying binary star population, (4) Graduate Student Samantha Chappell worked on the development of a new methodology for modeling the kinematic structure of the old stars at the Galactic Center, (5) Graduate Student Devin Chu investigated the origin of the stars located within one arcsecond of the central supermassive black hole, and (6) Researcher Witzel and Profs. Morris & Becklin worked on a simultaneous observations of Sgr A* using Keck, Spitzer, Chandra, and ALMA telescopes which will give more insight into the mechanism

that drives the Sgr A* outbursts.

The GCG welcomed several new group members this year. In order to be able to fully incorporate the effects of GR in the orbital analysis of S0-2, Aurelien Hees joined with the Heising-Simons Postdoctoral Fellowship. Undergraduate Kelly Kosmo has been working on improving orbital modeling techniques. Arezu Dehghanfar worked with Hees on GR orbital models. Laly Cano, a graduate student at the Instituto de Astrofísica de Andalucía with our collaborator Rainer Schoedel, visited our group, analyzing the speckle data. Undergraduate Christopher O'Connor searched for long-period variable stars in the central 10-arcsec area of the Galactic Center.



Figure 1: UCLA Galactic Center Group Visitor, Laly Cano (center), spent three months at UCLA collaborating with the group to develop new methods for improving the dynamic-range of high angular resolution imaging data.

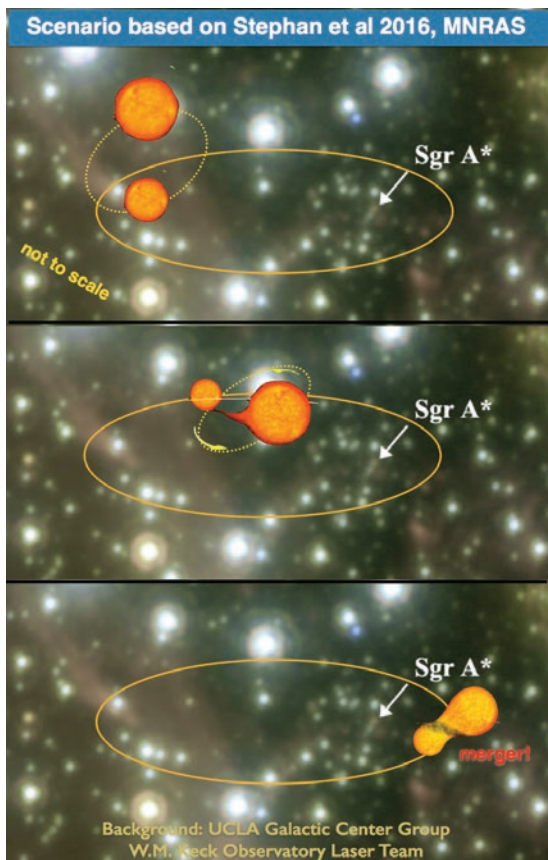


Figure 2: The Galactic Center has become a new and exciting laboratory for studying the physics and astrophysics of supermassive black holes. At an Aspen Center for Physics meeting organized by the UCLA Galactic Center Group, 72 people (from 42 institutions and 17 countries) came together to discuss new ideas about how to harness the power of high angular resolution measurements of the Galactic Center.

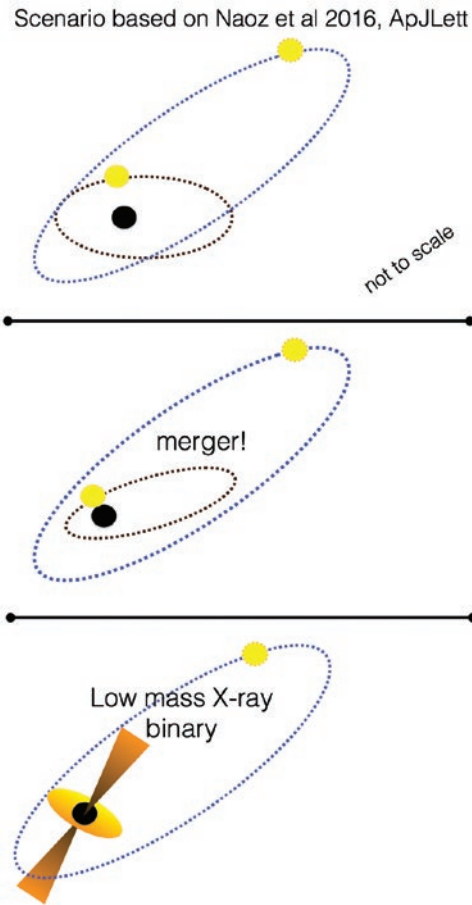
Smadar Naoz

During the past year Smadar Naoz continued to study the numerous dynamical effects in hierarchical triple body systems, at different astrophysical settings.

Galactic center: An interesting and timely application was explored at the center of our galaxy. In a paper led by UCLA graduate student, Alexander Stephan, Naoz and the UCLA Galactic Center group showed that gravitational perturbations from the central black hole in the center of the Milky Way can efficiently lead to the mergers of binary stars (Stephan et al 2016 MNRAS), as depicted in the cartoon. These merged products are offered as an explanation to the recent puzzling red objects in the galactic center. This study has also provided a theoretical prediction that the fraction of the young binary stellar systems in the galactic center should be larger than previously thought, and is estimated to be more than 60%.

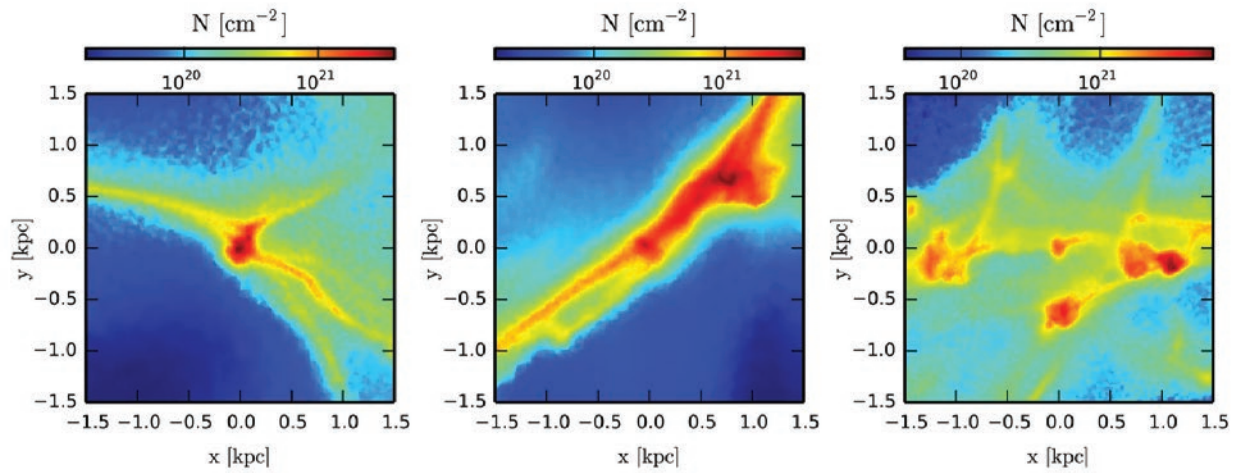


Black-Hole Low Mass X-ray binaries: In another paper (Naoz et al 2016, ApJLett), Naoz and collaborators from Geneva Observatory and Northwestern University, showed that gravitational perturbations from a stellar tertiary can explain a long standing puzzle of the formation of Black-hole Low-mass X-ray Binaries. A Low-mass X-ray binary is a binary system that has strong X-rays emission, and in which the binary star is composed out of a stellar black-hole and a low mass (typically close in mass to the



Sun). The formation of black-hole low-mass X-ray binaries poses a theoretical challenge, as low-mass companions are not expected to survive the stellar evolution (i.e., common-envelope scenario) with the BH progenitor. However, Naoz and collaborators showed for the first time that gravitational perturbations from a distant stellar companion can naturally form these systems (the process is depicted in the cartoon). Interestingly, many of the low-mass X-ray binaries are known or suspected triples. Naoz and her collaborators estimated the fraction of objects expected in the Galaxy from their new mechanism and showed that this scenario is consistent with observations.

High Redshift Gas-Dominated Structures: Naoz also investigates the formation of high redshift structures. Specifically, this year, Naoz and collaborators from MIT and Harvard studied the formation of gas-dominated clumps in the early Universe using state-of-the-art numerical simulations. As shown by the snapshot from the simulations, these non-linear gas-dominated structures exist in the early universe, as was suggested in an earlier analytical paper led by Smadar Naoz (Naoz and Narayan, 2014). Naoz and her collaborators suggested that these objects, and their dark matter dominated counterparts, may be connected to current day globular clusters and dark galaxies. Regardless of their present day configuration, those objects may have significant implications on the evolution of structures in the early Universe.



Gas density projections examples. These objects contain a gas fraction larger than the cosmic baryonic fraction inside the tightly fitted ellipsoids and are located outside the virial radius of the closest Dark Matter halo. Figure adopted from Popa et al (2016).

VERY HIGH ENERGY (VHE) ASTROPHYSICS

Rene Ong, Vladimir Vassiliev



Figure 1: Very Energetic Radiation Imaging Telescope Array System (VERITAS) at Whipple Observatory in southern Arizona.

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 very high-energy (>100 GeV) photons. Such gamma rays, that have energies 100 billion times greater than optical light, are emitted in physics processes far from thermal equilibrium, which take place in the vicinities of supernova remnants (SNRs), pulsars and their nebulae, black holes, such as in centers in active galaxies, and in enigmatic gamma-ray bursts.

At these energies gamma rays can also be created in physics processes beyond the standard model of particle physics, such as from the annihilation of unknown particles

comprising the dark matter of the universe or from the evaporation of primordial black holes if they were produced during early stages of universe evolution. Through their interaction with the cosmological low energy (radio through UV) diffuse radiation fields, very energetic photons also provide unique opportunities to probe cosmologically important backgrounds as well as the very weak intergalactic magnetic fields.

VHE astrophysics has been greatly advanced by the successful use of 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.

A major benefit of this technique is due to very large area of the Cherenkov light pool on the ground, approximately 100,000 square-meters, compared to the 1 square-meter scale area typical for a satellite instrument. This large collection area enables the detection of very low astrophysical fluxes of gamma rays. In addition, the images of the Cherenkov light in the cameras can be used to accurately reconstruct the direction and energy of the primary gamma ray.

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 imaging atmospheric Cherenkov telescopes (see Figure 1). 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 contributed significantly to several new publications and continued analysis work on a number of topics, including a map of the VHE sources in the Cygnus region of the Galaxy and a study of the nearby radio galaxy M 87.

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), see Figure 2. CTA is expected to have a large array in both the northern and southern hemispheres, with each array consisting of up to 100 atmospheric Cherenkov telescopes covering an area up to 10 square-kilometers. As shown in Figure 2, CTA will consist of telescopes of three sizes: large (~23 m diameter), medium (~10-12m diameter) and small (~3m diameter). CTA is being proposed by an international consortium of around 1,200 scientists from 32 countries. This consortium is developing all of the key instrumentation for the observatory, including the telescopes, electronics, readout software, and analysis software. Rene Ong has a significant role in the leadership of CTA and is currently serving as Co-Spokesperson of the consortium.

U.S. members of the CTA consortium are working on the development of a two-mirror medium-size telescope. This novel telescope, called the Schwarzschild-Couder Tele-

scope (SCT), is designed to achieve superior performance and wider field of view compared to conventional telescope designs such as used by VERITAS. The group organized by Vladimir Vassiliev at UCLA pioneered this new instrumentation development for VHE gamma-ray astronomy and is now leading the effort of more than a dozen institutions to construct a prototype SCT at the VERITAS site location, with support from the NSF and from UCLA. The construction of the prototype SCT is well underway with the main optical structures in place. The mirrors and camera are expected to be integrated into the telescope by early 2017 with first light coming a few months later.

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 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 and so a clear signal for them would be very interesting. A UCLA group led by Rene Ong is working with the other institutions in the U.S., Japan and Italy to develop the first dedicated search experiment for anti-deuterons, called the General AntiParticle Spectrometer (GAPS). In the GAPS instrument, an anti-deuteron would be detected through its interaction in lithium-drifted silicon detectors. The GAPS team developed a prototype instrument that had a successful flight in 2012 at the Taiki launch facility of the Japanese Aerospace Exploration Agency (JAXA) in Hokkaido, Japan. Based on the prototype results, the GAPS team is now developing the full science instrument. The GAPS instrument would be carried to the upper atmosphere by a balloon launched from the McMurdo station in Antarctica.

Currently the VHE astrophysics group consists of Professors Rene Ong and Vladimir Vassiliev, postdoctoral researchers Ralph Bird and Julien Rousselle, and graduate students Matt Buchovecky, Alexis Popkow, and Brandon Stevenson.

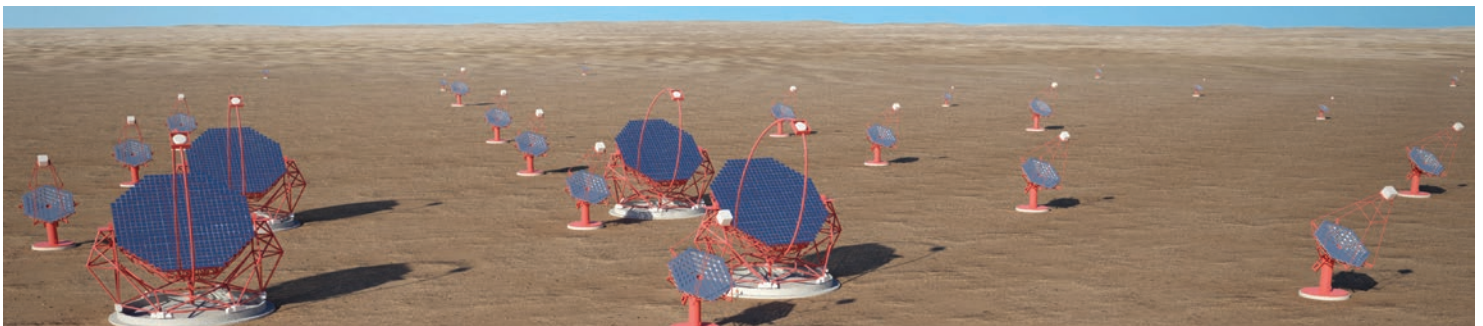


Figure 2: The VHE astrophysics group is heavily involved in the plans for the next-generation ground-based gamma-ray observatory called the Cherenkov Telescope Array (CTA). CTA is expected to have a large array in both the northern and southern hemispheres, with each array consisting of up to 100 atmospheric Cherenkov telescopes covering an area up to 10 square-kilometers. CTA is being proposed by an international consortium of around 1,200 scientists from 32 countries.

National Science Foundation Science and Technology Center

Deputy Director: Jianwei (John) Miao



Jianwei (John) Miao
Photo Credit: Annie Yu 2016

Jianwei (John) Miao, a UCLA professor of physics and astronomy and member of UCLA's California NanoSystems Institute has been appointed deputy director and to head up an NSF funded cutting-edge Science and Technology Center on Real-Time Functional Imaging. CU Boulder physics professor Margaret Murnane is the director. The center is funded by a five-year, \$24 million award from the National Science Foundation, and includes renowned scientists from UCLA, University of Colorado, Boulder, and UC Berkeley. It will tackle major scientific challenges in the physical sciences, life sciences and engineering.

According to Miao "The project addresses a critical national need for imaging science to enable scientific breakthroughs and technological advances at an import time for the United States to remain competitive in science and technology."

This new NSF Science and Technology Center, known as STROBE, will integrate advanced imaging methods using electrons, x-rays and super-resolution microscopy to address grand challenges in various research areas ranging from physical sciences to life sciences and engineering.

Recent major advances by the participating scientists in electron, X-ray and optical nano-imaging have paved the way for achieving the project's multidisciplinary goals.

Physicists, mathematicians, chemists and biolo-

***UCLA** is an international leader in state-of-the-art imaging, which will greatly benefit California and the United States," said Miguel García-Garibay, dean of the UCLA Division of Physical Sciences. "Under the leadership and remarkable scientific achievements of John Miao, UCLA will continue to set the highest standards of research, education and the transfer of major advances from the laboratory to industry, where they will benefit the public."*

gists from UCLA will work closely with some of the leading experts from University of Colorado Boulder and UC Berkeley to establish STROBE as a world-class imaging center.

UCLA undergraduate and graduate students will have an opportunity to participate in multidisciplinary and cutting-edge research provided by STROBE and will receive an excellent education for innovation to prepare for 21st century careers.”

UCLA faculty members participating in the project are Pietro Musumeci and Chris Regan (physics and astronomy), Stanley Osher (mathematics), Jose Rodriguez (chemistry and biochemistry), Shimon Weiss (chemistry and biochemistry, and physiology) and Z. Hong Zhou (microbiology, immunology, and molecular genetics).

UC Irvine, Fort Lewis College in Colorado and Florida International University will also participate. Industrial partners are Intel, IBM, Semiconductor Research Corporation, GlobalFoundries, Anasys, Interuniversity Microelectronics Centre, ASML and KMLabs.

“UCLA is an international leader in state-of-the-art imaging, which will greatly benefit California and the United States,” said Miguel García-Garibay, dean of the UCLA Division of Physical Sciences. “Under the leadership and remarkable scientific achievements of John Miao, UCLA will continue to set the highest standards of research, education and the transfer of major advances from the laboratory to industry, where they will benefit the public.”

NSF science and technology centers conduct “innovative, potentially transformative, complex research and education projects” involving world-class research through partnerships among academic universities and industrial organizations in important areas of basic research, the NSF stated. “They have catalyzed breakthroughs, built bridges of exchange with industry, spun off new technologies and businesses, and trained young scientists and engineers.”

“From deepening our understanding of intelligence to developing energy-efficient electronics and next-generation polymers, NSF’s Science and Technology Centers have stood at the forefront of discovery and innovation,” said Suzi Iacono, head of the NSF Office of Integrative Activities.

Miao’s research work includes development of a powerful tomography method to image three-dimensional positions of individual atoms. In a new article, published Sept. 23 in the journal *Science*, Miao and colleagues review recent advances produced by interdisciplinary science that make it possible to determine the three-dimensional atomic structure of crystal defects and non-crystalline materials with high precision. The work, Miao said, offers clues on how to modify and engineer materials that will improve performance of technological devices and likely lead to breakthroughs in fields ranging from electronics to energy conversion.

(The above text has been adapted from an article in UCLA Newsroom written by Stuart Wolpert)

The Miao Group

It is hard to overstate the importance of crystallography to mankind. By measuring the 3D arrangement of atoms with high precision, coupled with quantum mechanical calculations such as density functional theory (DFT), we can understand and engineer new materials with applications from electronics and energy conversion to disease fighting drugs. However, crystallography can only provide periodically averaged atomic structures and is blind to defects and aperiodicities in the atomic arrangements, which are often crucial to a material's performance. The development of powerful high resolution imaging methods such as scanning probe microscopy and aberration-corrected electron microscopy allow us to see individual atoms without the constraint of periodic averaging. However, seeing atoms is not the same as knowing their 3D coordinates with sub-angstrom precision, which is required for accurate prediction of properties using quantum mechanics: no DFT calculations can take a 2D image of atoms as an input and tell you the property of that material. However, we are now on the cusp of a solution to this problem. By combining atomic resolution electron imaging methods with powerful data analysis and tomographic reconstruction algorithms, Professor Jianwei (John) Miao and collaborators have recently pioneered atomic electron tomography (AET) to obtain the 3D atomic structure of crystal defects and non-crystalline systems.

Many challenges had to be overcome for AET to succeed, but in the past year the first such structures have begun appearing heralding a groundbreaking experiment in structural characterization [Xu et al., *Nature Mater.* 14, 1099-1103 (2015)]. Most recently, Professor

Miao published a review article [Miao et al., *Science* 353, aaf2157 (2016)], highlighting the recent advances and the interdisciplinary science enabled by AET that is expected to transform our understanding of materials properties and functionality at the most fundamental level.

