

REFLECTIONS

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SCIENCE AND TECHNOLOGY
RESEARCH BUILDING

3 FEATURE ARTICLE

Science and Technology Research
Building

8 DONOR RECOGNITION

- Matching Funds
- The Impact of Giving
- Donor Highlights
- List of Special Donors

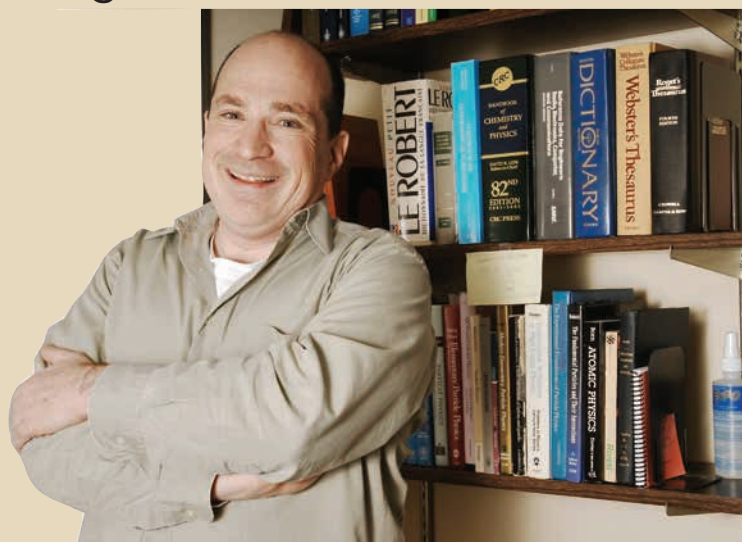
12 RESEARCH HIGHLIGHTS

25 FACULTY NEWS

- New Faculty
- Remembering Rubin Braunstein
- Professor Wright receives the
NASA Distinguished Public Service
Medal

26 STUDENT INFORMATION

- Astronomy Live
- Science for Kids
- UCLA Internal Research
Experience (REU) for Undergraduates



Welcome to this year's "Reflections" newsletter, as we have renamed the Annual Report of the Department of Physics and Astronomy. It's our hope this is useful to our alumni – but I use the word broadly. Yes, we want to keep connected to those who have participated in and graduated from our many programs. But also I include our staff, researchers, benefactors, and others who became part of the P&A Department at some point in our lives. I very much include our future alumni as our target reader, too; the feature article on the Science and Technology Research Building, and the many pages of Research Highlights will help prospective students see some of what UCLA has to offer.

I want to thank Professor Turner who was Chair during the period of this year's newsletter. Under her leadership and that of the vice chairs, the department has moved forward enormously. We've welcomed many wonderful new faculty. Newly created committees on diversity for physics and astronomy have made concrete impacts. A new introductory physics series for life sciences majors propels us into 21st century teaching and benefits thousands of UCLA undergraduates. The newly launched Bhaumik Institute for Theoretical Physics has started a phase transition. And much more.

All sizes of donations help our students and other scholars. Donors make possible the physics and astronomy clubs, participation in outreach events, teaching awards for graduate students, renovating undergraduate laboratories, and helping students in unforeseen crises. Giving to the Chair's Discretionary Fund (for which we have discreetly attached an envelope and web link) would be a fantastic way to enhance the young people's experience.

This newsletter can't cover it all, but I hope gives a feeling for the scholarly lives of our 60+ faculty, dozens of lecturers, 200+ graduate students, 100+ undergraduates in each year's class, 40+ researchers, 50+ postdoctoral scholars, and the many staff, who make it all happen.

David Saltzberg
Chair, Department of Physics & Astronomy

SCIENCE AND TECHNOLOGY RESEARCH BUILDING

by Walter Gekelman



The STRB building is located on the southernmost part of campus, 1040 Veteran Avenue, across the street from the Weyburn Graduate Apartments. There are few universities with comparable infrastructure. The facility is what you would expect at a large national laboratory.