Furthermore, Professor Miao's group continues to advance the applications of coherent diffractive imaging (CDI) in biology. In 2015, he led a team that reported the first experimental demonstration of cryo-CDI for quantitative 3D imaging of whole, frozen-hydrated cells using 8 keV X-rays. As a proof of principle, a tilt series of 72 diffraction patterns was collected from a frozen-hydrated *Neospora caninum* cell and the 3D mass density of the cell was reconstructed and quantified based on its natural contrast [Rodriguez et al., *IUCr* 2, 575–583 (2015)]. The 3D reconstruction reveals the surface and internal morphology of the cell, including its complex, polarized sub-cellular structure. It is believed that this work represents an important experimental milestone towards routine quantitative 3D imaging of frozen-hydrated cells with spatial resolutions in the tens of nanometres.

Finally, two of Professor Miao's former students got tenure-track faculty positions this year. Jose Rodriguez is now an assistant professor in the Department of Chemistry and Biochemistry at UCLA. Mary Scott will become an assistant professor in the Department of Materials Science and Engineering at UC Berkeley and Lawrence Berkeley National Laboratory since January 2017.

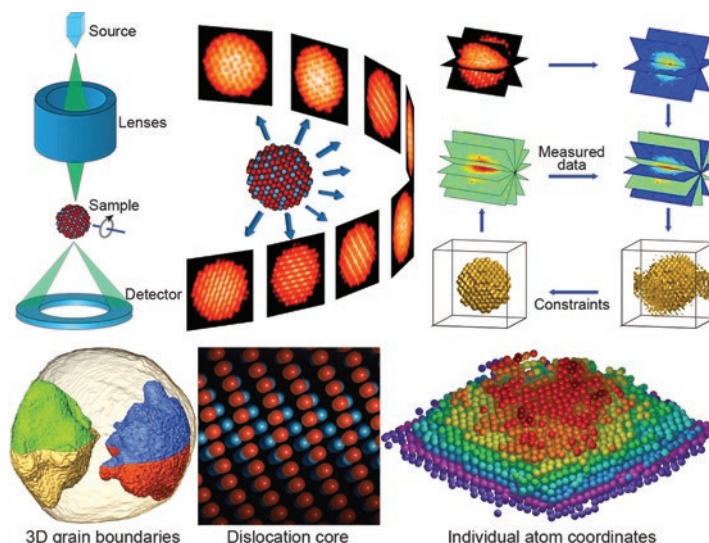


Figure 1: Atomic electron tomography (AET) and its transformative impact on the physical sciences. (Top) Schematic diagram of AET, in which 2D images are measured using scanning transmission electron microscopy by tilting a sample to many different orientations. The 3D structure of the sample is iteratively reconstructed from the images and the coordinates of individual atoms are localized. (Bottom) AET enables 3D imaging of crystal defects such as grain boundaries, stacking faults, dislocations and point defects at atomic resolution. The ability to precisely determine the coordinates of individual atoms allows direct measurements of atomic displacements and the full strain tensor in materials.

ATOMIC-MOLECULAR-OPTICAL PHYSICS

Quantum Physics with Atoms and Molecules

Wes Campbell

When a physicist starts an experiment by making something extremely cold, it is often because quantum mechanics lives at very cold temperatures. The discretization of energy levels determines “very cold” in this statement, but for many systems this means less than a degree above absolute zero. If we were to take a familiar chemical reaction and cool the energies of the reactants to ultracold temperatures, the process would bear almost no resemblance to the behavior that we see in a beaker. Some states wouldn’t seem to react at all, some would quantum-mechanically tunnel through barriers, or take multiple pathways simultaneously, while still others would resonate and occur much faster than the room-temperature average. In essence, we would be able to see the reaction process happening at the finest level of detail allowed by nature, each input state revealing its unique mechanisms, rates, and reaction products. If we could develop this type of control, it would allow for push-button, “atom-by-atom” molecular synthesis, reversible chemistry, and reactions near delicate thresholds. The aim of our work is to realize this goal.

Unfortunately, the chemicals that atomic physicists can laser-cool to these temperatures are very chemically exotic, and reactions between them are of limited value in aiding our understanding of things like organic chemistry. Our group has recently developed a technique to laser cool chemically relevant species, such as hydrogen, carbon, nitrogen, and oxygen. By using a laser known as an optical frequency comb to drive a two-photon transition in rubidium atoms, we have demonstrated a laser cooling and trapping process that is designed specifically to access these common elements. This proof-of-principle result has shown us a new path to access ultracold chemistry with nature’s most abundant building blocks.

In collaborative efforts between Eric Hudson’s and Wes Campbell’s group, we have been investigating another way to observe cold, controlled chemistry with non-exotic species. A few (~ 10) trapped carbon ions will sympathetically cooled to the milliKelvin regime and serve as a nearly-stationary target for cold beams of molecules. Since one of the reactants is an ion and the other is a polar molecule, the ion’s charge can polarize the molecule and pull it in to react. For this specific pair of reactants, reaction cross-sections are large enough to allow their observation in the lab, even with a small number of ions and a cryogenic molecular beam. By looking at these processes with the state-purity afforded by the cold temperatures, our group hopes to tease out the details of these common, poorly-understood reactions.

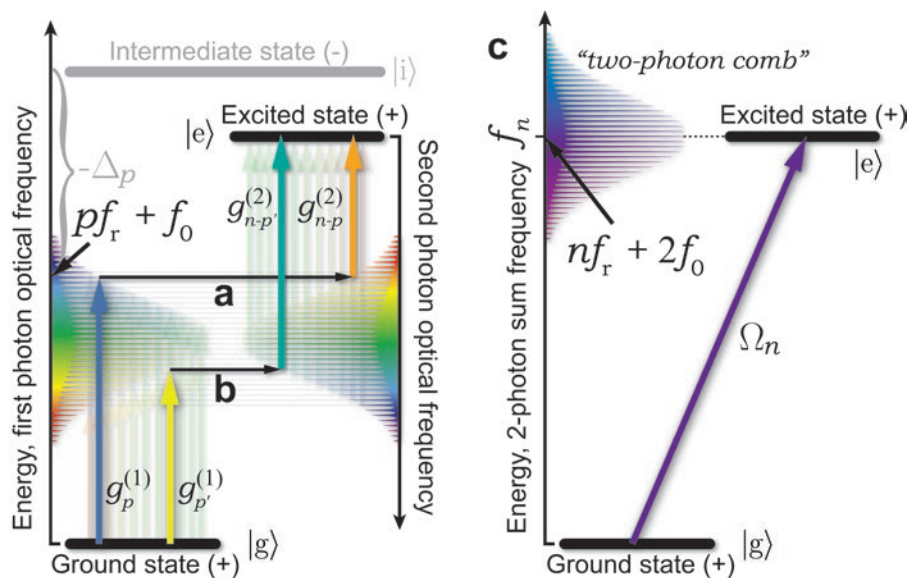


Figure 1: A two-photon transition driven by an optical frequency comb. All of the different ways that two photons can be selected from the comb light to excite the atom can be made to interfere constructively, driving the cooling transition in a massively-parallel fashion.

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

Harnessing quantum interactions for the future of science and technology

Eric Hudson Group

One of the most exciting discoveries of this year was the resolution of a problem that had gone unsolved for almost 40 years! It is well known that when ions, held in traps like those used in mass spectrometers, are immersed in a cold gas the ions do not cool to the same temperature as the gas. This is roughly akin to leaving a warm apple pie in a winter window to cool down, only to find that it spontaneously bursts into flames!

Using the MOTion trap system developed at UCLA, we prepared a microscopic sample of laser-cooled ions of the chemical element barium and immersed them in clouds of roughly 3 million laser-cooled calcium atoms. By making such a pristine system, like that shown in the figure, we were able to tease out the underlying cause for this mystery as the result of an interplay between the ion motion and the trap dynamics. Perhaps most surprisingly, through this work we also observed a bifurcation in the ion temperature; the ions could choose two different final temperatures based on their initial temperature when immersed in the cloud! This work has allowed us to both optimize and set the fundamental limits to this technique, called Buffer gas cooling, for the production of low energy ions.

Since buffer gas cooling is crucial in fields ranging from forensics to the production of antimatter. Our work has discovered important nuances that revise the current understanding of the cooling process, explain the difficulties

encountered in previous cooling experiments and show a new path forward for creating ultra-cold ion samples.

The research was funded by supported by the National Science Foundation (grant PHY-1205311) and Army Research Office (grants W911NF-15-1-0121 and W911NF-14-1-0378).

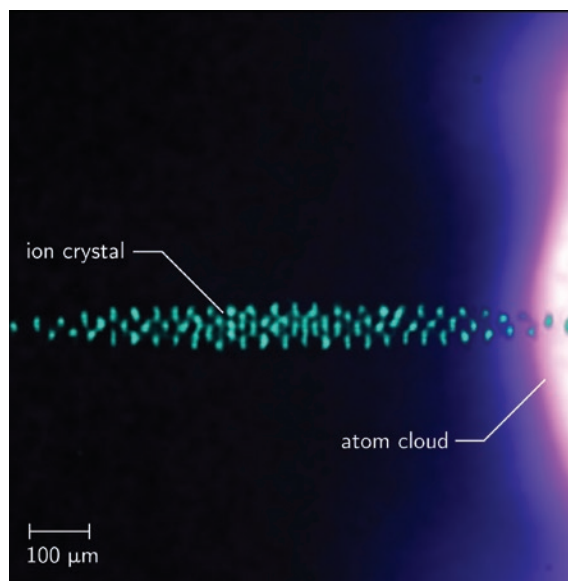


Figure caption: A microscopic sample of barium ions, shown in teal, immersed in a cloud of calcium atoms whose temperature is 1/1,000th of a degree above absolute zero

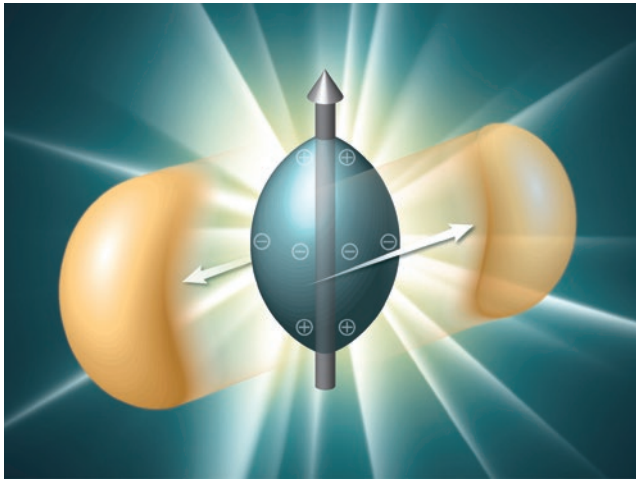
EXPERIMENTAL ELEMENTARY PARTICLES AND NUCLEAR EXPERIMENTAL PHYSICS

Nuclear Physics Group Huan Huang Group

The UCLA Nuclear Physics Group (HUANG) has research programs on studies of hot QCD (Quantum ChromoDynamics) matter of quarks and gluons and on searches for neutrinoless double beta decays. The group has been active in the STAR (Solenoidal Tracker at RHIC) experiment and recently became a founding member of the newly formed sPHENIX experiment at Relativistic Heavy Ion Collider (RHIC) in the Brookhaven National Laboratory (BNL). The neutrino program centers on the CUORE experiment at the Gran Sasso National Laboratory in Italy.

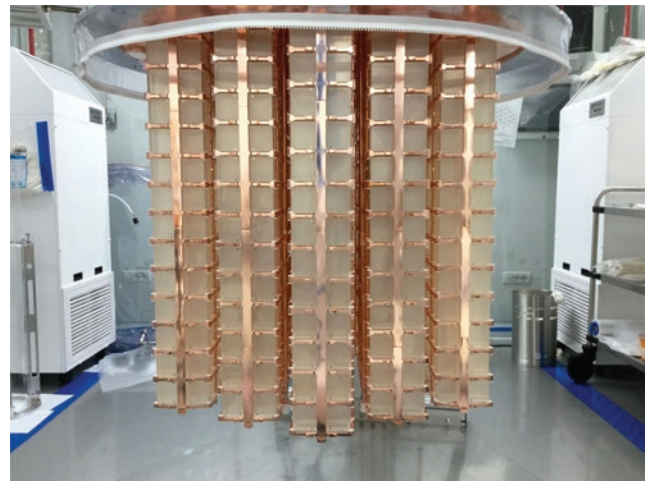
We have been studying quark chirality properties of the quark-gluon plasma (QGP) at RHIC. As an intrinsic

property of the QCD theory that dictates the interactions among quarks and gluons, a chirality imbalance of quarks (unequal numbers of left-handed and right-handed quarks) can be produced in finite domains owing to topological excitations of gluon fields. When coupled to the strong magnetic field ($\sim 10^{15}$ Tesla) created in nucleus-nucleus collisions by spectator protons moving at the speed of light, the chirality imbalance induces novel transport phenomena, such as the chiral magnetic effect (CME) and the chiral magnetic wave (CMW). The UCLA group has been a leading experimental group in the study of chirality effects in nucleus-nucleus collisions. We have organized another



QCD workshop on chirality, vorticity and magnetic field in heavy-ion collisions at UCLA in February 2016. Our work on the search for the CMW with the STAR experiment at RHIC was published in Physical Review Letters 114, 252302 (2015) (selected as Editors' choice).

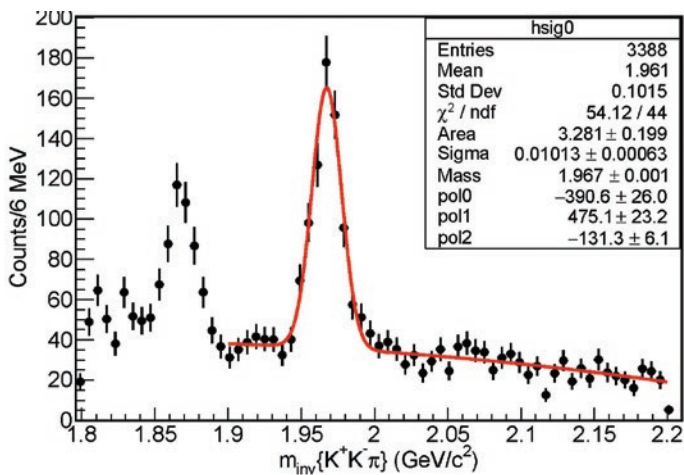
The STAR experiment has recently completed a heavy flavor tracker (HFT) upgrade to enable measurements of charm quark mesons through fully reconstructed hadronic decay topologies. We have successfully completed another Au+Au run in 2016 at the full RHIC energy for the heavy



quark physics program. The UCLA group is interested in the D_s meson measurement from Au+Au collisions. The D_s meson consists of a charm and a strange quark and can be used to probe the strangeness equilibration of the QGP created at RHIC. We can reconstruct D_s mesons from HFT tracks with position resolutions the order of 10's micron.

On the neutrino physics front, the CUORE is expected to be among the most sensitive experiments to search for neutrinoless double beta decays in the coming years. A major milestone has been achieved – we have completed the installation of all 19 crystal detector towers inside the cryostat. These crystal towers will be cooled to a temperature of 10 mK to operate as a bolometer detector with an excellent energy resolution. The CUORE detector commissioning is expected to start in late 2016 or early 2017.

The Nuclear Physics Group continues to provide training for many undergraduate students. We have REU (Summer 2016) student Rachel Smith from UIUC, Fufang Wen, Yiwen Huang, Manvir Grewal and Peter Zheng from UCLA working on the STAR experiment, and Charles Gao from UCLA working on CUORE simulations. Rachel, Fufang, Yiwen and Peter will present their results at a NSF sponsored CEU (Conference Experience for Undergraduates) poster session at the Division of Nuclear Physics Conference in the fall 2016 at Vancouver, Canada.



CERN'S LARGE HADRON COLLIDER

Postdoctoral scholars on the compact muon solenoid experiment

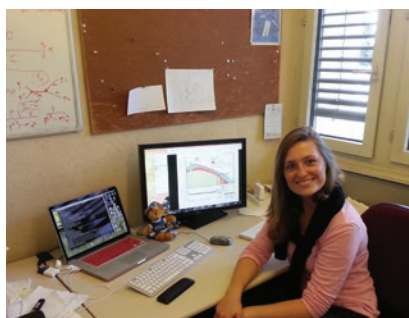
Postdoctoral scholars — affectionately known as “postdocs” — are critical to the elementary particle physics research conducted by the UCLA group at CERN's Large Hadron Collider, led by Profs. **Robert Cousins**, **Jay Hauser** and **David Saltzberg**. Postdocs already have the experience and knowledge gained by successfully completing their Ph.D. research, but are not yet dividing their time with formal teaching duties. They concentrate full-time on research by analyzing data for new discoveries and building detectors for future, even better, data taking. Yet they do still serve as valuable teachers, by working side-by-side with UCLA graduate students on their Ph.D. thesis work.



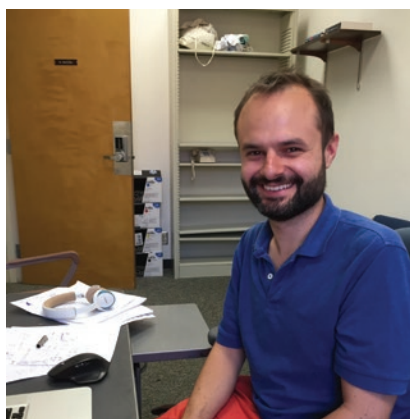
Pieter Everaerts, originally of Belgium, came to us five years ago with a Ph.D. from MIT. He kept the timing of over a half million muon detector channels accurate to a nanosecond. He looked for evidence of so-called “supersymmetry”, a proposed but as-yet unseen symmetry of space-time that would approximately double the number of physical particles. Supersymmetry has been a long-time favorite of many particle theorists since it allows the Higgs mass to be at its accessible scale and may even provide a dark matter candidate particle. Pieter’s particular search channel used multiple leptons (electrons, muons and taus) as one of the cleanest places to find such evidence. He subsequently took a leadership position in one of the collaboration’s data analysis groups working to find supersymmetry. Meanwhile he shared his expertise with UCLA Ph.D. student Riju Dasgupta. Pieter just left our group, taking a prestigious position as a CERN Fellow.



Matthias Weber, originally of Germany, arrived at nearly the same time after receiving his Ph.D. from ETH Zürich. He built the missing muon chambers for the outermost, and previously thinnest part, of the detector. While at UCLA, Matthias provided the data analysis to verify the most modern theories of the production of “jets” of particles initiated by gluons or quarks, as calculated by UCLA theorist Professor Zvi Bern and his collaborators. In both these efforts, he mentored UCLA student Eric Takasugi in his Ph.D. work. He participated in collaboration analysis management as one of the analysis leaders of Standard Model processes using jets. Matthias also just moved on from our group this year, also taking a position as a CERN Fellow.



Alice Florent, originally of France, came to our group two years ago with a recent Ph.D. from the Université Paris-Sud. Her expertise was in the high energy collisions of heavy ions and the behavior of quarks and leptons at high temperature. Entering our group, Alice moved to proton-proton collisions and completed a search for a heavy cousin of the Z boson particle, itself a kind of heavy photon. She helps guide UCLA Ph.D. student Christian Schnaible with this work as well, which will be a cornerstone of his Ph.D. thesis. She is now supervising Schnaible and Dasgupta on measurements at CERN’s Gamma Irradiation Facility, which uses a 14 Terabecquerel cesium-137 source to project the performance of our experiment in the much higher radiation environment foreseen in the next ten years.



Nickolas McColl is the newest postdoc in our group, arriving this year with a Ph.D. from UC Santa Barbara. While our other postdocs came to us from distant lands, Nick is not only a native Californian, but also was a UCLA undergraduate. And Nick is well known to many at UCLA, having been awarded the E. Lee Kinsey award, which goes to the top UCLA Physics graduate each year. Nick is working along with UCLA graduate student Cameron Bravo on building new trigger electronics for new muon detectors based on gas electron multiplication. He is currently polishing his data analysis looking for the supersymmetric partner of top quarks, the heaviest known particle, and looks forward with us to being part of a major discovery with the new LHC data.

UCLA postdocs are key members of the research team for all aspects of our experiment, from ionization to publication.

ELECTROMAGNETIC DETECTION OF HIGH ENERGY PARTICLES

David Saltzberg

Undergraduate physics major Peihao Sun was named a finalist for the LeRoy Apker Award for Undergraduate Physics Achievement Award by the American Physical Society (APS). He worked with Professor David Saltzberg on designing a fast, large magnetic toroid to detect the passage of high-energy particles, such as cosmic rays with energies greater than 100 PeV. The device would be sensitive to femtosecond passage of particles and could be built as large as hundreds of meters in radius, to cover a large area. The device essentially invokes a combination of Ampère's and Faraday's laws to instrument an area from only its perimeter. Peihao presented his work in Washington, DC and both he and the department were given an honorarium by the APS. (For more information see: <http://arxiv.org/abs/1502.04763>)



Figure 1: Peihao Sun, a UCLA physics major, was named a finalist for the LeRoy Apker Award. He is now a graduate student in physics at Stanford.

NOBLE LIQUID DETECTOR LAB FOR RARE EVENT SEARCHES

Hanguo Wang's Group

Dark matter, as an invisible form of matter which is five times more abundant than ordinary matter (humans, planets, galaxies, etc.) in the current universe, has been hunted for by physicists for decades, while its nature still remains as a puzzle. Among all the direct detection efforts in the world, Professor Hanguo Wang's group participates in two of the major efforts: XENON and DarkSide, both international collaborations utilizing dual-phase (liquid-gas) noble liquid time projection chambers (TPCs), inside which both scintillation and ionization signals induced by possible dark matter interactions with target medium can be detected simultaneously by highly-sensitive low-radioactive photosensors.

The XENON program, utilizing liquid xenon (LXe) as the target medium, had been the top runner in the competitive field of direct dark matter detection for years. The latest iteration, XENON1T, is the first ton-scale detector with 1-ton liquid xenon as sensitive target. Professor Wang's group is responsible for designing and testing the photomultiplier tube (PMT) assembly system, as well as designing and constructing the high voltage feedthrough (HVFT). The PMT assembly system, composed of only extremely low-radioactive copper and polytetrafluoroethylene (PTFE), is crucial to mechanically assure PMTs

working safely at the LXe temperature. XENON1T completed all the constructions in early 2016 and is in commissioning phase to comprehensively test all aspects of the experiment, deep underground at Gran Sasso National Laboratory (LNGS) in Italy. Physics data-taking is expected to begin in late 2016. Graduate student Alec Stain is working on the analysis of the commissioning data. The DarkSide program, similarly to XENON, alternatively uses liquid argon as the target medium. Professor Wang's group is deeply involved in the DarkSide collaboration

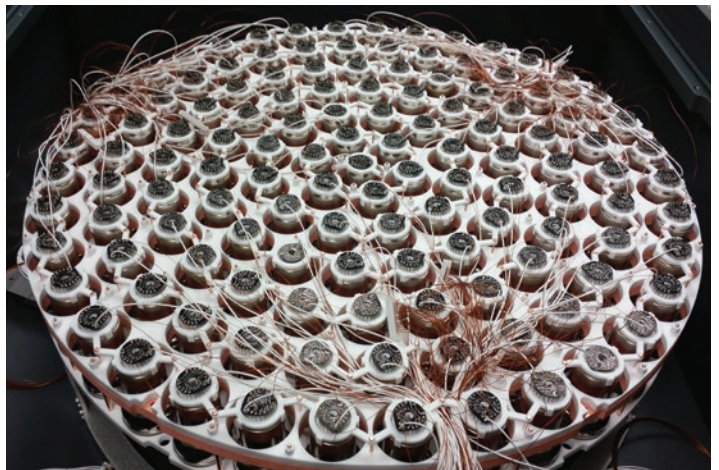


Figure 1: Final PMT assembly for XENON1T. A prototype had passed liquid nitrogen test in UCLA to validate its mechanical robustness in liquid xenon temperature.

from design and construction to operation and analysis. The current iteration, DarkSide-50, also located at LNGS, features a dual-phase TPC with 50-kg underground argon as target medium. In early 2016, DarkSide-50 published the world's first dark matter search results using low-radioactive underground argon. Graduate student Alden Fan was the principal analyst for the paper, playing a key role to extract physics results from tons of data. The next iteration of DarkSide, DarkSide-20k, has entered the designing phase in middle of 2015, aiming to continue pursuing the dark matter puzzle with a 20-ton underground argon TPC. Professor Wang's group is responsible for designing and constructing the cryogenics system and the TPC. Professor Hanguo Wang is also consulting the design of other sub-systems with his world-renowned expertise. The close-to-final designs of both the cryogenics system and the TPC

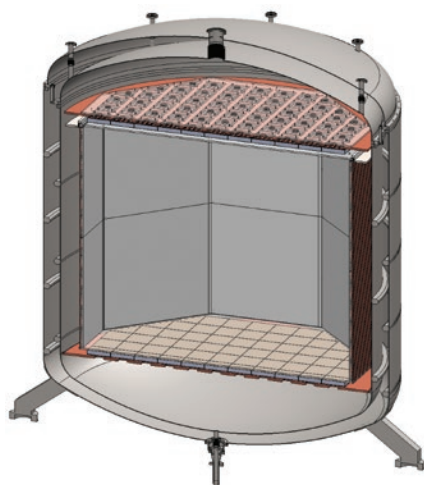


Figure 2: 3D rendering in cross-sectional view of the TPC inside the cryostat of DarkSide-20k.

have been worked out, and Professor Hanguo Wang is leading postdocs Yury Suvorov and Xiang Xiao to construct and test key components of the cryogenics system at UCLA, in order to nail down the final design. DarkSide-20k is planned to take data in 2020, and a 1-ton scale prototype

for mechanical and cryogenics testing is aimed to begin construction in 2017.

Professor Wang's group has been undertaking two parallel R&D efforts at UCLA to comprehensively understand the properties of scintillation and ionization signals of noble liquids TPC, which is essential for direct dark matter detection and other rare event searches. The LAr system, which was mainly developed by Alden Fan, was shipped to Paris, France for a dedicated neutron beam run for purpose of understanding intrinsic characteristics nuclear recoil in LAr. Professor Hanguo Wang led the re-construction work on site with other collaborators. The re-assembled system is now towards the final shape with thorough testing, and waiting for the beam run which is scheduled in early October 2016.

The R&D work for a novel photosensor, the Silicon Geiger Hybrid Tube (SiGHT), is in good shape in Professor Wang's lab with the main focus of Yi Wang, a visiting graduate student from IHEP, Beijing. The main idea of SiGHT is to replace conventional multi-dynode PMTs with

a hybrid technology, consisting of a low temperature sensitive bialkali photocathode for conversion of photons into photoelectrons and a low dark count silicon photomultiplier (SiPM) for photoelectron signal amplification. SiGHT can achieve ultra-low intrinsic radioactivity, high quantum efficiency and stable performance at low temperatures, which are required features for rare event searches such as direct dark matter detection and neutrinoless double beta decay experiments. CsI photocathode capable of remaining sensitive at low temperatures has been successfully coated and tested in the lab, and the first SiGHT prototype is currently under development.

Finally, with successful experiences of developing HVFT for several large experiments such as ICARUS, ZEPLIN, XENON, DarkSide and CAPTAIN over years, Professor Wang's group is responsible for the design and construction of HVFT for the Deep Underground Neutrino Experiment (DUNE), a leading-edge, international experiment for neutrino science and proton decay studies. By utilizing LAr TPC technology as well, DUNE needs to bias the cathode of TPC to a voltage as high as -185 kV, which is quite a challenge for the HVFT. With the main focus of Xiang Xiao, the design of HVFT and the associated filter box is completed, and the group is moving to the construction phase.

Yixiong Meng graduated in November 2015 and works as data scientist in financial industry. Alden Fan graduated in July 2016 and works as postdoc (Kavli fellow) in the LUX-ZEPLIN collaboration at SLAC. Xiang Xiao joined Professor Wang's group as postdoc in March 2016.



Figure 3: A sample for assembling test of SiGHT.

THEORETICAL ELEMENTARY PARTICLES

Eric D'Hoker

Eric D'Hoker has extended his research on connections between string theory and number theory in collaboration with Michael Green (Cambridge, England), Pierre Vanhove (IHES, Paris, France), and inaugural Schwinger Fellowship recipient Justin Kaidi -- who is a second year graduate student. In a series of papers, they have shown how to associate modular forms with graphs, which are basically Feynman diagrams for a conformal scalar field theory on a two-dimensional torus, and then use this associating to prove remarkable differential and algebraic identities between modular graph forms relating different loop orders. These identities help resolve several outstanding questions in string theory. Further relations with polylogarithms and multiple zeta values have also been established and exploited.

D'Hoker has presented some of these results recently at a workshop "Automorphic forms and string theory" at the Simons Center for Geometry and Physics at Stony Brook University. In collaboration with UCLA colleague and present chair of the Department of Mathematics, William Duke, he is now exploring implications in number theory of these identities between modular graph forms relating different loop orders. These identities help resolve several outstanding questions in string theory. Further relations with polylogarithms and multiple zeta values have

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In collaboration with Michael Gutperle, Andreas Karch, and future UCLA postdoc Christoph Uhlemann, D'Hoker is exploring the holographic dual to the mysterious 5-dimensional gauge theories whose existence is mandated by string theory, but whose field theory structure is unresolved to date.

Specifically, they were able to solve the complex system of supergravity differential equations needed to find solutions with the appropriate amount of supersymmetry. The project has really taken off, and there is a good chance that the structure of these field theories, which do not appear to admit a Lagrangian description, will be significantly elucidated as a result.

The grant proposal made to the NSF by Eric D'Hoker, Michael Gutperle, and Per Kraus was approved for a 3-year period until 2019.

THEORY OF ELEMENTARY PARTICLES, ASTROPARTICLE PHYSICS, AND PHENOMENOLOGY

Alexander Kusenko

Professor Alexander Kusenko and collaborators showed that primordial black holes could have masses in the range of interest to LIGO. The LIGO discovery of gravitational waves from the black hole mergers has opened a new window on the universe, and one expects exciting new discoveries in the near future. In a separate work, Kusenko and his students showed that relaxation of the Higgs field or another scalar field after inflation can explain the matter-antimatter asymmetry of the universe. This work was featured in Physical Review Letters as "Editor's suggestion" and "Featured in physics". It was also featured in Washington Post, Scientific American, and Astronomy magazine.

TEPAPP News:

- Congratulations to our alumna, Kalliopi Petraki, now a faculty member at University of Paris, on winning two major research Awards in Europe: the Vidi (800,000 Euro) and the ANR grant (450,000 Euro), totaling 1.4 million U.S. dollars! Kalliopi received her Ph.D. degree from UCLA in 2009 working with her thesis advisor Professor Alexander Kusenko.



Professor Kusenko and UCLA graduate students attending PACIFIC conference in French Polynesia. From left to right, Warren Essey (now a Software Engineer at Google, Inc.); Kalliopi Petraki (now a faculty member at U. of Paris); Ian Shoemaker (now a faculty member at USD).

- Professor Graciela Gelmini gave the "Paco Indurayn Colloquium" on Feb 10, a prestigious series of colloquia at the Universidad Autonoma de Madrid.
- Professor Alexander Kusenko was invited to give a Summary and Conclusion talk at the major international conference "TeV Particle Astrophysics" (TeVPA-2015) held in Kashiwa, Japan, October 26-30, 2015.
- The annual PACIFIC (Particle Astrophysics and Cosmology, Including Fundamental Interactions) conference is five years old and going strong! The conference was held every September since 2011 at the University of California R. Gump Research Station. The conference is funded by NSF and by RIKEN (Japan).

THEORETICAL AND COMPUTATIONAL PLASMA PHYSICS

Jenko Group:

Turbulence is widely recognized as an important and exciting frontier topic of both basic and applied plasma physics – as well as of many neighboring fields of science. Numerous aspects of this paradigmatic example of nonlinear multiscale dynamics remain to be better understood. Meanwhile, for both laboratory and natural plasmas, an impressive combination of new experimental and observational data, new theoretical concepts, and new computational capabilities (on the brink of the exascale era!) have and will become available. Thus, we are facing a unique window of opportunity to push the boundaries of our grasp of plasma turbulence. In this context, a main goal is to further unravel its crucial role in phenomena like cross-field transport of mass, momentum, and heat, particle acceleration and propagation, plasma heating, magnetic reconnection, or dynamo action. In this context, several key aspects of plasma turbulence research are being addressed in our group. Below, a brief overview of some of the main activities is given. More information can be found at: www.physics.ucla.edu/~jenko

Fundamental aspects of plasma turbulence

In several collaborative projects, we were able to significantly push the boundaries on the basic understanding of plasma turbulence by applying – for the very first time – several concepts and techniques from fluid dynamics to this kinetic problem. In this context, various nonlinear energy transfer processes in phase space were analyzed in detail and condensed into reduced models. In particular, it was found that complex self-organization processes tend to establish power law fluctuation spectra with non-universal exponents. Applications to experimental fluctuation measurements in the ASDEX Upgrade tokamak were given, and it was also discovered that similar phenomena occur in a much wider range of physical systems, including active fluids (e.g., turbulent bacterial suspensions). Furthermore, building on these insights, it became possible to develop Large Eddy Simulation (LES) techniques for kinetic plasma turbulence systems, which helped to reduce the computational effort for select test cases by more than an order of magnitude.

The role of turbulence in other plasma phenomena

One remarkable feature of plasma turbulence is that it plays an important role in several other research areas, including energetic particles, dynamos and the magneto-rotational instabilities, as well as magnetic reconnection. Therefore, one goal was to explore the links between them in novel ways. One example for this approach was to carry out MHD simulations with an unprecedented level of realism (using the Heracles and SFEMaNS codes) for the Princeton MRI experiment, aiming at guiding a redesign of the laboratory set-up to maximize the chances of detecting the MRI under controlled conditions. One key idea developed in this context, the use of conducting endplates, is to be tested experimentally shortly. Another set of (MHD and kinetic) simulations, supported by analytical theory, was used to shed new light on the interaction between turbulence and energetic particles, as far as both acceleration and propagation are concerned. This line of research was applied to two problems, namely the properties of cosmic rays and the creation of collisionless shocks in the LAPD experiment at UCLA. In the latter case, various conditions facilitating this ambitious goal have been identified, increasing the chances of realizing this long-standing dream of an entire community. Also, gyrokinetic and fully kinetic simulations of turbulent reconnection have been performed and analyzed. One key finding in this context has been the discovery that the turbulent dissipation in weakly collisional plasmas is not well correlated spatially with the location

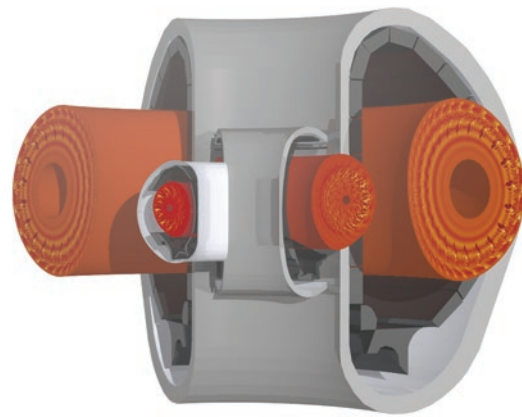


Figure 1: Simulations of turbulent dynamics for three tokamak experiments (ASDEX Upgrade, JET, and ITER) carried out with the GENE code.

of current sheets. Instead, while energy is transferred from fields to particles in their neighborhood, it is transported away by kinetic processes before it is subject to collisional dissipation.

Turbulent transport in stellarators

Recently, the gyrokinetic turbulence code GENE, originally developed for tokamak applications, has been extended to cover full-flux-surface variations of non-axisymmetric magnetic geometries and employed to study geometric turbulence control in stellarators. The magnetic surfaces of modern stellarators are characterized by complex, carefully optimized shaping and exhibit locally compressed regions of strong turbulence drive. Massively parallel computer simulations of plasma turbulence revealed, however, that stellarators also possess two intrinsic mechanisms to mitigate the effect of this drive. In the regime where the length scale of the turbulence is very small compared to the equilibrium scale set by the variation of the magnetic field, the strongest fluctuations form narrow band-like structures on the magnetic surfaces. Thanks to this localization, the average transport through the surface is significantly smaller than that predicted at locations of peak turbulence. This feature results in a numerically observed upshift of the onset of turbulence on the surface towards higher ion temperature gradients as compared with the prediction from the most unstable regions. In a second regime lacking scale separation, the localization is lost and the fluctuations spread out on the magnetic surface. Nonetheless, stabilization persists through the suppression of the large eddies (relative to the equilibrium scale), leading to a reduced stiffness for the heat flux dependence on the ion temperature gradient.

First gyrokinetic turbulence simulations for the scrape-off layer region of tokamaks

While there has been a lot of progress in doing gyrokinetic simulations of turbulence in the main core region of fusion devices, it is much more challenging to handle their edge region, where there are major computational challenges, such as handling large-amplitude fluctuations robustly and implementing effective boundary conditions for modeling the sheath at plasma-wall interfaces. In the past few months, the first successful GENE simulations in a SOL region were carried out. For this purpose, the GENE code has been extended from a “delta-f” code to a fully non-

linear “full-f” code, which is important in the edge region where the fluctuation amplitudes can be large. A first series of tests of this full-f capability for a 1D2V ELM heat pulse problem has demonstrated that GENE is able to reproduce the earlier results from another gyrokinetic code.

Turbulent dissipation in the solar wind

Meanwhile, the GENE code has also been applied to the study of turbulent dissipation in natural plasmas like the solar wind, a problem which is widely regarded as a key unsolved problem in space plasma physics. Interestingly, gyrokinetic theory, originally derived to describe strongly magnetized fusion plasmas, is very well suited to efficiently capture the physics of the dissipation range in turbulent natural plasmas. Nonlinear energy transfer and dissipation in Alfvén wave turbulence were analyzed in the first gyrokinetic simulation spanning all scales from the tail of the MHD range to the electron gyroradius scale. For typical solar wind parameters at 1 AU, about 30% of the nonlinear energy transfer close to the electron gyroradius scale is mediated by modes in the tail of the MHD cascade. Collisional dissipation occurs across the entire kinetic range (below the ion gyroradius). Both mechanisms thus act on multiple coupled scales, which have to be retained for a comprehensive picture of the dissipation range in Alfvénic turbulence. Questions regarding the relevance of phenomena not contained in gyrokinetics (like cyclotron resonances) have also led us to initiate a systematic comparison between gyrokinetics, a hybrid kinetic-ion/fluid-electron approach, and a fully kinetic approach. It was found that the gyrokinetic model, while lacking high-frequency solutions and cyclotron effects, faithfully reproduces the fully kinetic Alfvén wave physics close to, and sometimes significantly beyond, the boundaries of its formal range of validity.

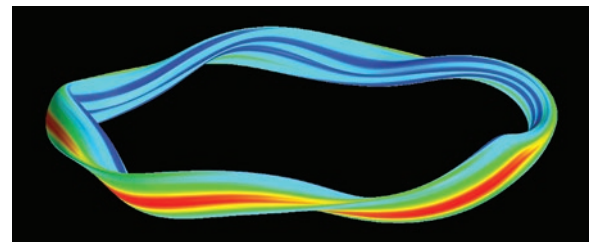


Figure 2: GENE simulations of stellarators like W7-X indicate that systematic optimizations of these configurations with respect to turbulent transport are possible.

THEORETICAL/COMPUTATIONAL BIOPHYSICS

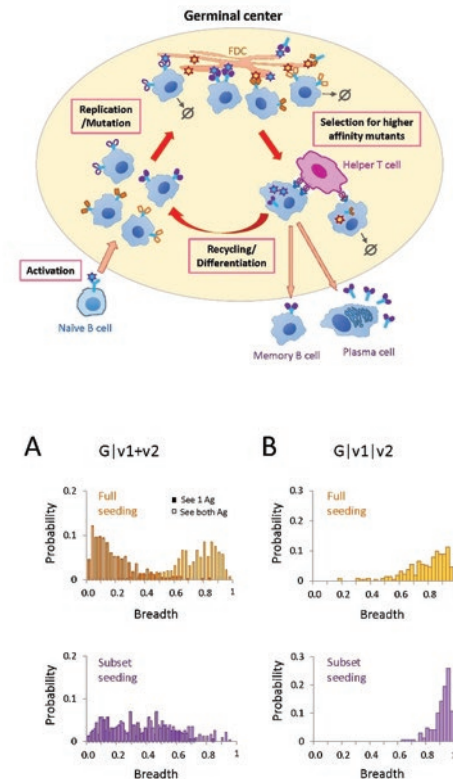
Shenshen Wang Group

Since her arrival in UCLA January 2016, Professor Shenshen Wang has focused on setting up her research program. Professor Wang works at the interface of physics and biology, specialized in two areas of biophysics research – mechanics and dynamics of active matter (dynamic assemblies of self-driven components) and evolutionary dynamics of the

immune system (an adaptive hierarchical organization of cells and molecules that evolve to defend the host against diverse invaders). She is developing a multiscale theoretical framework rooted in statistical physics and employing computational techniques to describe these complex living systems, which self-organize in space and time and operate off equilibrium. The understanding achieved will help innovate design of responsive materials and useful vaccines not currently existing.