It all started after the Plasma Science and Technology Institute was formed in the 1990s. Plasma physics at UCLA was (and still is) distributed among the departments of physics, earth and space science, atmospheric science, electrical engineering and mechanical engineering. The faculty at that time envisaged a place that would house office and lab space for everyone in the diverse collection of plasma groups. The original plan was for two buildings. The first was laboratory space, which became after many iterations, the STRB. A second building next to where the graduate student dorms now stand had offices for faculty and students, a sizable auditorium, computing facilities, a library, and smaller meeting rooms. The office building was postponed (forever) and after several design iterations, work began on the STRB. Most university buildings are funded by bonds or paid for by the UC system. This was not in the cards. Instead, funding came from the state under a bill sponsored by Congressman John Garamendi. Unlike other UC buildings, the mortgage was to be paid from the overhead on grants. After some discussions, the Dean of Physical Science at the time, Professor Roberto Peccei (who was also Vice Chancellor for Research) agreed to be in charge and the building is now in the hands of the College of Letters and Science. Without Professor Peccei's help throughout difficult financial and institutional changes at the time, the STRB would have never been constructed.

The STRB is a two storey building with a large basement lab. It has a 30 Megawatt electrical substation to power it, a chiller plant next door which provides cold water to cool the machines (remember the second law of thermodynamics), and easy access for trucks. It was constructed to house large machines which is why plasma physics occupies nearly all of it. The high bay area on the ground floor is two storeys high, has a crane capable of lifting 10 tons and 480 volt power rails capable of delivering 10 MW of power. Who could ask for more?



Figure 1. The UCLA electric tokamak (now the Enormous Toroidal Plasma Device, ETPD). The 32 toroidal magnets are painted red and the vertical field coils are blue. The total magnetic field spirals within the machine. The vacuum vessel is 1 inch thick stainless steel with an inner radius of 3 m and outer radius of 5 m. The vessel is 3 meters high and weighs in at 300 tons.

Construction of two large plasma devices began as the building reached its final stage of completion. The Electric Tokamak (ET) is shown in Figure 1. Weighing in at 300 tons, it was welded together under the supervision of Bob Taylor. ET was the largest tokamak in the world and is presently the largest device anywhere for basic plasma research.

After five years of successful operation, which tested several concepts for advanced Tokamaks, the fusion

work was terminated as part of a Department of Energy (DOE) strategy to move such devices into national labs. It has since been repurposed by the plasma group led by Professor Walter Gekelman as a high pressure plasma device. Plasma production utilizes a high emissivity cathode (developed at UCLA) which makes a hot, collisionless plasma, shown in Figure 2. The plasma has been run at a 1 Hz repetition rate for one year without failure. The group plans to use it for an experimental lab/astrophysics program.