Building on her previous work (Wang et al. Cell, 2015) that has received direct experimental support (Escolano et al. Cell, 2016), Professor Wang has recently considered an important new aspect of antibody evolution – diversity loss of founder cells, which can significantly affect evolutionary dynamics of finite lymphocyte populations in response to a changing antigen environment. Antibody-producing cells undergo a real-time Darwinian process to improve their binding affinity for encountered antigens (see image below), where a large diversity of seeding cells is thought to be associated with efficient adaptation. Wang has shown that, very counterintuitively, a less diverse seed not necessarily hampers adaptation, but can even favor the expansion and dominance of cross-reactive clones that can recognize many variants of the highly mutable pathogen, a desirable outcome of vaccination. The key lies in the temporal arrangement of selection forces – the unexpected evolutionary benefit only occurs when selection forces are presented sequentially rather than in parallel. Furthermore, the proposed scheme can focus antibody response onto the target vulnerable part of the pathogen, despite distracting

binding sites being more accessible and entropically favored. These findings not only provide mechanistic guides to aid in design of vaccine strategies against fast mutating pathogens (such as flu and HIV), the principles of focusing evolutionary processes under constraints of diversity bottleneck and distracting selective pressures have implications in a much broader context of evolutionary dynamics in nature. This work is under revision.



Christian Fronsda

Fronsda is continuing his development and advocacy of Action Principles in Hydrodynamics, Thermodynamics, Electromagnetics and Astrophysics. This year has seen the publication of 3 papers (1,2,3). Most recently Fronsda has completed two applications in new areas. The first is an investigation of angular momentum conservation in the theory of fluids. It is found that (1) The concept is well defined only in a formulation based on an Action Principle and (2) Angular momentum is conserved in irrotational motion only if the pressure is constant. (4) This accounts for the notorious failure of Rayleigh's criterion in stability analysis, still quoted in modern textbooks without explanation of the fact that it is in contradiction with experiment. The second application argues that the constitutive relations of electromagnetism have nothing to do with Lorentz invariance (as claimed by Einstein and Laub in 1908 and refuted by Pellegrini and Swift in 1995) but that these relations must be found among the Euler-Lagrange equations of a dynamical theory of the material. (5)

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Sergio Ferrara

The main research over the last academic year has been devoted to spontaneously broken Supersymmetry in Cosmology and Particle Physics. More specifically, a detailed investigation has been made of supergravity models for inflation consistent with the latest CMB observations of Planck 2015, which provide very accurate measurements of the spectral index of scalar perturbations, as well as of the tensor-to-scalar ratio. Using techniques of non-linear realizations of supersymmetry, which are particularly powerful when applied to de Sitter plateau inflation, minimal supergravity models for the inflaton potential have been proposed which can be made consistent with dark energy and supersymmetry breaking at the end of inflation [1].

Other important investigations, which also use non-linear realizations of rigid broken supersymmetry, include the study of non-linear theories of vector fields that generalize the Born-Infeld theory of non-linear electromagnetism [2]. In the local case higher-curvature Lagrangians, which are dual to standard Supergravity coupled to matter, have been derived, one of which is actually dual to the local version of the Volkov-Akulov Theory [3]. The latter plays a role in the description of the string landscape, using brane dynamics, in the Supergravity regime.

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- [2] S. Ferrara, A. Sagnotti and A. Yeranyan, "Two-Field Born-Infeld with Diverse Dualities," arXiv:1602.04566 [hep-th], doi:10.1016/j.nuclphysb.2016.06.027. To appear in a special *Nucl. Phys. B* issue dedicated to the memory of Raymond Stora.
- [3] E. Dudas, S. Ferrara, A. Kehagias and A. Sagnotti, "Properties of Nilpotent Supergravity," *JHEP* **1509** (2015) 217 doi:10.1007/JHEP09(2015)217 [arXiv:1507.07842 [hep-th]].

AWARDS:

Medal of Honour of JINR (Joint Institute for Nuclear Research), Dubna, Russia, Nov.2015;

Ettore Majorana Medal of EMFCSC (Ettore Majorana Foundation, Center for Scientific Culture, Erice, Italy, June 2016).

Foreign Member of the Russian Academy of Sciences(Elected on October 2016)

BASIC PLASMA PHYSICS EXPERIMENTS

Industrial Plasma Experiments , A Collaboration With Industry And Simulation.

**Patrick Pribyl, Walter Gekelman, Anders Hansen (UCLA)
Mark Kushner, Steven Lantham (Dept of EE Univ. Michigan)
Alex Patterson LAM Corporation**

World production of silicon amounts to about 8 million tons per year. Of this, about 0.1% ultimately ends up in semiconductor integrated circuits, or "chips". These chips typically start out as blank silicon wafers, 300 mm in diameter and less than a millimeter thick, cut from a single crystal. Ultimately, about one square inch of this highly refined silicon is produced yearly for every person in the world (about 7 billion square inches). In the production of these integrated circuits, the silicon wafer is typically exposed to different plasmas up to 200 times, so understanding the physics of the plasma processing is immensely important. At UCLA we are collaborating with an industrial partner, the LAM Corp, to research some of the more troublesome, but scientifically more interesting, aspects of the plasma operation.

There are several kinds of plasma reactors used to do semiconductor processing, distinguished primarily by the plasma production mechanism. We are studying a common scheme, using an external coil of wire located near a ceramic window to produce the plasma. This scheme is called ICP, or Inductively Coupled Plasma. A high power radio frequency (RF) source is used to drive the coil. Once the gas breaks down, the external "antenna" induces an anti-parallel current in the plasma that sustains and heats it. The ICP source donated to UCLA by the LAM Corporation is shown in figure 1.

A view into a similar processing chamber is shown in figure 2.

Much of the plasma processing involved in semiconductor manufacturing employs well-behaved reactions. Increas-

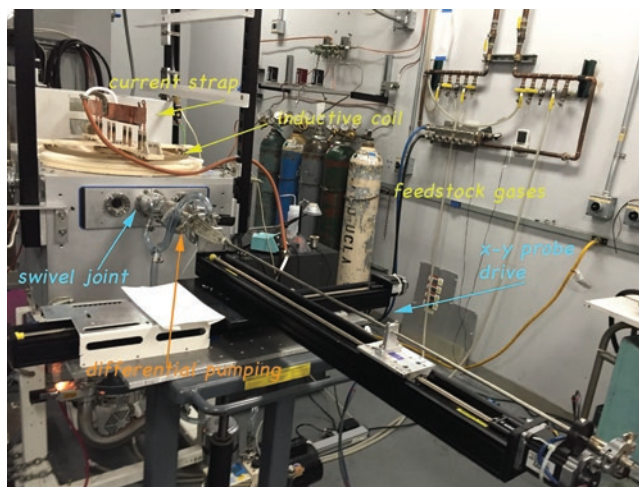


Figure 1: View of Lam tool with 2 D probe drive installed. The X-Y drive is computer controlled and may be programmed to go to any number of locations over the silicon wafer. A Langmuir probe is currently installed but it may be easily changed to other probes to measure electric fields, magnetic fields etc. The probe is differentially pumped as it moves so that no air can get into the device. The inductive coil is shown at the top. It is on a ceramic slab such that RF can be coupled into the device to make the plasma.

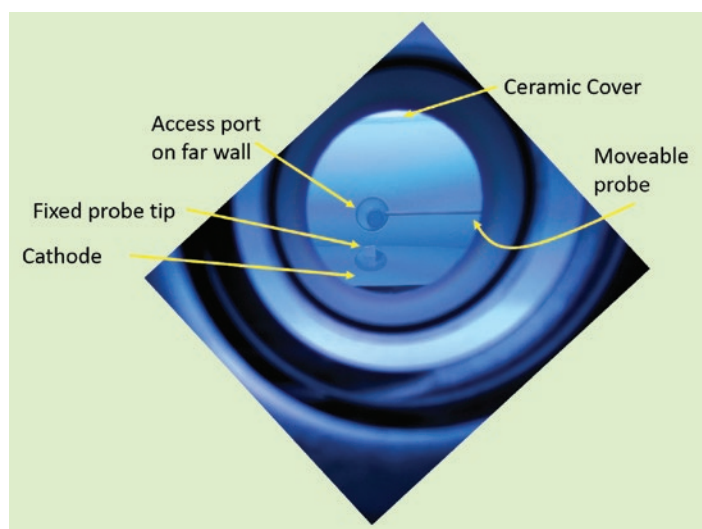


Figure 2: This shows the view inside a processing plasma reactor, with some probe diagnostics visible. Different gases have different characteristic colors; in this case we are using sulfur hexafluoride which gives the distinctive blue color. We have constructed a number of these reactors at UCLA.

ing power tends to proportionately increase the plasma density, at least above a threshold called the E-to-H transition (i.e. from "E-mode" at low power and "H-mode" at higher power). In many cases this threshold takes place at sufficiently low power as to be outside the realm of typical operating parameters. These plasmas have an abundance of positive ions interspersed with and neutralized by their lost electrons. However, several important gas reactants are highly electronegative - that is, the electrons tend to stick to the heavier atomic or molecular species.

These plasmas are composed primarily of positive and negative ions, with electrons being less than 10% of the charged species. They are frequently not stable, exhibiting complicated behavior in the middle of the target operating regime. The operating point may oscillate at a few hundred Hertz to 10 kHz. As such they may make results of the reaction less predictable, or even unusable.

Understanding and mitigating this electronegative instability is part of our research effort. We are making detailed measurements of plasma production and recombination effects in an effort to compare the experiment to several theoretical predictions. Work is proceeding in partnership with a parallel modeling effort undertaken by Mark Kushner's group at University of Michigan. We are partners with the LAM Corporation in an NSF GOALI grant. One unknown facet of the instability has been how much the external RF driving circuit connected to the antenna, together with its controls, affects the dynamics of the instability. We have been able to reduce the circuit to a minimum, with completely "open-loop" operation to demonstrate that there is little qualitative difference in the instability. We also have observed the transition with microsecond time resolution, demonstrating that the transition occurs globally across the radius of the wafer, within one or two cycles of the applied RF drive; there is no observable propagation from one region to another.

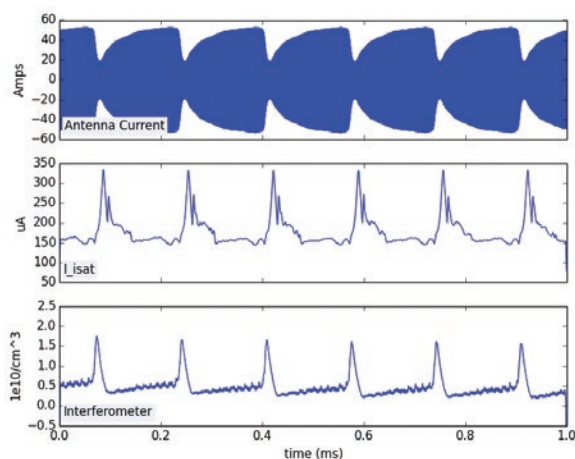


Figure 3: The electronegative instability leads to dynamic plasma behavior despite the steady state application of input power and gas pressure. In this case, the current in the antenna shows the effect of the increased loading, while the other two traces are measurements proportional to the positive ion density and the electron density respectively. In the third trace a microwave interferometer was used to determine the line average density across the device. This technique eliminates disturbances caused by placing a probe in the plasma as well as relying on theoretical assumptions to interpret the probe data. The probe can be therefore calibrated using the microwaves.

BASIC PLASMA SCIENCE FACILITY

Troy Carter, Walter Gekelman, George Morales, Steve Vincena, Shreekrishna Tripathi, Bart Van Compernelle, Pat Pribyl

UCLA Physics and Astronomy will continue to host a unique national experimental user facility as DOE and NSF have renewed their support for the Basic Plasma Science Facility (BaPSF) located in the Science and Technology Research Building (5 year award with \$13.5M in total funding). BaPSF provides a platform for studying fundamental processes in magnetized plasmas, such as waves, instabilities, turbulence, transport and magnetic reconnection. The centerpiece of the facility is the Large Plasma Device (LAPD) which generates magnetized plasmas using a large area hot cathode discharge inside a 20m long, 1m diameter vacuum chamber. Research on the device is carried out by a diverse set of external users from universities, national laboratories and industry as well as the local UCLA plasma group, which controls 50% of the facility experimental time. Some research highlights generated by users of the facility and the UCLA group are given here.

Resonant excitation of whistler waves by a helical electron beam (X. An, B. Van Compernelle, J. Bortnik, R. M. Thorne)

A major scientific problem of current interest is the determination of the dominant physical processes that drive the dynamic variability of the outer radiation belt. Resonant interactions between energetic electrons and whistler mode waves are thought to play an essential role.

Experiments at LAPD have focused on the excitation of whistler waves by energetic electrons under various plasma and beam conditions. The injected electrons couple to whistler waves in the plasma in a broad frequency band. Cross correlation techniques allow the reconstruction of the mode pattern of the wave at each frequency (see figure). Using this analysis it was found that the beam electrons resonantly transfer energy to the waves, both through Landau resonance $\omega = k_{\parallel} v_{\parallel beam}$ and through cyclotron resonance $\omega = k_{\parallel} v_{\parallel beam} \pm \Omega_e$. Experimental results

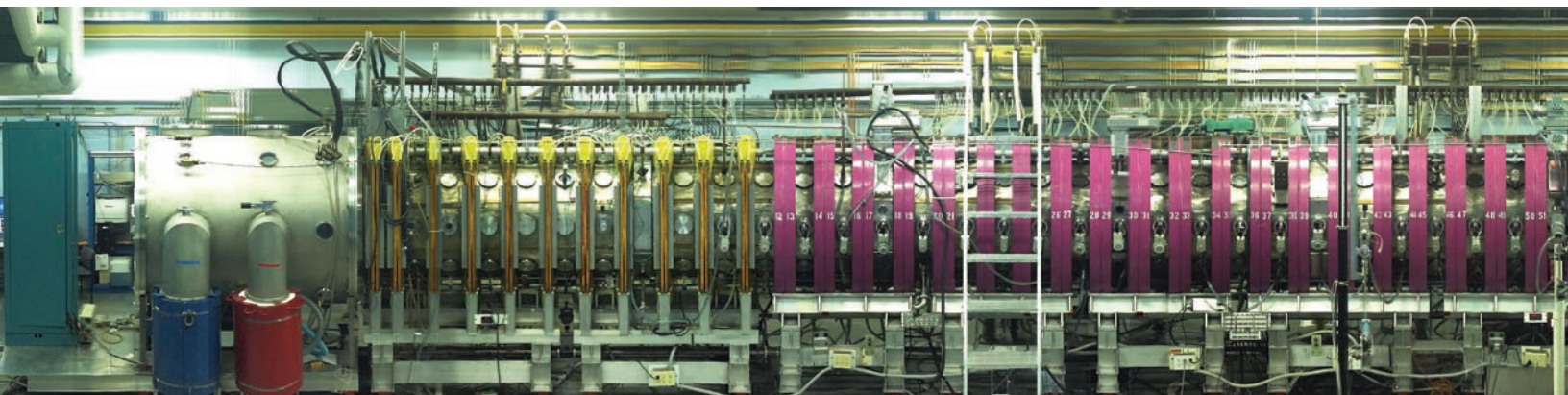
using beams with varying energy and density compared favorably to theoretical predictions.

X. An et al, Geophys. Res. Lett. 43, 2413-2421 (2015)

First observation of a parametric instability of shear Alfvén waves (Seth Dorfman, Troy Carter)

Alfvén waves are fundamental low frequency modes in a magnetized plasma; they are analogous to waves on a violin string where instead of a string vibrating, the magnetic field lines vibrate and carry the plasma along for the ride. These waves are important in astrophysical plasmas such as accretion disks and stellar winds. In these plasmas, turbulence that arises can be thought of as a collection of interacting Alfvén waves, transferring energy between each other and with the charged particles which comprise the plasma. Understanding nonlinear interactions between these waves is therefore of fundamental importance to understanding, e.g. accretion of matter and heating in accretion disks around compact objects such as black holes. Using the Large Plasma Device, we have studied the behavior of large amplitude antenna-launched Alfvén waves. For the first time in the laboratory, we have observed a parametric instability of shear Alfvén waves, where a large amplitude wave decays into two daughter waves (see figure). This process is thought to contribute to the generation of turbulence in, e.g, the solar wind.

S. Dorfman and T.A. Carter, Physical Review Letters 116, 195002 (2016).



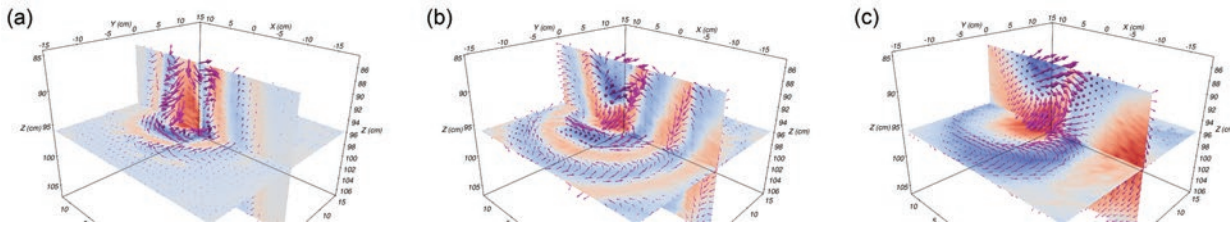


Figure 2: Measured mode structure of whistler waves excited by a 3 keV electron beam at (a) $\omega = 0.15 \Omega_e$, (b) $\omega = 0.25 \Omega_e$ and (c) $\omega = 0.35 \Omega_e$.

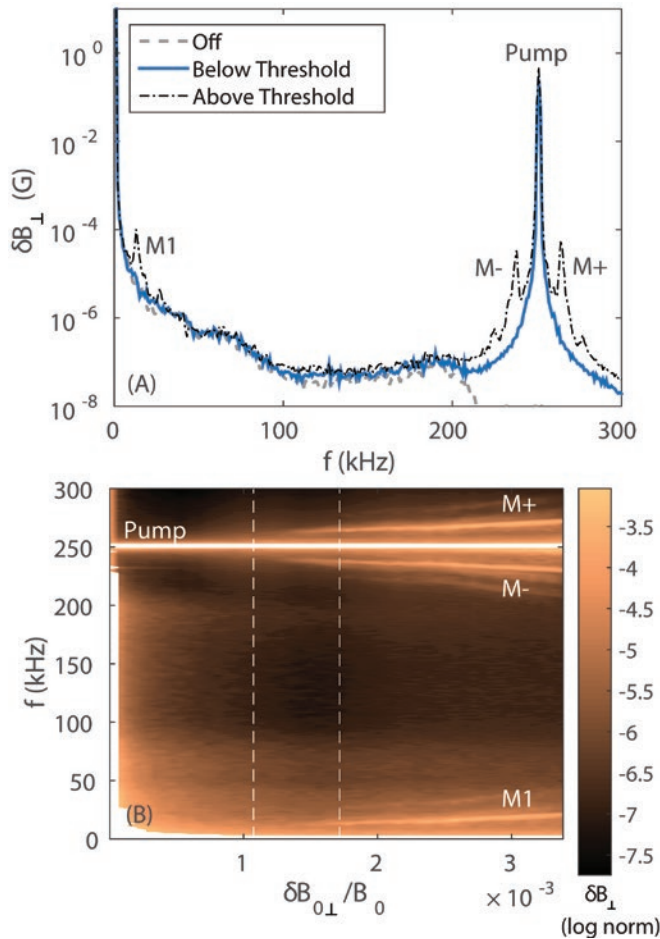


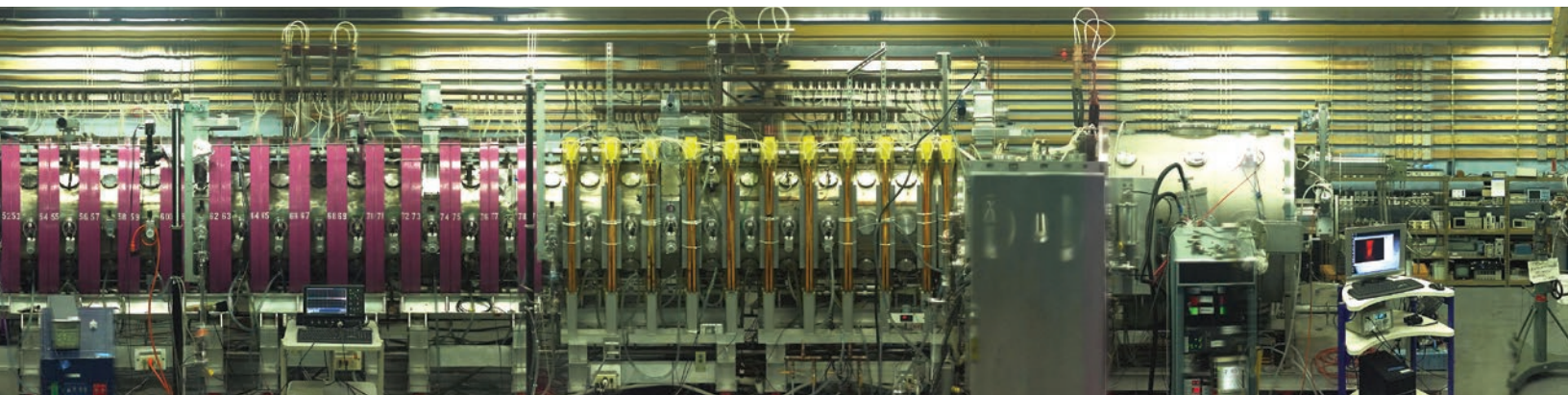
Figure 3: (A) Frequency spectrum of magnetic field fluctuations showing development of daughter waves (M1, M+, M-) when the pump wave is above an amplitude threshold. (B) Parametric dependence of the daughter wave frequencies as a function of pump amplitude.

Ohms law and resistivity of magnetic ropes

Walter Gekelman, T. De Hass, P. Pribyl

Magnetic flux ropes are twisted bundles of magnetic fields associated with spiraling currents. They are found everywhere on the surface of the sun and presumably all other stars. Sometimes they erupt to become a coronal mass ejection, which can travel all the way to earth, wreaking havoc on satellites and communications.

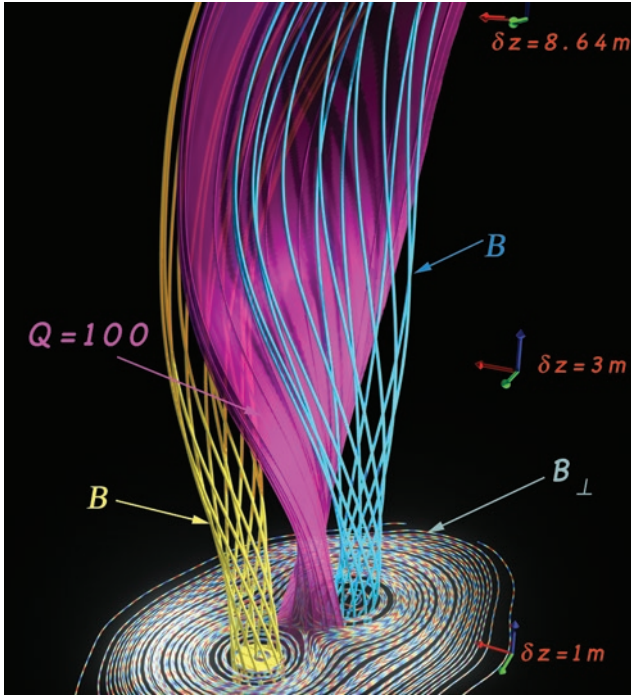
In an experiment, two flux ropes, (each 7.5 cm diameter with the inner edges 3 cm apart) were created using a highly emissive LaB_6 cathode. The cathode was masked with a carbon plate with two holes in it through which electron could pass. The anode was 11 m away; this set the length of the ropes. The experiment was done in a background He plasma in a uniform magnetic field of 330 G. The ropes were designed to contain current just above the kink instability threshold so that their interaction would not be highly chaotic. This allowed the flux ropes to bounce against one another, and allowing for fully three dimensional magnetic field line reconnection to occur. Magnetic field data was acquired at 2800 locations, 7000 time steps ($\delta t = 0.33 \mu\text{s}$), and 15 planes parallel to the machine axis. A newly designed emissive probe was also used to measure the plasma potential, ϕ , at the same locations as $\mathbf{B} \rightarrow$. The combination of these measurements allowed us to derive the total electric field, $\vec{E} = -\nabla\phi - \frac{\partial \vec{A}}{\partial t}$. The plasma density temperature, and flow velocity were also measured, resulting in enough data to evaluate all



the terms in the fluid version of Ohm's law and to determine the plasma resistivity. Figure 1 is the experimental magnetic field line data, which shows the two ropes and a region called the quasi-separatrix layer (QSL), calculating from the magnetic field data, snaking between them. The reconnection rate, which is the electric field induced along magnetic field lines, was also measured. Magnetic field is partially annihilated somewhere within the QSL, and the energy is released in the form of waves or flow. It is thought that the resistivity should be enhanced within the QSL.

$$\frac{m_e}{ne^2} \frac{\partial \vec{J}}{\partial t} = \vec{E} + \vec{u} \times \vec{B} - \frac{1}{ne} \nabla \cdot P + \frac{1}{ne} \vec{J} \times \vec{B} - \eta_{\parallel} \vec{J}_{\parallel} - \eta_{\perp} \vec{J}_{\perp}$$

The resistivity parallel to the local magnetic field was calculated from Ohm's law, and one instance of it is shown



in Figure 2. The resistivity can be as high as 20 times the classical value and is localized to the region of large currents. There is no evidence of enhanced resistivity in the QSL, although calculations using the magnetic helicity suggest otherwise. From these measurements of helicity, the average helicity within the QSL is 5 to 10 times the classical value, suggesting that localized regions within the QSL to be much greater. What is troubling is that there are regions where the resistivity is negative, an unphysical result. It is quite possible that the Ohm's law description is inadequate. Instead, we used the Kubo AC conductivity, which is derived from velocity correlations.

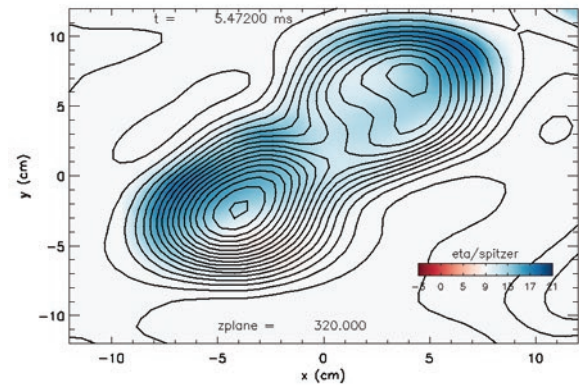


Figure 2: Plasma resistivity, , from Ohm's law on a plane 3.2 meters from the origin of the ropes. It is divided by the local value of the classical, or Spitzer, resistivity due to Coulomb collisions a function of the plasma density and temperature. The black lines are contours of constant current in the flux ropes. The current is largest at the center of each rope.

This, in effect, determines a collision frequency (and hence resistivity) for the 5 kHz repetition of these flux rope collisions. The Kubo conductivity is shown in Figure 3.

The conductivity in the center of the rope far from their origin ($z=7.68\text{m}$) as shown in Figure 3 is $3.7 \times 10^4 \text{ Ohm-m}$. The plasma resistivity at that location is equal to the classical value. Close to the source of the ropes at $z = 1.28 \text{ m}$ the resistivity is five times the classical value in the reconnection region between the two ropes. A lengthy paper on these measurements and their implication is in preparation for the Physics of Plasmas.

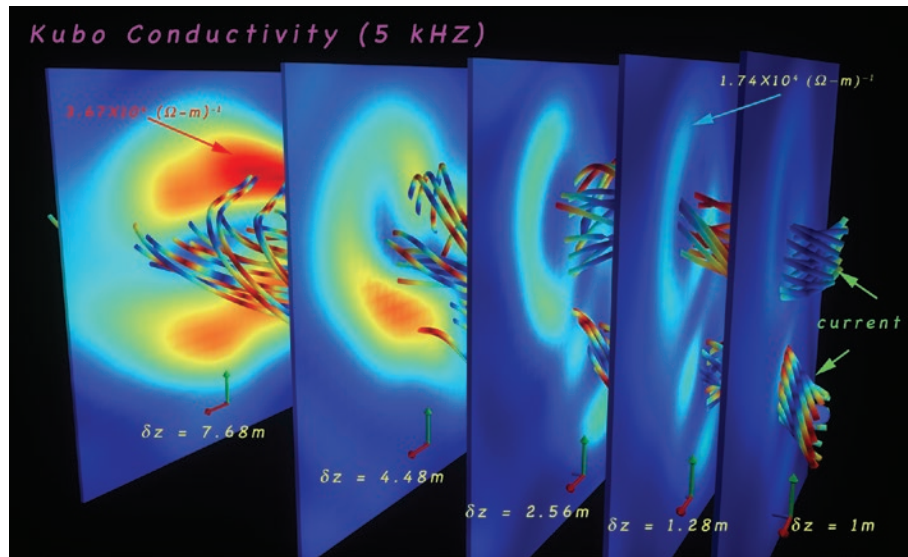


Figure 3: Plasma AC conductivity shown as colored contours on 5 planes. Also shown are current lines of the two ropes.

PLASMA DIAGNOSTICS GROUP

Terry Rhodes, Neal Crocker, Ed Doyle, Lothar Schmitz, Tony Peebles, David Brower, Troy Carter

The UCLA Plasma Diagnostics Group (PDG) are experts in advanced microwave and millimeter wave plasma diagnostics, plasma turbulence and transport and global plasma instabilities. The UCLA PDG advances the state of art in microwave and millimeter wave plasma diagnostics—including scattering, interferometry, polarimetry, reflectometry and radiometry—developing and implementing these diagnostics in fusion research experiments across the world and exploiting them to collaborate in the investigation of plasma turbulence and transport, and global plasma instabilities in fusion research plasmas. UCLA has participated in plasma research in the MegaAmpère Spherical Tokamak in the UK, the Experimental Advanced Superconducting Tokamak in Hefei, China, the Madison Symmetric Torus in Madison, WI, the Alcator C-Mod tokamak in Cambridge, MA, the DIII-D Tokamak in San Diego, CA and the National Spherical Torus Experiment – Upgrade, in Princeton NJ.

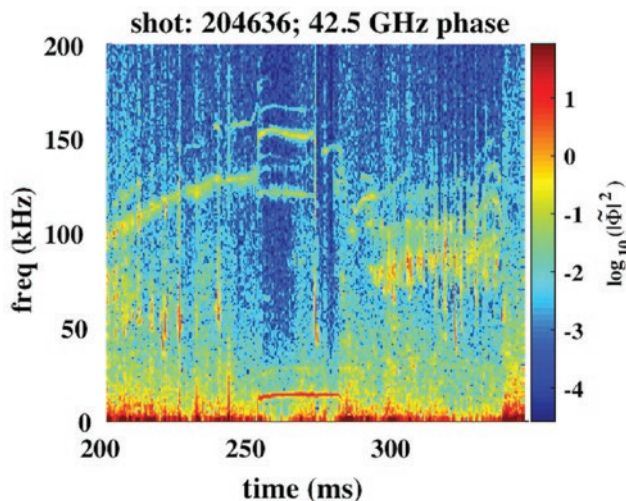


Figure 1: Spectrum of path length fluctuations ($\delta\phi$) from 42.5 GHz reflectometer in an NSTX-U plasma discharge.

A highlight of 2016 was the first measurement of density fluctuations with UCLA's fixed frequency reflectometer array (PI Terry L. Rhodes, Co-PI Dr Neal A. Crocker) in the National Spherical Torus Experiment – Upgrade (NSTX-U). Research operations of the NSTX plasma confinement device were suspended in 2011 to permit extensive capability upgrades, including a doubling of magnetic field strength to 1 Tesla, plasma current to 2 MA and neutral beam heating power to 12 MW, and a quintupling of plasma discharge duration to 5 seconds. The

upgraded device achieved its first confined plasma in late 2015 and research operations began in early 2016. UCLA installed an array of fixed frequency reflectometers for density fluctuation measurements in May of 2016 and is collaborating in several areas to exploit the measurements that are now possible. Figure 1 illustrates this with a spectrum microwave path (0ϕ) from one of the reflectometers. The optical path length provides an approximate measure of the plasma density fluctuations. The spectrum shows several time-evolving narrow-band peaks that correspond to global plasma oscillations, or modes, excited by the neutral beams and plasma gradients, as well as broadband turbulent fluctuations. One of the most exciting areas in which UCLA is collaborating is an experiment to validate gyrokinetic theory for turbulent transport in so-called Low-confinement mode (L-mode) plasmas in NSTX-U through comparisons of density fluctuation measurements with turbulence simulations. This experiment exploits the NSTX-U capability for higher magnetic field and longer plasma discharge duration.

UCLA has also developed and bench-tested a system for density fluctuation measurements in the core of NSTX-U via Doppler Backscattering (DBS). The system will be installed at NSTX-U for experimental use in early 2017. DBS measures density fluctuations via scattering of radiation launched into the plasma at a frequency low enough to undergo significant refraction. The radiation scattered directly backward by plasma turbulence is collected. The measurement is spatially localized by refraction of the incident microwaves as they

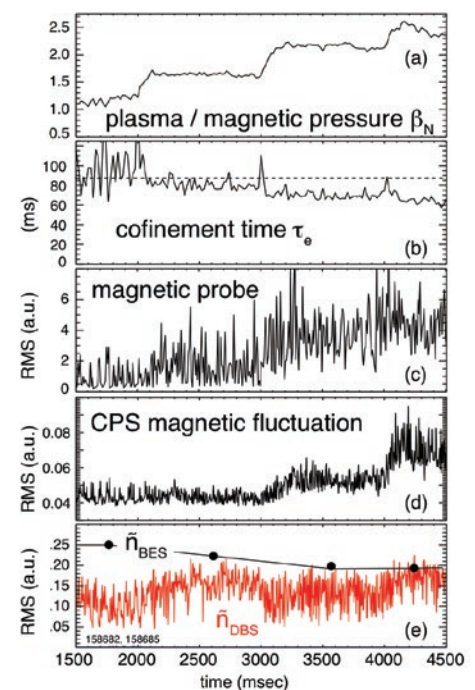


Figure 2: Plasma parameters and fluctuations in a DIII-D plasma discharge during a scan β of (ratio of plasma to magnetic pressure): (a) β ; (b) energy confinement time; (c) magnetic fluctuations measured by coil at plasma edge; (d) magnetic fluctuation measured by CPS; and (e) density fluctuations measured by Doppler Backscattering (\tilde{n}_{DBS}) and beam emission spectroscopy (\tilde{n}_{BES}). Barada, et al., RSI 87, 11E601 (2016)

approach cutoff in the plasma. The incident electric field swells in amplitude, enhancing the scattering cross-section and the wavenumber decreases, so the scattered radiation is dominated by scattering from larger amplitude, lower frequency turbulent fluctuations. The Doppler shift of the scattered radiation is then used to determine the propagation speed of the turbulence in the lab frame, which can be used to infer the plasma flow speed.

Another highlight of 2016 is recent advances made in the development of cross-polarization scattering (CPS) as a magnetic fluctuation diagnostic (PI Dr Terry L. Rhodes). Cross-polarization scattering of electromagnetic radiation, in which the scattered radiation has a polarization orthogonal to that of the incident radiation, is caused by magnetic perturbations in a magnetized plasma. These developments were the subject of an invited talk [K. Barada, et al., Rev. Sci. Ins. 87, 11E601 (2016)] delivered by UCLA Postdoctoral Scholar Kshitish Barada at the 21st Topical Conference on High-Temperature Plasma Diagnostics, Madison, Wisconsin, USA, June 2016. Barada showed results from a variety of experiments testing and validating the CPS system that UCLA has implemented on the DIII-D tokamak at General Atomics in San Diego, CA. These tests focused on the launch and receive polarization purity, spurious cross-polarized signals, and comparison to magnetic probes and expected response of magnetic fluctuations to plasma β (ratio of plasma to magnetic pressure) (Fig. 2), which are expected to increase in amplitude as β increases, in contrast with density fluctuations. Based upon these tests, it was concluded that when properly executed, the CPS signal is produced by internal magnetic fluctuations for a given location and wavenumber range.

UCLA's participation in the NSTX-U and DIII-D pro-

grams also serves its educational mission.

UCLA graduate student Shawn Tang (Thesis advisor Professor Troy Carter) participates in UCLA's research at NSTX-U, working with Neal A. Crocker to investigate the stability of high frequency Alfvén eigenmodes in NSTX-U and their contribution to energy transport. This investigation also afforded an educational opportunity for Nicholas Geiser, a visiting undergraduate from Fordham University, who performed a summer research project under Crocker's mentorship as a participant in the Physics and Astronomy Department's NSF-funded Research Experiences for Undergraduates (RE) program.

New UCLA graduate student Madeline Baltzer (Thesis advisor Professor Carter), who worked with Rhodes as an undergraduate this summer on an electron temperature fluctuation diagnostic for DIII-D, will also be engaged in thesis research there.

UCLA graduate student László Bardóczi (Thesis advisor Professor Carter) participates in UCLA's research at DIII-D under the supervision of Rhodes, where he investigates the interaction of turbulence with neoclassical tearing modes, a type of gradient-driven global mode. He recently (2016) published two journal articles, one in Physics of Plasmas and another in Physical Review Letters, and he led a DIII-D experiment in January 2016 directed at the topic of his investigation. Neoclassical tearing modes are naturally growing magnetic instabilities that tear the magnetic fabric of the plasma, creating magnetic islands, as shown in Fig. 3a, which can degrade plasma performance. The experiment on DIII-D led by Bardóczi discovered that plasma turbulence becomes weaker inside large magnetic islands (Fig. 3c). This reduction of turbulence helps large islands to become even larger, which can have deleterious effects on the confinement of fusion plasmas. However, the experiment also showed that turbulence can also prevent small islands from growing large, suggesting that small magnetic islands can sometimes inhibit their own growth into harmful large islands by driving turbulence while they are still small. Bardóczi was awarded an Invited Talk at the 58th Annual Meeting of the APS Division of Plasma Physics, San Jose, California, November 2, 2016, where he will present the findings. Working together, UCLA Postdoctoral Scholar A. B. Navarro (under the supervision of Professor Frank Jenko) and Bardóczi conducted nonlinear gyrokinetic turbulence simulations with magnetic islands using the GENE code (Fig. 3b). Initial comparisons to the experimental data are promising with GENE replicating the observed scaling of turbulence modification with island size.

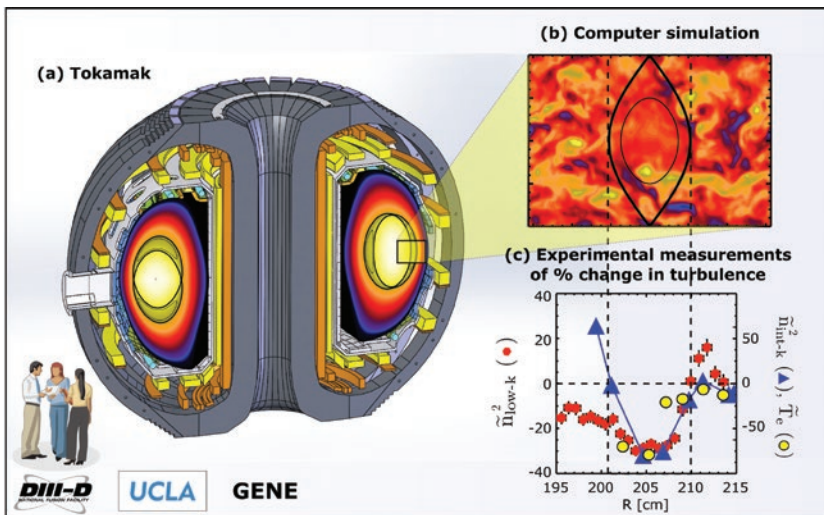


Figure 3: (a) Schematic view of the DIII-D tokamak with reconstructed electron temperature showing the magnetic islands. (b) GENE non-linear gyrokinetic simulations show modifications of turbulence levels across the magnetic islands. (c) Measured percentage change of turbulent density and turbulent temperature.