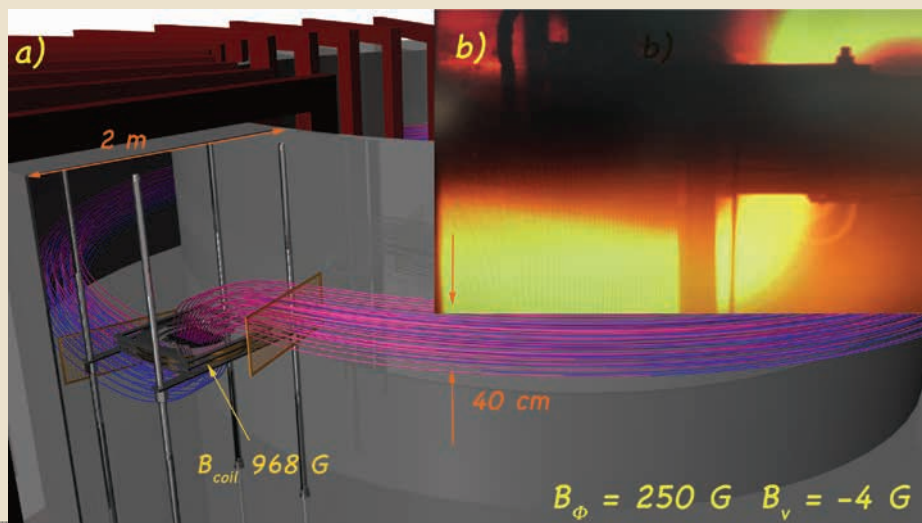


Figure 2(a). Schematic drawing of the magnetic field lines and plasma source within the ETPD. Plasma comes from the top and bottom of the source, which is placed between two large internal magnets. The vessel walls are colored gray, some of the magnets are visible. (b). Photograph of a helium plasma streaming from the top and bottom of the cathode. The plasma density is greater than 10^{19} ions/electrons per cubic meter and the temperature is of order 20 eV or 232,000 degrees Celcius.

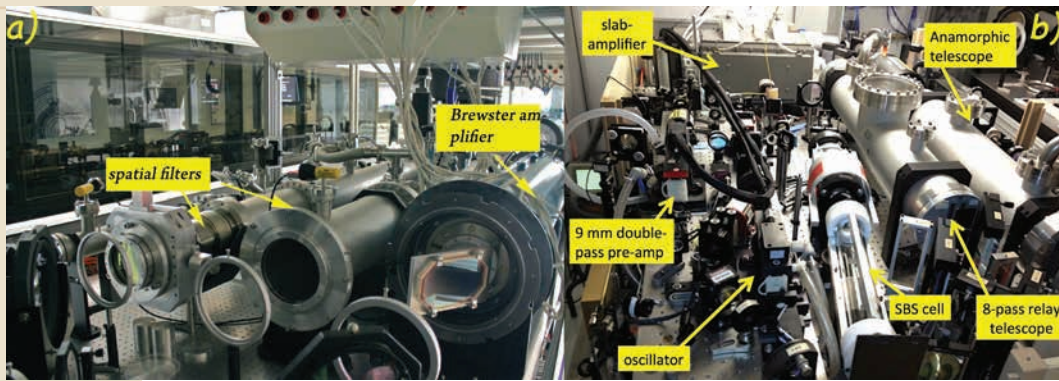
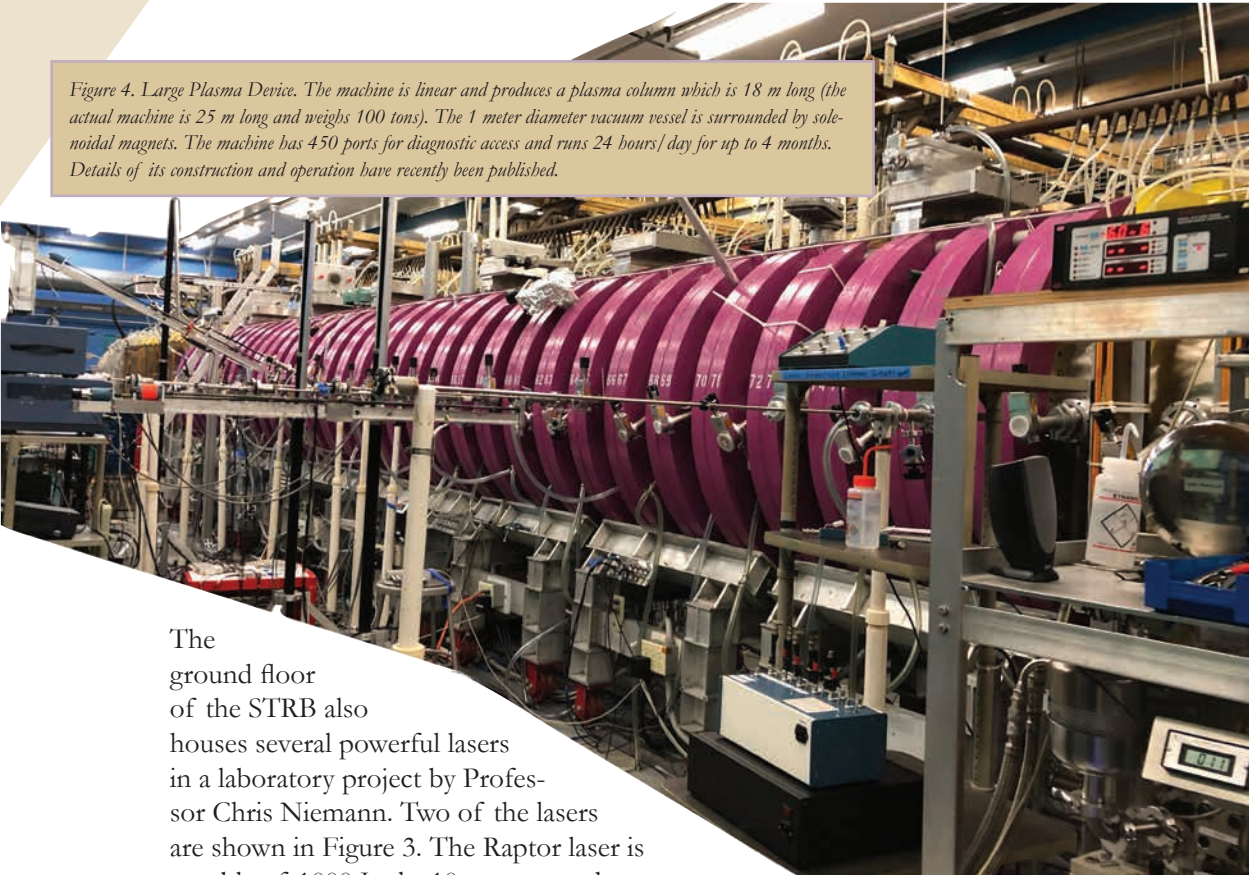