THEORETICAL PLASMA PHYSICS

George Morales

Stability of drift-cyclotron loss cone waves at the edge of fusion plasmas

An analytical study by W. Farmer, former UCLA graduate student and now research scientist at Lawrence Livermore National Laboratory, and Professor Morales, explored the possibility that a peculiar type of plasma instability that was identified to occur in linear mirror machines more than 50 years ago could play an important role at the edge of modern tokamak devices whose geometry is toroidal. The essence of the process is that in a mirror magnetic field there is an intrinsic loss of particles along the magnetic field direction that creates a 'loss cone', i.e., the velocity distribution function has a hole that results in a source of free energy that drives waves unstable. While in toroidal geometry there is no such parallel loss, it was realized that the gradient-drift due to the curved field lines causes ions moving opposite to the plasma current to be lost preferentially to the divertor surrounding the confined plasma. This generates a one-sided loss cone that can result in large fluctuations that impact energy and particle confinement. The calculations, published as a rapid publication in Nucl. Fusion 56, 064003 (2016), show that for conditions typical of H-mode plasmas in the DIII-D tokamak, the U.S. flagship fusion device, the critical gradient for such an instability is exceeded.

Model for avalanches in a hollow pressure filament

A theory and modeling study by graduate student Matt Poulos and Professor Morales considered a novel heating configuration recently implemented in the LAPD device at UCLA [B. Van Compernelle et al. PRE 91, 031102 (2015)]. The geometry essentially consists of a hollow pressure filament embedded in a cold, magnetized plasma. An eigenmode-based stability analysis was made of drift-waves excited by simultaneous gradients in density and temperature. A Braginskii transport code that includes the ExB flows of the unstable modes was used to self-consistently evolve the profile modifications in the presence of external heating. A shooting code was used to calculate the evolving mode structures as the profiles were modified by the flows. It was found that intermittent avalanches are triggered and their properties are in good agreement with the experimental observations. During the recovery phase after an avalanche the large difference between the relaxation times of density and temperature results in azimuthal filamentation of the profiles, as illustrated in Figure 1.

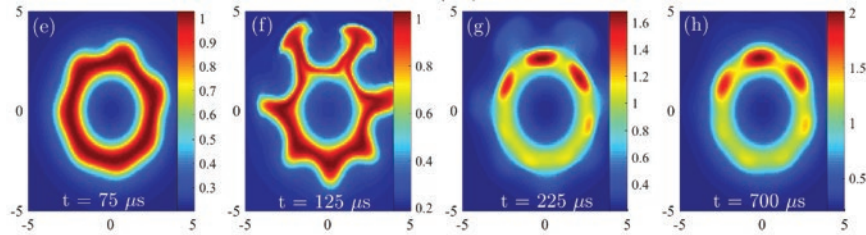


Figure 1: Color contours of electron temperature across magnetic field show evolution of an avalanche event and recovery to a filamented profile.

Self-adjoint integral operator for bounded nonlocal transport

Dr. J. Maggs and Professor Morales have developed a new integral operator to describe nonlocal transport in a 1D system bounded on both ends by material walls. The 'jump' distributions associated with nonlocal transport are taken to be Lévy α -stable distributions, which become naturally truncated by the bounding walls. The truncation process results in the operator containing a self-consistent, convective inward transport term (pinch). The properties of the integral operator as functions of the Lévy α -stable distribution parameter set $[\alpha, \gamma]$ and the wall conductivity have been determined. The integral operator continuously recovers the features of local transport when $\alpha=2$. The self-adjoint formulation allows for an accurate description of spatial variation in the Lévy parameters in the nonlocal system. Spatial variation in the Lévy parameters is shown to result in internally generated flows. An example of cold-pulse propagation in a nonlocal system illustrates the capabilities of the methodology, as seen in Figure 2. Examples of contemporary topics in which this methodology can be used include heat transport in semiconductor alloys, relaxation of photo-excited electrons in graphene, thermal conduction in crystalline silicone, and, of course, anomalous transport in magnetically confined plasmas.

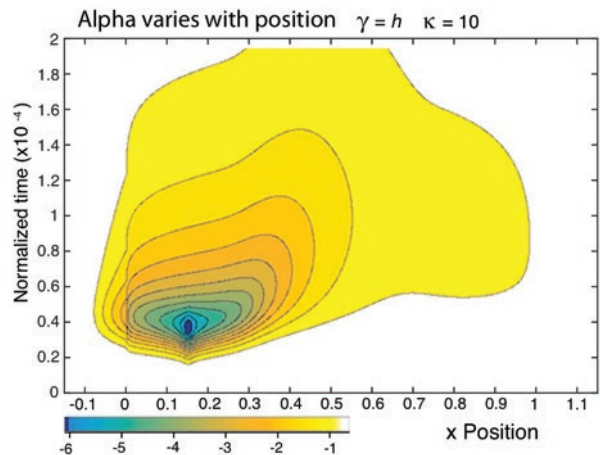


Figure 2: Spatio-temporal evolution of an initial cold-pulse applied to a system whose Lévy α -parameter varies with position from highly nonlocal at the edge to classical, $\alpha=2$, at the center, shows that core acts as a thermal barrier.

SPACE PLASMA SIMULATION GROUP (SPSG)

Maha Ashour-Abdalla, Jean Berchem, Mostafa El-Alaoui, Haoming Liang Robert Richard, David Schriver, Meng Zhou

The Space Plasma Simulation Group (SPSG) has continued to carry out cutting edge research on a number of different problems in space physics. The overall theme in these projects is to use various types of numerical plasma simulation codes in close coordination with observations made by NASA satellites at the Earth and at other planets. The satellite data is used both to initialize the simulations and to validate the results. The simulations are then used to determine the physical mechanisms that are operating and also to put the single point satellite measurements in a global context.

In March 2015 the Magnetospheric Multiscale Mission (MMS) was launched. This four spacecraft mission is investigating one of the most critical problems in solar and space physics – the physics of magnetic reconnection. In particular reconnection is generally believed to be the main driver of dynamics in the Earth's magnetosphere. MMS will provide the first up close observations of these phenomena. The SPSG was selected as one part of a theoretical team to work with the experimenters to understand this mechanism. In addition to members of the Physics and Astronomy Department, the MMS project includes Professor Ray Walker of the Department of Earth, Planetary, and Space Sciences and Professor Giovanni Lapenta from Katholic University in Belgium. To support the MMS mission, the SPSG have developed a new numerical simulation technique whereby a particle in cell simulation (iPIC3D) is embedded within a global magnetohydrodynamic (MHD) simulation of Earth's magnetosphere.

The reconnection process is thought to occur in the electron diffusion region (EDR) where electron motion is no longer controlled by the magnetic field (un-magnetized

electrons). Recently MMS observations of a putative electron diffusion region were presented. They were based on the observation that crescent-shaped electron velocity distributions in the plane perpendicular to the magnetic field occur in the electron diffusion region near reconnection sites at Earth's magnetopause. We used the new MHD/iPIC3D simulation technique to examine the origin of the crescent-shaped distributions in the light of our new finding that ions and electrons are drifting in opposite directions when displayed in magnetopause boundary-normal coordinates. The leading interpretation of the origin of the crescents was that they were caused by $\mathbf{E} \times \mathbf{B}/B^2$ drift motion where \mathbf{E} is the electric field and \mathbf{B} is the magnetic field. In Figure 1 we present electron and ion distribution functions observed by MMS. Note that both the ions and electrons have crescent shaped distributions but that they are in opposite directions ruling out the $\mathbf{E} \times \mathbf{B}$ drift explanation. Our high-resolution multi-scale simulation captured sub-electron skin depth scales. The results suggest that the crescent-shaped distributions are caused by meandering orbits without requiring any additional processes found at the magnetopause such as the magnetopause ambipolar electric field [Lapenta *et al.*, 2016]. In addition we used an adiabatic Hamiltonian model of particle motion to confirm that the conservation of canonical momentum in presence of magnetic field gradients causes the formation of crescent shapes without requiring an $\mathbf{E} \times \mathbf{B}$ drift. In addition we found crescent distributions in regions outside of the EDR. Crescent distributions alone are not unique signatures of the EDR. An important consequence of this finding is that we expect crescent-shaped distributions also to be observed in the magnetotail, a prediction that MMS will be able to test next year.

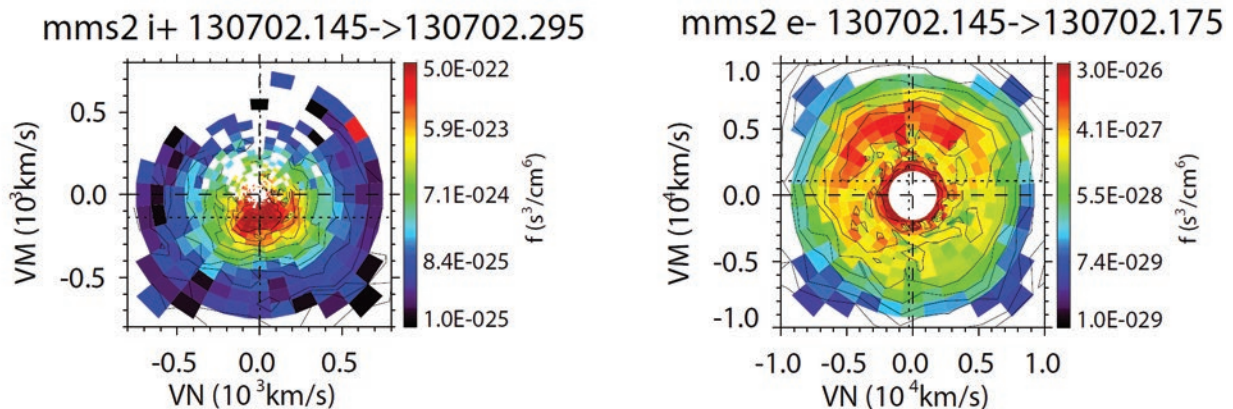
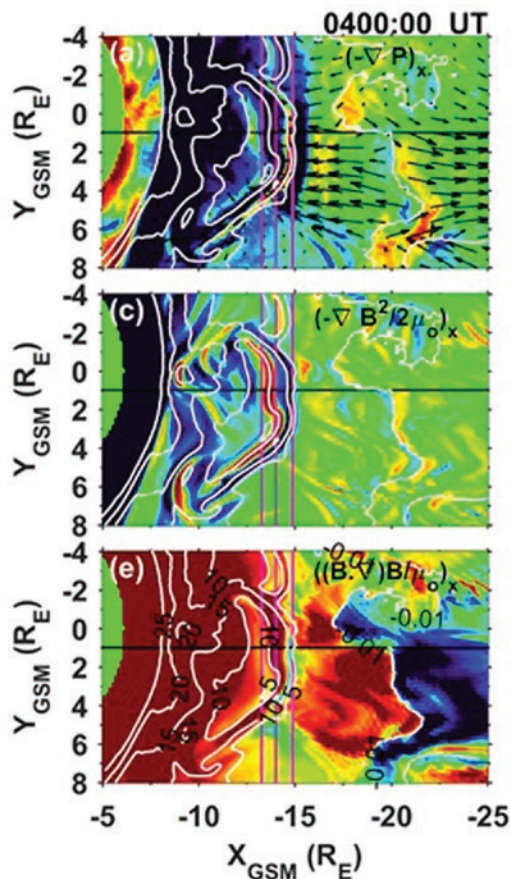


Figure 1: Velocity distributions observed by the Magnetospheric Multiscale Mission. Note the the distributions form crescent shapes in velocity space. The electron (right) and ion (left) crescents are in opposite directions.

The SPSG has also examined the role of turbulence in Earth's magnetosphere. In the magnetotail, plasma and magnetic flux is transported earthward by convection. Transport is intermittent, and localized fast flow channels are a major contributor to it. The fast flow channels originate at reconnection sites in the magnetotail and terminate at dipolarizations, earthward moving regions of enhanced magnetic field. We have used the global MHD simulation of magnetotail dynamics during a substorm event to investigate the stresses in the magnetotail associated with flow channels and dipolarizations. One major consequence of fast earthward flow channels is that they drive large scale vortices that initiate turbulence. Figure 2 shows forces in the X direction on the maximum pressure surface at 0400 UT during the interval studied. The top panel in Figure 1 shows that the pressure gradient force is weakly earthward tailward of $-17 R_E$, but strongly tailward earthward of this, acting against penetration of the fast flow earthward of $-14 R_E$. The leading edge, trailing edge and center of a dipolarization located along the horizontal dashed line are indicated by magenta lines. The magnetic pressure gradient force shows the opposite pattern in the middle panel,



which shows the magnetic pressure gradient force, while the bottom panel shows the magnetic tension force. In Figure 1 earthward of the reconnection region fast flows are associated with a strong earthward tension force (bottom panel). The tension force is dominant over a large area where the other

forces are strong only in relatively small regions. At the earthward edge of this area, bands of strong tailward pressure force appear (top panel). As the flow approaches the dipolarization the tension force diminishes and the gradient in the magnetic and plasma pressure slow the flow. Earthward of the dipolarization, a tailward magnetic pressure gradient force becomes important, but is partially cancelled by a reversed (tailward) gradient in the thermal pressure. Still closer to the Earth, the total force is weak.

Members of the SPSG, in collaboration with colleagues from ESA (Noordwijk, The Netherlands), IRAP (Toulouse, France) and APL at the Johns Hopkins University carried out 3D global simulations of the interaction of the solar wind with the geomagnetic field to investigate the entry of solar wind ions into the dayside magnetosphere when a large rotation of the interplanetary magnetic field (IMF) occurs. The study uses idealized solar wind conditions where the IMF rotates smoothly from a southward toward a northward direction. Results of large-scale kinetic simulations reveal that a strong north-south asymmetry develops in the pattern of precipitating ions. For a counterclockwise IMF rotation, a spot of high-energy (about 12 keV)

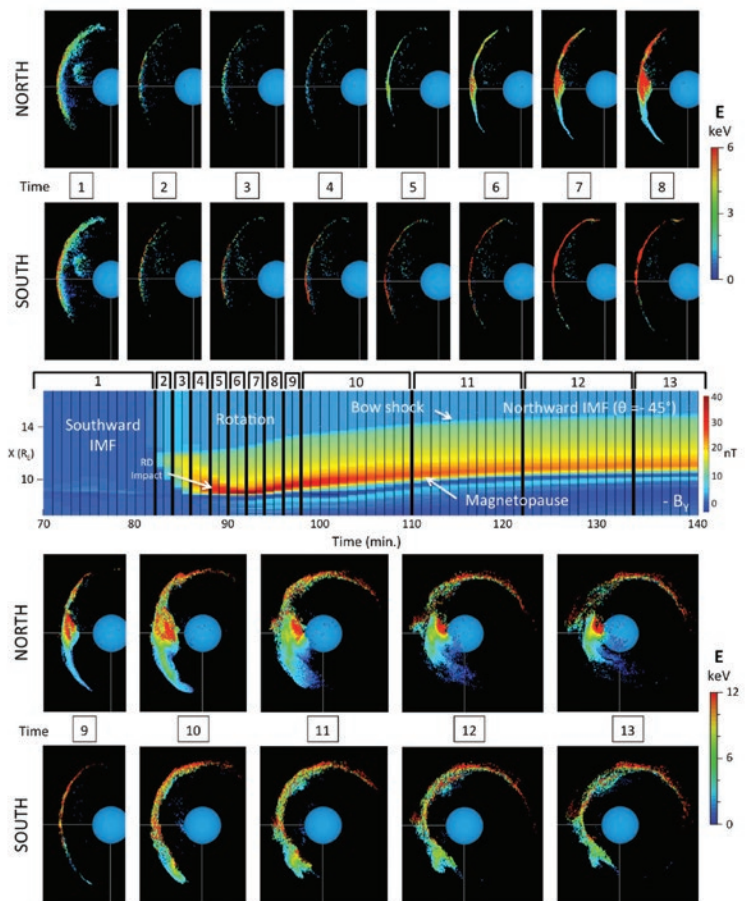


Figure 3: Precipitation patterns corresponding to time intervals TI-1 through TI-8 are shown in the upper panel, while those for TI-9 to TI-13 are shown in the lower panel. The simulation indicates that for a counterclockwise IMF rotation from its original southward direction, a spot of high-energy particle injections occurs in the northern hemisphere but not in the southern hemisphere (see snapshots from TI-11 to TI-13).

particle injections develop in the northern hemisphere, but not in the southern hemisphere. This is shown in Figure 3 that display snapshots of the simulation's spherical detector centered on Earth, which is used to capture the time history of the ion entry through the magnetospheric boundary. The location of each particle crossing the detector has been coded according to the particle's energy. The upper and lower panels display time series of the northern (top rows) and southern halves (bottom rows) of the detector. Each hemisphere is viewed from above the northern hemisphere. The Sun is to the left. The middle panel shows the time history of the IMF, with Time Intervals (TI) delimited by thick black lines. Additional study of the evolution of the topology of the magnetic field lines indicates that the draping and subsequent magnetic reconnection of newly opened field lines from the southern hemisphere over the dayside magnetosphere cause the symmetry breaking. The reverse north-south asymmetry is found for a clockwise IMF rotation from its original southward direction. Trends observed in the ion dispersions predicted from the simulations are in good agreement with the ion precipitation measured by the Cluster spacecraft in the mid-altitude northern cusp, which motivated the study.

The group has also continued to make progress in understanding Mercury's magnetosphere using a global hybrid simulation that fully resolves the ion gyro-radius. This research effort provides theoretical support for the MESSENGER spacecraft mission, which began orbiting Mercury in March 2011 and crashed into the planet in April 2015. The focus of the research has continued to be on the transport and acceleration of electrons in Mercury's magnetosphere. The modeling approach is to use the electric and magnetic fields from the self-consistent hybrid simulations for Mercury's global magnetosphere and to follow individual electrons within these fields as launched from the solar wind and the magnetotail. This is done since the hybrid simulation itself treats electrons as a massless fluid and thus cannot provide information about electron dynamics. Results from the electron particle tracing in Mercury's magnetosphere for relatively quiet solar wind with northward interplanetary magnetic field (IMF) are shown in Figure 4.

The results in figure 4 show that typically on the nightside plasma sheet, electron energies are of the order of 1-10 keV, with some higher energy populations along the dawn flank up to ~ 100 keV. These results are consistent with data from the MESSENGER spacecraft, which indicates that bulk electron energies are for the most part of the order of a few keV, with occasional observations of higher energy (~ 100 keV) electrons. In the lower right panel of figure 3, the kappa parameter (ϵ) is defined as the square root of the local magnetic field radius of curvature divided

by the local electron gyroradius, and provides a measure of the particle's adiabaticity; when $\epsilon \gg 10$ the particle is generally adiabatic, for $\epsilon < 10$ the particle can become demagnetized and behave non-adiabatically. It can be seen in figure 3 that the electron is initially energized in the magnetotail via non-adiabatic acceleration near low field reconnection regions where the electron can become demagnetized, as indicated when ϵ drops below about 8. The electron then gains more energy as it is convected planetward on the nightside and as it moves into a stronger region of magnetic field it gains energy by betatron acceleration, ultimately reaching about 2 keV before precipitating onto the planet surface. Although this shows the trajectory of only one single electron, this behavior is typical of the bulk of electrons that constitute the near-planet plasma sheet on the nightside, many of which eventually precipitate at the planet due to the large loss cone at Mercury ($\sim 35^\circ$).