Figure 3(a). Photograph of the Raptor laser system. It is a Nd-Yag system. The Brewster amplifier is driven by a 500 J capacitor bank. The optics in the four pass system are folded; the unfolded beam length is 45 m. (b) View of the Penning laser with several components identified. Despite its apparent complexity, it can run at a 1 Hz repetition rate for days on end.

Figure 4. Large Plasma Device. The machine is linear and produces a plasma column which is 18 m long (the actual machine is 25 m long and weighs 100 tons). The 1 meter diameter vacuum vessel is surrounded by solenoidal magnets. The machine has 450 ports for diagnostic access and runs 24 hours/day for up to 4 months. Details of its construction and operation have recently been published.



The ground floor of the STRB also houses several powerful lasers in a laboratory project by Professor Chris Niemann. Two of the lasers are shown in Figure 3. The Raptor laser is capable of 1000 Joule, 10 nanosecond operation (10^{11} Watts). It is one of the largest lasers at any university in the US. The second Penning laser is a 20 Joule system capable of 1 Hz operation (the Raptor can be fired once every 45 minutes). The high repetition rate is made possible by a sophisticated phase conjugation system. The laser lab has a test vacuum system and target chamber for beam and target studies. Either laser beam can be transported to the laboratory on the floor below where they have been used successfully to create magnetic shock waves.

The basement of the STRB has two laboratories. The Large Plasma Device (LAPD) was constructed under the supervision of Professor Walter Gekelman at the same time as ET was built. The LAPD is shown in Figure 4.

The LAPD device is the centerpiece of the Basic Plasma (BaPSF) Science Facility (<http://plasma.physics.ucla.edu/bapsf>).

There is no comparable basic plasma physics device in the world. When the LAPD was completed the DOE and National Science Foundation (NSF) funded it as the centerpiece of a national user facility for experimental plasma physics.

Professor Gekelman was the director for 15 years with Professor George Morales and Dr. Jim Maggs as co-directors. The present director is Professor Troy Carter with co-directors Professor Walter Gekelman, Professor George Morales and Dr. Stephen Vincena. The bargain made with the funding agencies called for half the machine time to go to the UCLA local group (UCLA PIs, graduate students, and research scientists) and the balance to visiting plasma physicists. Since its inception, the facility has hosted dozens of scientists from other institutions. Work at the facility has generated 178 peer-reviewed scientific papers and the doctoral dissertations of 32 students from UCLA and other universities. The STRB is key to the existence of LAPD and ETPD. There is no other place on campus

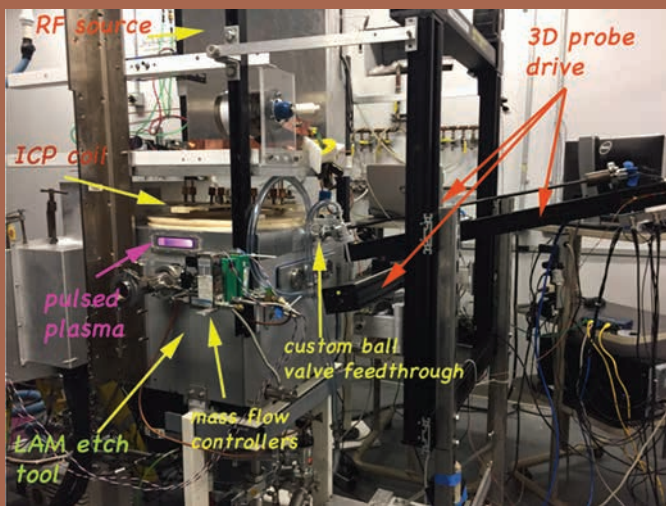


Figure 5. Plasma etch tool for manufacture of semiconductor devices. The machine was modified with addition of a three-dimensional probe drive and pulsed RF sources. The group is headed by Professor Gekelman and Patrick Pribyl.

that can house them; they are too big with electrical power and cooling requirements that cannot be met anywhere else.

That's not all. Next door to the LAPD is a low temperature plasma laboratory. Low temperature or industrial plasmas are used in a large variety of processes key to the US economy. Plasma tools are used in the production of all semiconductor based devices including CPUs, FPGAs, mobile phone components, and so on. Each year one square inch of silicon covered in transistors and other circuitry is manufactured for every living person on the planet. Figure 5 shows a plasma etch tool donated by one of the world's largest manufacturers, LAM Research Corporation.

Low temperature (0.25-1.0 eV) devices use internal AC bias voltages to accelerate ions towards a silicon wafer onto which a series of coatings is deposited and unwanted atoms are etched away. Current machines are capable of making structures with 10 nm features. The UCLA effort studies ways to improve the uniformity