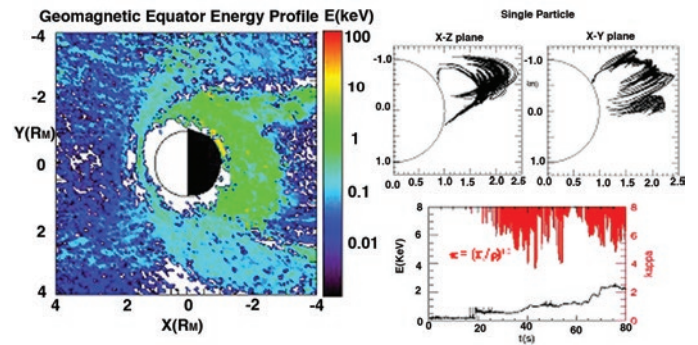


Figure 4: On the left panel the electron energy profile is shown for Mercury in the geomagnetic equator looking down from the North (Sun to the left) with color coding such that blue-green are lower energies and yellow-red are higher energies according to the color bar. In the right panels are single particle trajectory results for a precipitating electron with the particle trajectory in the X-Z plane (noon-midnight meridian) upper left, the X-Y (equatorial) plane upper right and the particle's energy (black) and kappa parameter (red) time history lower right.

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UCLA BASIC PLASMA PHYSICS LAB

R. L. Stenzel And J. M. Urrutia

Whistler waves with orbital angular momentum

Research on whistler waves in highly nonuniform magnetic fields

We continue to extend our experiments on whistler waves and have recently published two papers: one establishing the existence of Trivelpiece-Gould modes in unbounded plasmas and one where the radiation efficiencies of electric and magnetic dipoles are compared. Both papers and all previous publications may be downloaded from our web site (<http://www.physics.ucla.edu/plasma-exp/>) free of charge. Our current work explores the propagation of whistler modes in nonuniform magnetic fields with O-point, X-point and three-dimensional null points. The simplest case is that of closed field lines around a line current as shown in the accompanying figure. Theory states that whistler modes propagate along field lines, that is, along the almost circular field lines shown. Observations demonstrate that the phase fronts of the whistler wave are nearly aligned with the circular magnetic field lines. In time, the waves propagate radially outward across the field lines. The explanation for the difference is strong wave refraction in the highly nonuniform background magnetic field.

Such results are important for understanding wave propagation in space plasmas where in situ wave propagation cannot be measured from single satellites. Whistler modes arise naturally from instabilities and from artificial wave injections from satellites or ground transmitters. Whistler waves scatter energetic electrons trapped in radiation belts, which can damage satellites. Laboratory experiments can demonstrate the radiation and propagation of whistler modes from magnetic loop antennas in plasmas.

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Whistler waves on circular magnetic field lines

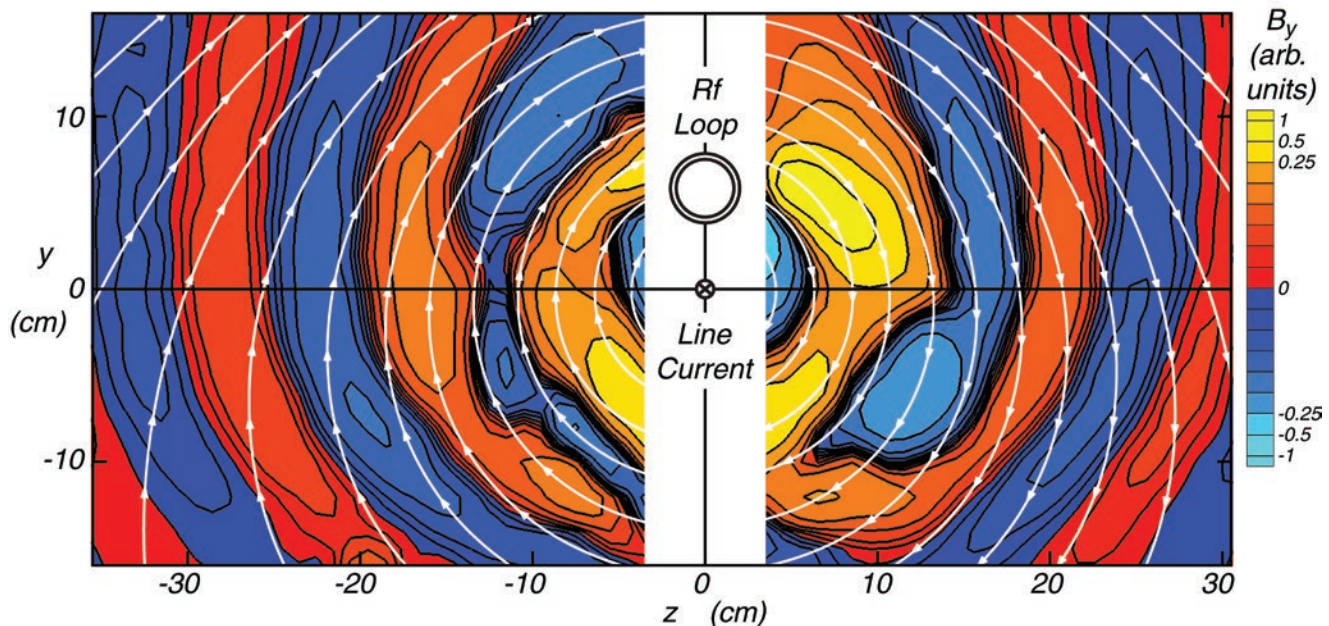


Figure 1: Snapshot of the B_y component of a whistler mode in a magnetized plasma. The white, almost circular magnetic field is produced by adding the field due to the displayed line current (its return current follows a semi-circle close to the chamber walls) to the z -aligned background magnetic field. The waves are excited by driving an oscillating current on a small loop antenna whose normal is parallel to the x -axis and propagate radially outward across the ambient field.

EXPERIMENTAL PLASMA AND BEAM PHYSICS

Pietro Musumeci

The Pegasus Laboratory

The Pegasus Laboratory under the direction of Professor Musumeci continues to push the frontier of high brightness electron beams and their applications. Among the notable results achieved this year was the first demonstration of single shot transmission electron microscopy using relativistic electron with sub-picosecond pulse lengths. Electron microscopes typically take millisecond to second long exposure to acquire an image of a sample. Using the 4 MeV beam from the radiofrequency photoinjector Professor Musumeci's group has shown the possibility to capture an image in less than a picosecond opening the door to imaging of ultrafast processes.

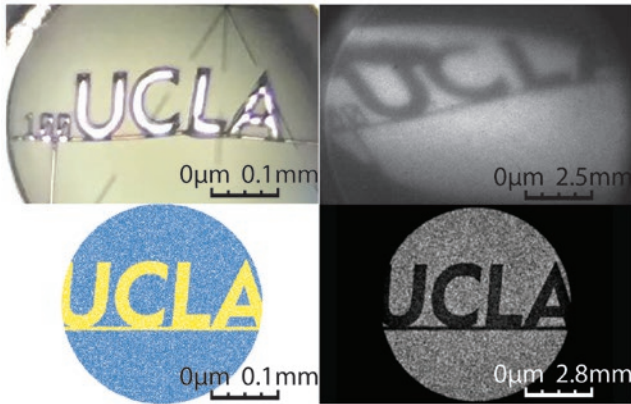


Figure 1: a) Optical and b) electron beam image of a "UCLA" target etched out of copper. The letter size in the target is 100 \AA with a line width of 20 \AA for the UCLA letter and 4 \AA for the other lines. The image on the right is the first single shot ps-time resolved TEM image using a MeV energy electron beam.

Special ultrastrong permanent magnet quadrupole based lenses were developed for this experiment. The spatial resolution of the instrument was limited by the fact that only one magnification stage was used, but it is expected to improve in the upcoming experiments when multiple magnification stages will be employed (D. Cesar et al. Phys. Rev. Lett. 117, 024801, 2016)

Another important application of high brightness electron beams is linked to the large collaboration grant recently awarded from the Moore Foundation aiming at the development of Accelerator on a Chip. Taking advantage of the large progress in laser and nanofabrication technology the goal of this ambitious project is to shrink the size of modern particle accelerators by four orders of magnitude through the change of the drive frequency from radio-

frequency to infrared waves. The first experiments at the UCLA Pegasus Laboratory conducted earlier in the year together with SLAC researchers showed record high accelerating gradients in excess of GV/m and uncovered for the first time the effect of non linearities in the acceleration.

It should also be mentioned that Professor Musumeci's research group has secured long-term funding resulting from the participation in two out of the four prestigious Science and Technology Centers that the National Science Foundation has just awarded (link to news release). Professor Musumeci will be involved with the STROBE effort for the developing of electron imaging techniques and will be the UCLA point of contact for the Cornell-led Center for Bright Beams effort aimed at improving by orders of magnitude the beam brightness from state-of-the-art electron sources.

A final note regarding student awards. The dissertation of former student Joseph Duris has been selected as one of the winners of the 2016 RHIC & AGS Thesis Award for his work on "High Efficiency Electron-Laser Interactions in Tapered Helical Undulators".

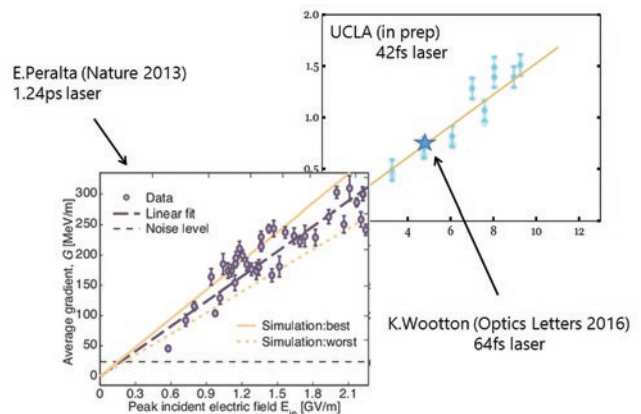


Figure 2: Accelerating gradient in laser driven dielectric structures as a function of incident electric field. Due to the shorter laser pulse length, the UCLA experiments were able to demonstrate record high gradients approaching 1.5 GV/m before the onset of non linearities (not shown here) limits the acceleration process.

EXPERIMENTAL CONDENSED MATTER

Hong-Wen Jiang

Professor Jiang's group explores basic properties of nano-structured quantum dot devices for storing and manipulating quantum information. These experimental devices are normally called qubits which are encoded by a variety of quantum states in semiconductors.

Coherence of electrically controlled qubits in silicon, particularly for exchange based qubits, is susceptible to charge noise, which can create fluctuations in both qubit energy levels and orbital motion of electrons. It has been speculated that Si/SiO₂ may be particularly susceptible to background charge fluctuations relative to other systems, such as Si/SiGe, as the amorphous SiO₂ may give rise a rough interface containing higher defect/impurity density. To definitively settle this important issue, the group has investigated and compared the charge noise in Si/SiO₂ and Si/SiGe gate defined quantum dots with identically patterned gates by measuring the low frequency 1/f current noise through the biased quantum dots in the coulomb blockade regime. It was found that the measured charge noise in Si/SiO₂ compares favorably with that of the SiGe device as well as previous measurements made on other materials. This finding is somewhat surprising since it has been observed that charge impurities in Si/SiO₂ devices tend to have a strong effect on dot locations and tunneling rates from device to device. The result has been published in *Applied Physics Letter* [1] and graduate student Blake Freeman is the lead author of the paper. Recently, Blake has also received a 2016/2017 UCLA Dissertation Year Fellowship.

It has become increasingly apparent that valley states play a critical role in both the encoding and the read-out of silicon qubits. In an effort, lead by graduate student Joshua Schoenfield, the group has, for the first time, encoded a qubit based on two valley states of a Si quantum dot. Coherent evolutions between the states, as shown in the figure, is excited by a fast electrical pulse and the quantum state vector are projected as the occupations of two different charge states for read-out. The experiment shows the valley states being manipulated are good quantum numbers. The coherent manipulation also provides a method of measuring valley splittings which are too small to probe with conventional methods.

In a collaboration with former graduate student

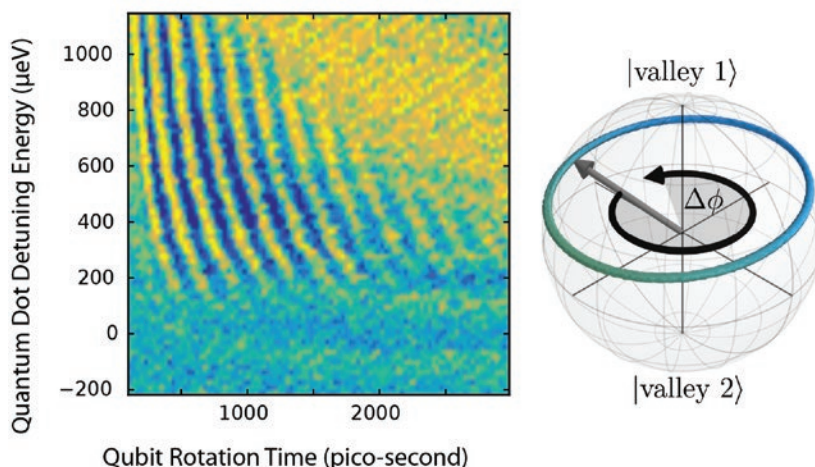
Ming Xiao's research group at University of Science and Technology of China, we experimentally demonstrate a spin-charge hybrid qubit in a five-electron GaAs double quantum dot device. This work [2] shows a new way to encode a semiconductor qubit that is controllable and coherent.

Microwave detectors based on the spin-torque diode effect are among the key emerging spintronic devices. In another research, a very high-detection sensitivity of magnetic tunnel junctions has been realized in PI's lab at UCLA.[3] The sensitivity is significantly larger than both state-of-the-art semiconductor diode detectors and existing spintronic diodes. Micromagnetic simulations and measurements reveal the essential role of injection locking to achieve this sensitivity performance. This mechanism may provide a pathway to enable further performance improvement of spin-torque diode microwave detectors.

References:

- [1] Blake M. Freeman, Joshua S. Schoenfield, and Hong-Wen Jiang, "Comparison of low frequency charge noise in identically patterned Si/SiO₂ and Si/SiGe quantum dots", *Applied Physics Letters*, 108, 253108 (2016).
- [2] Gang Cao, Hai-Ou Li, Guo-Dong Yu, Bao-Chuan Wang, Bao-Bao Chen, Xiang-Xiang Song, Ming Xiao, Guang-Can Guo, Hong-Wen Jiang, Xuedong Hu, and Guo-Ping Guo, "Tunable Hybrid Qubit in a GaAs Double Quantum Dot", *Phys. Rev. Lett.*, 116, 086801 (2016).
- [3]. Bin Fang, Mario Carpentieri, Xiaojie Hao, HongWen Jiang, Jordan A. Katine, Ilya N. Krivorotov, Berthold Ocker, Juergen Langer, Kang L. Wang, Baoshun Zhang, Bruno Azzerboni, Pedram Khalili Amiri, Giovanni Finocchio and Zhongming Zeng, "Giant Spin-Torque Diode Sensitivity in the Absence of Bias Magnetic Field", *Nature Communications*, 7, 11259 (2016).

Valley Qubit Operation



THEORETICAL CONDENSED MATTER

Elihu Abrahams

Elihu Abrahams is a condensed matter theorist, whose research is on the application of quantum many-body theory to understand the physical properties of strongly-correlated systems. These are 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 zero temperature. It is found in many "heavy-fermion" metals and is at the forefront of research in condensed-matter physics. An essential characteristic of a quantum critical point is that dynamical fluctuations of an order parameter play a key role in determining the behavior in its neighborhood. Although quantum phase transitions between distinct ground states occur at absolute zero, their effects are observed over a range of non-zero temperature. Abrahams has collaborated on the development of a new theory of how quantum critical fluctuations affect the electronic properties in heavy-fermion metals. Among his most recent contributions in this area is "Strong-coupling theory of heavy-fermion criticality", *Phys. Rev. B* 90, 045105 (2014) and "Critical quasiparticle

theory applied to heavy-fermion metals near an antiferromagnetic quantum phase transition", *Proc. Natl. Aca. Sci.* 109, 3238 (2012), in which remarkable agreement has been shown between this "critical quasiparticle theory" and experiment.

Another, related research activity has been on the recently-discovered iron-based superconductors, in which quantum criticality has been associated, by Abrahams and collaborators, to strong electron correlations with the consequence that magnetic properties are therefore best understood as arising from interacting quasi-localized spins. This approach forms the framework for an understanding of the superconductivity in these materials, as described in a major review article by Abrahams and coworkers: "High-temperature superconductivity in iron pnictides and chalcogenides", *Nature Reviews Materials*, 1, 16017 (2016).

Elihu Abrahams 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 a Fellow of the American Physical Society.

A list of several of Abrahams' important recent publications may be found at http://www.pa.ucla.edu/sites/default/files/abrahams_recent_pubs.pdf

Sudip Chakravarty

Professor Chakravarty's research interest involves quantum theory of collective behavior of electronic systems. His interest is in theories of cuprate high temperature superconductors, newly discovered FeSe/SrTiO₃ superconductors, chiral superconductors, dissipative quantum systems, quantum phase transitions and criticality, localization transition in interacting systems, and between topologically non-trivial and trivial states which do not fit the conventional paradigm, and the concept of von Neumann entropy in quantum phase transitions. Chakravarty has published in the past year (June 15-July 16) six papers, all in *Physical Review B*, except one in a special issue on skyrmions of *Mod. Phys. Lett. B* (ed. M. Rho and I. Zahed). Two additional papers are posted on the arXiv.org (discussed below). Two of Chakravarty's graduate students have received their Ph.D's. in the current year and have excellent postdoctoral jobs starting this fall. He has currently two more graduate students, one of whom has advanced to candidacy in the current year. Chakravarty's work is collaborative, including his students and members elsewhere, such as Stanford, University of Maryland and UC Riverside, as well the theoretical elementary particle group at UCLA.

Here is a brief highlights of two most recent papers.

(1) **Half filled Landau level** (arXiv:1606.00899): The nature of compressible states at the half filled quantum Hall regime has been a fascinating topic since the pioneering work by Halperin, Lee, and Read (HLR). In this picture this state is interpreted as a liquid of non-relativistic composite fermions coupled to a fluctuating Chern-Simons gauge field. It provides a nice explanation for the experimental observations of acoustic wave propagation and has been further supported by other measurements. However, the HLR theory has a long-standing issue in that it is incompatible with the particle-hole symmetry. Recent experiments contradict the HLR picture, which apparently breaks the particle-hole symmetry.

To resolve this issue, recently D. T. Son has proposed a particle-hole symmetric theory in which the underlying composite fermions are taken to be Dirac particles. This proposal has sparked a great deal of interest because it can not only resolve the old particle-hole symmetry issue but also provide another avenue to study some seemingly completely unrelated topics such as strongly-correlated

topological insulator surface states. However, the possible mechanism for realizing these states is not clear at all. Chakravarty and his student Zhiqiang Wang have pursued a new idea. Applying the mechanism of dynamic screening, they show that there can be nonzero pairing of Dirac CFs in higher angular momentum channels. There is a quantum phase transition from the Dirac CF liquid state to the states as they tune the effective coupling constant.

(2) Superuniversality and Disorder-Driven Phenomena in Weyl Semimetals, Semiconductors and Related Systems in high dimensions (arXiv:1603.03763): The quantum phase transition between two clean, non interacting topologically distinct gapped states in three dimensions is governed by a massless Dirac fermion fixed point, irrespective of the underlying symmetry class, this constitutes a remarkably simple example of superuniversality. For a sufficiently weak disorder strength, Chakravarty and his collaborator show that the massless Dirac fixed point is at the heart of the notion of superuniversality.

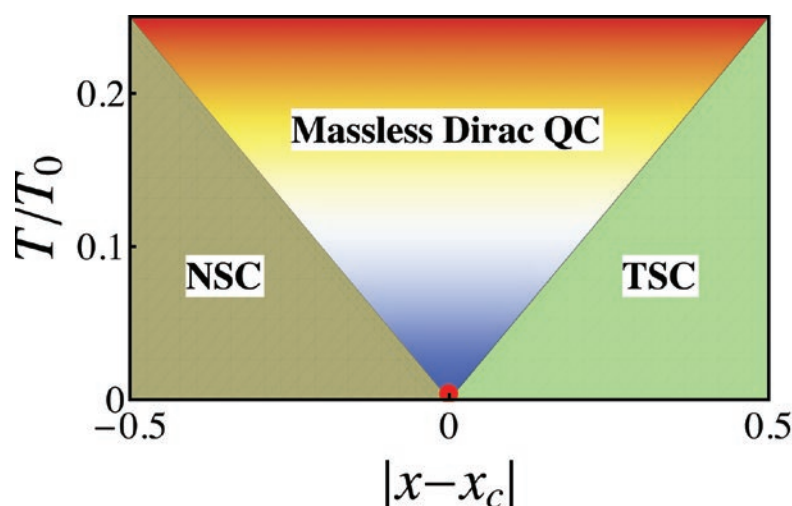


Figure 1: Quantum critical (QC) fan for the direct quantum phase transition between topologically distinct localized states. In the absence of disorder, the topologically distinct insulating states possess sharp spectral gaps, described by the Dirac mass. In the presence of disorder, there is no sharp spectral gap, and the inverse of the disorder averaged Dirac mass describes the localization length for the sub-gap states. The tuning parameter x is a combination of disorder couplings, and at x_c the disorder averaged Dirac mass vanishes, which determines the phase boundary between two localized states. Here T_0 corresponds to a microscopic energy scale and T is the temperature. NSC: normal superconductor and TSC: topological superconductor.

For models of continuous quantum phase transitions (QPT) involving order parameter, critical exponents are entirely determined by the symmetry of the order parameter and the dimensionality. An interesting question is whether the critical exponents for a class of continuous quantum phase transitions can even become independent of the underlying symmetry properties. If so, the critical exponents can only depend on the dimensionality. This phenomenon will be termed as superuniversality and it plays an important role in the theory of topological QPTs.

This is established by considering both perturbative and nonperturbative effects of disorder. The superuniversality breaks down at a critical strength of disorder, beyond which the topologically distinct localized phases become separated by a delocalized diffusive phase. The theory departs strongly from the age-old paradigm of disorder-driven from Anderson localization. It has manifestations in many observables and is receiving considerable attention in the context of recently discovered 3D Weyl and Dirac materials but has also been suggested in the context of cold-atom systems with long-range interactions.

PROFESSOR MICHAIL BACHTIS



We are proud to announce the arrival of a new Experimental Elementary Particles physics professor, Michail (Michalis) Bachtis. Michalis received his Bachelor and MSc degrees in National Technical University of Athens (Greece) working in the installation and commissioning of the Monitored Drift Tube chambers of the ATLAS experiment. Eager to experience the American educational system, in 2007 he was accepted for a Ph.D. in the University of Wisconsin-Madison working in the CMS experiment. His thesis on final states with tau leptons introduced a novel hadronic tau identification technique and set the standards for the first observation of Higgs decays to fermions. After his Ph.D., in 2012, he joined the CERN physics department first as a post-doctoral fellow and then as a staff physicist working on the search and discovery of the Higgs boson in the four lepton final state. During the LHC shutdown period (2013-14), he was responsible for preparing the CMS Physics Object identification algorithms for Run II and in parallel he started working on a long term effort to measure the mass of the W boson at the LHC. Professor Bachtis arrived at UCLA in October 2016.

Michalis' plans in his own group at UCLA are to exploit the maximum potential of CMS and the LHC by searching for new physics beyond the Standard model and improving the electronics systems responsible for real time selection of proton collisions.

FACULTY 2015-16

Professors

Elihu Abrahams (Adjunct)
Katsushi Arisaka
Zvi Bern
Dolores Bozovic
Stuart Brown
Robijn Bruinsma
Troy Carter - Vice Chair of Resources
Sudip Chakravarty
Ferdinand V. Coroniti
- Associate Dean of Physical Sciences
Robert Cousins
Eric D'Hoker
Sergio Ferrara
Christian Fronsdal
Steven Furlanetto
Walter Gekelman
Graciela Gelmini
Andrea Ghez
George Grüner
Michael Gutperle
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Jay Hauser
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Huan Huang
Frank Jenko
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Jean-Luc Margot
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Warren Mori
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Pietro Musumeci
William Newman
Christoph Niemann
Rene Ong
Seth J. Putterman
James Rosenzweig
David Saltzberg
David Schriver (Adjunct)
Alice Shapley
Terry Tomboulis

Tommaso Treu
Yaroslav Tserkovnyak
Slava Turyshev (Adjunct)
Jean Turner
- Department Chair
Vladimir Vassiliev
Hanguo Wang (Adjunct)
Gary A. Williams
Giovanni Zocchi

Associate Professors

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Michael Fitzgerald
B. Chris Regan

Assistant Professors

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Wesley Campbell
Ching Kit Chan (Adjunct)
Paul Hamilton
Zhongbo Kang
Smadar Naoz
Ni Ni
Rahul Roy
Martin Simon (Adjunct)
Shenshen Wang

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Eric Becklin
Rubin Braunstein
Charles Buchanan
W. Gilbert Clark
John M. Cornwall
Robert Finkelstein
George Igo
Steven Moszkowski
C. Kumar N. Patel
Roberto Peccei
Claudio Pellegrini
Joseph A. Rudnick
William E. Slater
Reiner Stenzel
Roger Ulrich
Alfred Wong
Chun Wa Wong
Edward Wright
Benjamin Zuckerman

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Gang Wang
Gunther Witzel

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Patrick Pribyl
Guiding Wang
Lei Zeng

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Carmen Constantin
Jeffrey Zweerink

Assistant Project Scientists

Warren Essey
Gregory Martinez
Patricia Quinones

Maha Ashour-Abdalla

1944 - 2016



Maha Ashour-Abdalla, a professor of physics with expertise in space plasma physics and a passion for teaching, died May 1. She was 72.

Maha Ashour-Abdalla was born and raised in Alexandria, Egypt. Maha excelled in mathematics and finished high school very young: She was in college at age 15. After completing her B.Sc. at Alexandria University in 1964, she pursued graduate studies at Imperial College in London where she was awarded her Ph.D. in 1971. She then became a research scientist at the Centre National d' Etudes des Telecommunications in France, before moving to Los Angeles where she was a geophysics researcher in the UCLA Institute of Geophysics and Planetary Physics from 1976-1985.

Maha was appointed as a Professor in the UCLA Department of Physics and Astronomy in 1985. She was elected a Fellow of both the American Physical Society (1986) and the American Geophysical Union (1993).

In the early 1980's Maha founded the UCLA Space Plasma Simulation Group (SPSG), which pioneered using plasma simulations for magnetospheric physics in close coordination with spacecraft data. Maha's boundless enthusiasm for space science research resulted in her establishing collaborations with scientists from around the world. In 1982 she initiated the International School/Symposium for Space Simulations (ISSS-1) along with colleagues from Japan and France. She helped organize the most recent ISSS-12 held in Prague in 2015.

Teaching at UCLA was one of Maha's passions and her undergraduate courses were very popular. Maha's excellence in teaching over the years resulted in her receiving the Outstanding Teaching Award 11 times from the Department of Physics and Astronomy. The ultimate appreciation of her teaching abilities was shown in January 2000 when she was named one of the Top 20 UCLA Professors of the 20th Century by UCLA Today. During her tenure at UCLA, Maha supervised eleven Ph.D. graduates as well as many postdoctoral researchers.

Maha's love for teaching and use of computers intersected with her development of educational programs for students (K-12 and college) that utilized innovative digital technologies. In 1999 she founded and became the director of the UCLA Center for Digital Innovation (CDI) and oversaw the development of numerous educational software products for science, math and computer literacy. An early groundbreaking effort of CDI was the launching of the Transpacific Interactive Distance Education (TIDE) program, which allowed students at UCLA and at Kyoto University in Japan to participate in face-to-face collaborative lectures.

A scholarship in Space Physics which is managed by the American Geophysical Union, is set up in Maha Ashour-Abdalla's name. The scholarship is to encourage and support women who are starting graduate studies in the field of space physics. To contribute, go the organization's contribution website and choose the Maha Ashour-Abdalla Scholarship Fund from the "Student Grants, Scholarships, Activities" drop-down menu. If you prefer, you may send a check, payable to the American Geophysical Union and with the note "Ashour-Abdalla Fund" on the memo line, to: Development Department, American Geophysical Union, 2000 Florida Avenue NW, Washington, DC 20009.

Over the years, Maha was principal and co-investigator on numerous grants from NASA and NSF. Most recently, she was the UCLA principal investigator of an Interdisciplinary Scientist grant for NASA's Magnetospheric Multiscale (MMS) mission, a four spacecraft mission launched in 2015 to study magnetic reconnection, one of the most critical problems in space physics. During her extensive career she received many awards of recognition and served on numerous national and international advisory panels.

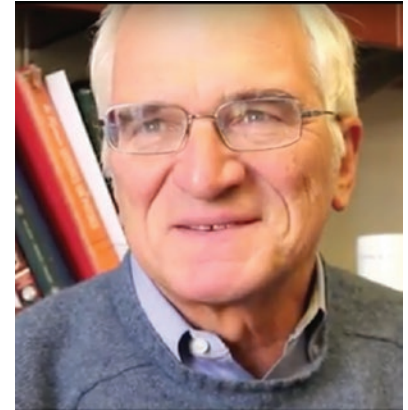
Maha Ashour-Abdalla was a tireless worker and prolific researcher. Until the very end she was actively working on research and teaching. Maha was charismatic, engaging, extremely loyal, and those who met her quickly came to appreciate the force of her personality. Maha was truly a one of a kind individual who left an indelible impression on everyone she met. She will be greatly missed.

She is survived by her husband Dr. Mohamed Abdalla and her daughter Kenz Abdalla.

IN MEMORIAM

Michael Jura

1948 - 2016



Professor of astronomy Michael Jura, who played a major role in advancing scholarship in his field and in shaping UCLA's Division of Astronomy and Astrophysics over the course of four decades, died on Jan. 30 following a lengthy illness. He was 68.

Jura earned his bachelor's degree in physics from UC Berkeley in 1967 and his Ph.D. in astronomy from Harvard University in 1971, and went on to become a postdoctoral scholar at Princeton University. He joined UCLA's faculty in 1974 as an assistant professor, was promoted in 1977 to associate professor and to full professor in 1981. He continued teaching through the fall quarter of 2015.

Jura brought a unique, theory-oriented viewpoint to the analysis of astrophysical data.

His research spanned a broad range of topics including intensity fluctuations in pulsars, excitation of molecular hydrogen, star formation and dust in galaxies, the chemical composition of interstellar gas, mass loss from red giant stars, and diffuse interstellar bands. He was especially interested in planetary systems outside the Earth's solar system — their comets, asteroids and planets — and in determining if there is life outside our solar system.

Among his many contributions to UCLA astronomy and astrophysics, Jura was instrumental in developing the infrared focus of the division when he chaired the department of astronomy in the late 1980s, and he played a central role in hiring many of the astronomy faculty, including Zuckerman, with whom he published research for more than 30 years.

"Mike was really dedicated to science; he really cared, and he was very creative," said Benjamin Zuckerman, a UCLA professor of physics and astronomy who knew Jura for nearly 50 years.

"Mike was highly respected by his senior colleagues and students for his groundbreaking science, his originality and for what a good person he was. He mentored young scientists with great dedication and was very concerned about them."

move the campus toward increased use of renewable energy. He drove an electric car, and he and his wife installed solar panels on the roof of their home in West Los Angeles.

"Our panels provide enough energy both for our house and electric car; the end of gasoline and electricity bills for a lifetime," Jura wrote on his UCLA website. "This home experiment suggests that transition to a sustainable, modern economy is within technical and financial reach. It is most pleasing to have an inexhaustible supply of energy from the sun."

Jura is survived by his wife, Martha; their son, Michael, and Michael's wife, Ying; and two grandchildren, Sean and Stella.

His recent research, on the "pollution" of white dwarf atmospheres, opened a whole new area of research and has allowed the characterization of the chemical composition of small bodies, such as asteroids, in extrasolar planetary systems. His creative approach has provided direct information on extrasolar planetary systems that is very difficult to measure otherwise. By measuring the abundances of elements common to the terrestrial planets, he has been able to infer levels of tectonic activity in these systems, a remarkable feat.

Committed to finding ways to reduce our society's consumption of non-renewable energy, Jura taught courses at UCLA on energy and the environment and strove to

The Michael A. Jura Graduate Award Fund

The Michael A. Jura Graduate Award Fund has been established to support awards for astronomy graduate students in the Department of Physics and Astronomy.

To contribute, please visit the online giving website. For questions, or to contribute by check or securities, please contact Desirae Vanek by email at: dvanek@support.ucla.edu or by phone at 310-267-5194. Gifts to the Michael Jura Graduate Award fund are tax deductible.

ASTRONOMY LIVE! & THE UCLA PLANETARIUM

On November 8th, 2015 we hosted the seventh annual Exploring Your Universe events. These free public events included talks, demonstrations, exhibits, and hands-on activities from the Departments of Physics and Astronomy, Earth and Space Sciences, Atmospheric and Oceanic Sciences, Chemistry, Engineering and Applied Sciences, the Center for Environmental Implications of Nanotechnology. Two sets of lectures were geared toward younger and older audience members, and Professor Adam Frank of University of Rochester gave the evening presentation. This event has grown dramatically over the past few years, and EYU 2015 drew approximately 6,000 attendees. Visitors come from all over the Los Angeles area, including many students, staff, and faculty of local schools and UCLA. This EYU 2016 promises to be a major event once again.



Pauline Arriaga

In 2016, the UCLA Planetarium and Astronomy Live! hosted a summer observing workshop for high school students for the third year running. 10 local high school juniors and seniors were chosen based on their applications. Over the course of 8 weeks, students learned the basics of observational astronomy. During the workshop, students used the 11-inch and 14-inch telescopes at UCLA, and heard lectures from graduate students at UCLA on scientific concepts such as coordinate systems, the nature of light, and how CCDs work. This program was granted two nights on the Lick 1-meter Nickel telescope to observe targets for student projects. The high school students participated in one of these remote observing nights, and used data taken



Kevin Stahl and Brittany Miles

with the Nickel telescope to complete individual research projects culminating in a final presentation of their work. The students reduced and analyzed data using custom Python scripts developed by UCLA graduate students. We hope this workshop will continue in future years.

In addition, the UCLA Planetarium has had another very successful year. The graduate student-led planetarium hosted 109 shows with 4693 attendees over the 2015-2016 school year. Shows were given to 38 different schools from the Los Angeles area. It played a major role in Exploring Your Universe 2015 and our High School Summer Program. The UCLA Planetarium has also been included

in lists of fun and free activities to do in Los Angeles.



Richard Mebane

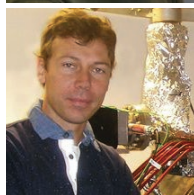


2016 American Physical Society Fellows

UCLA Physics & Astronomy faculty members, Jianwei "John" Miao and Pietro Musumeci, have been elected Fellows of the American Physical Society for its class of 2016. Recipients are nominated by professional peers and selected by the Society. The honor recognizes "exceptional contributions to the physics enterprise".

Jianwei "John" Miao, professor of physics and astronomy, is recognized for his pioneering contributions to the development of diffractive imaging methods for characterizing a wide range of material systems and a general electron tomography method for three-dimensional imaging of crystal defects at atomic resolution.

Pietro Musumeci, professor of physics and astronomy, is cited for his pioneering work in the physics of high brightness beams, including ultrafast relativistic electron diffraction, and high gradient inverse free electron laser acceleration



29 UCLA faculty on 'Thomson Reuters 'most cited' list for influential scholarship

Twenty-nine UCLA faculty members are among the most influential scientists in their fields for 2015, as determined by Thomson Reuters. Of those 29 faculty 3 are faculty members of the Physics and Astronomy Department.

The media organization's latest Highly Cited Researchers list names nearly 3,000 scientists from around the world whose studies were among the top 1 percent most referenced

in academic journals from 2003 to 2013. (Read more about the rankings methodology.)

Professors Ni Ni, Alice Shapley, and Edward Wright are among the most influential scientists in their fields for 2015, according to Thomson Reuters Corp.

The Astronomical Society of the Pacific Announces Its 2016 Award Recipients For Astronomy Research And Education



The Maria and Eric Muhlmann Award recognizes recent significant observational results made possible by innovative advances in astronomical instrumentation, software, or observational infrastructure. Professor Ian McLean (University of California Los Angeles) and Professor Charles 'Chuck' Steidel (California Institute of Technology) for their roles as Co-Principal Investigators on the

Multi-Object Spectrometer for Infrared Exploration (MOSFIRE) imager, a revolutionary low-resolution multi-object near-infrared spectrograph on the Keck 10-meter telescope on Mauna Kea, Hawai'i.

A Symposium to Celebrate the Life of Michael A. Jura



Michael Jura passed away in January 2016, on Wednesday, September 13, 2016 a symposium was held to celebrate the life and accomplishments of Professor Michael A. Jura. Michael played a major role in advancing scholarship in his field and in shaping UCLA's Division of Astronomy and Astrophysics over the course of four decades. This day-long symposium offered us an opportunity to share our memories of Professor Jura.

Dr. Aomawa Shields is the recipient of the 2016 Origins Project Postdoctoral Lecture-ship Award.



Dr. Aomawa Shields is the recipient of the 2016 Origins Project Postdoctoral Lecture-ship Award. This \$10,000 award, the largest of its kind in the world, is offered to promising young scholar-scientists on the basis of their scholarly achievement and potential, as well as their skills in science communication.

Shields' research focuses on exploring the climate and potential habitability of extrasolar planets orbiting low-mass stars. Currently an NSF Astronomy and Astrophysics Postdoctoral Fellow, Shields is also a UC President's Postdoctoral Fellow in the UCLA Department of Physics and Astronomy and the Harvard-Smithsonian Center for Astrophysics. She is also a TED Fellow whose TED talk "How We'll Find Life on Other Planets" has nearly 1 million views. In addition to her many scientific accomplishments, Shields is a classically trained actor with an Master of Fine Arts degree, a skill she uses to communicate her love of science.

A Centennial celebration of Robert Finkelstein



The UCLA Physics & Astronomy Department celebrated the 100th birthday of Professor Emeritus Robert Finkelstein with a meeting and dinner on Saturday, April 2, 2016 at the UCLA Faculty Center. A session of invited talks in the Sequoia Room, followed by dinner at 6pm in the Main Dining Room East.

Ned Wright elected to National Academy of Sciences

Three UCLA professors were elected to the National Academy of Sciences on Tuesday "one of the highest honors an American scientist can receive." One of those recipients was Edward "Ned" Wright from the Department of Physics and Astronomy. The academy serves as an official adviser to the federal government on matters of science and technology. The 72 new members elected to the academy this year were selected for their careers of distinguished and original research.



KEYNOTE SPEAKER 2016 PHYSICS & ASTRONOMY GRADUATION CEREMONY, CHARLES WOO

Family and friends gathered at Ackerman Union Grand Ballroom on June 12, 2016 to celebrate the graduation ceremony in honor of the students graduating from the UCLA Department of Physics and Astronomy. The graduating class keeps growing from year to year and as a result we had to change venue this year to accommodate that growing number. In all, 113 undergraduate students and 24 graduate students received degrees this year. Professor Turner, the Chair, presided over the celebration, which included lively student addresses and a very relevant keynote address given by a highly successful and highly respected alumnus of the Department, Charles Woo. Using his own path as an example, he highlighted the relevance of physics in many walks of life beyond academe and talked about what it takes to be a successful entrepreneur and businessman, and he described how his education in Physics provided him with the problem-solving abilities and the discipline needed to follow such a path. The speech was very well received by everyone and was followed by the presentation of the class of 2016, announcements of honors and awards, and finally a reception where all enjoyed a light buffet, animated conversation, photo opportunities and emotional goodbyes.



Charles Woo

RESEARCH EXPERIENCE FOR UNDERGRADUATES (REU) 2016

The department hosted its 14th annual Research Experience for Undergraduates program (REU) during Summer 2016. The program is a 10-week immersion in research for physics and astronomy students coming from all over the country and also California. In 2016, 14 students were selected from over 400 applications and were matched with a faculty mentor according to the student's stated interests, and a 10-week research project is designed and carried out in close collaboration with that faculty mentor and their group. The program culminates with oral presentations at a one-day symposium and with the production of professionally formatted research papers—some of those papers result in publications in professional journals. During the program, participants hear seminars which give them a broad overview of the field of physics and astrophysics; are offered tutorials in such things as machine shop, science ethics, and strategies for taking the physics GRE exam. Through the program, students broaden their capacity to do high-level research while at the same time discover UCLA and what the department has to offer. To date, the program has hosted 195 students.



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