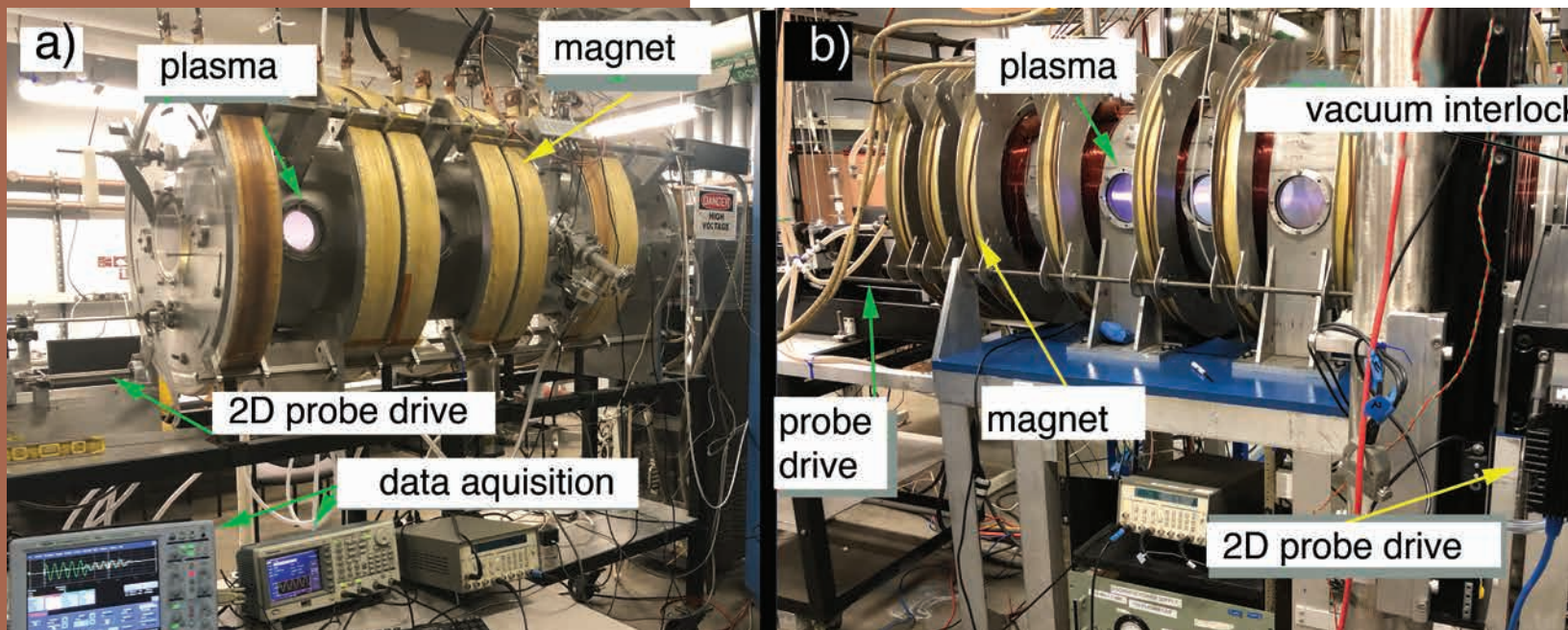


Figure 6. Two plasma devices constructed for the 180E undergraduate plasma lab. (a) A 1.5 m long device with an inductively coupled plasma source. The plasma is weakly ionized but is magnetized ($B < 100$ Gauss) and has axial and transverse probe drive systems. (b) A two cathode source which produces a dense plasma 3 cm in diameter. The axial magnetic field is $B_z < 200$ G. The machine has two independent probe drives. Both machines run 24 hours a day and have computerized data acquisition.

of the plasmas with the aim of making features smaller still.

The STRB is also home to the plasma diagnostics group headed by Dr. Tony Peebles. The diagnostics group has a large, nationally visible program through which they supply microwave interferometers, reflectometers, and other diagnostics for measurement of plasma density, electron temperature, and wave activity. The diagnostic group has permanent presence at the D3D tokamak at General Atomics, provides hardware for the Princeton Spherical Tokamak, has collaborations with China and will build instruments for the (International Tokamak Experimental Reactor) ITER in France.

Tucked into a corner of the STRB ground floor is the physics 180E plasma laboratory. The location allows the undergraduate lab access

to the large amount of equipment available to the BaPSF. When a repair has to be made the chances are good that a spare part is available and the class does not have to be shut down while a replacement is ordered. The lab instructor and TAs all have experiments in the STRB and are available all day long to help the students. The devices are shown in Figure 6. The students are split into groups of 2-3 and every day another group takes over one of the machines to do their experiment. The lab also has 4 computers available for data analysis.

The STRB has been used by other groups that needed the infrastructure that the building provides. The muon detectors now in use at the Large Hadron Collider (LHC) in CERN were tested here before shipment to Switzerland. The project led by Professors Katsushi Arisaka, David Cline, and Dr. Misha Ignatenko started in 2001 went on for several years. The first shipment of completed detectors to CERN happened in 2002. An element of the detector as well as the test stand are shown in Figure 7. UCLA received parts for 74 muon chambers along with front-end electronics and triggers. They were assembled and tested at the STRB.

The nuclear physics group headed by Professors Chuck Whitten and George Igo also used the STRB to test detectors in a small lab space on the second floor of the STRB. That space is now occupied by a high school outreach program, LAPTAG (Los Angeles Physics Teachers Alliance Group). LAPTAG has run for the past 25 years and over that time mentored over two hundred high school students from high schools from all over the city. The LAPTAG students have their own plasma device, funded by DOE, and the prototype for the machine is shown in Figure 6b.

When the STRB was constructed, the second floor of the building was allocated to the Mars lander project led by Professor David Paige from Earth, Planetary and Space Sciences. A team of roughly 130 scientists worldwide participated in MVACS (Mars Volatiles and Climate Surveyor) and set up offices and a fast computer link to the Jet Propulsion Lab in Pasadena for the mission. A duplicate of the lander occupied a sandbox to test commands before they were to be issued to the real one. Unfortunately, the 165 million dollar mission crashed somewhere near the South Pole of Mars a week after a festive celebration held at the STRB and attended by the then head of NASA, the UCLA chancellor, several politicians and the MVACS team.

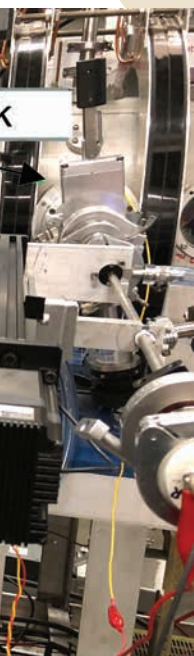


Figure 7. (a) Photograph of CMS muon detector illustrating components constructed by UCLA and other institutions. (b) Photo of several muon detectors being calibrated and tested in the STRB.

Donor Highlights

Julian Schwinger Foundation

The Schwinger Foundation gift totaling \$4.5M will grow the Julian Schwinger Graduate Fellowship from one fellowship recipient to four by 2021-2022. The four graduate students selected for this prestigious fellowship will be fully funded throughout the academic year and the summer, enabling them to focus on making tremendous strides in pursuing research on multi-scale physical phenomena. Thank you to Professor Seth Putterman for his important role as the Schwinger Family Foundation Director and being instrumental in facilitating this gift. We have fittingly named the Schwinger Lounge within the Bhaumik Institute space on the fourth floor of PAB.



Mani L. Bhaumik

Physicist and philanthropist Mani Bhaumik established the **Mani L. Bhaumik Institute of Theoretical Physics at UCLA** in 2016, donating the largest gift the UCLA Division of Physical Sciences has ever seen at \$11M. Since then, he has continued to be a champion of science, the department and division as a whole through establishing the Mani L. Bhaumik Graduate Fellowship in Theoretical Physics, establishing a dedicated study and collaboration space in Young Hall, and through allocating support from the Institute to Exploring Your Universe, UCLA's largest free public outreach day for science. Dr. Bhaumik's most recent gift, The Mani L. Bhaumik Graduate Fellowship in Theoretical Physics totals \$3M and continues Mani's tremendous legacy and the impact he has had and will have on countless Bruins.



Donor Highlights

John M. Cornwall

Thank you to Professor Emeritus John M. Cornwall for his generous planned gift to establish the **John M. and Ingrid Cornwall Gift Annuity**, an endowment that will support the UCLA Department of Physics and Astronomy in perpetuity. Professor Cornwall joined the UCLA faculty in 1965 with a research focus in elementary particle theory, a subject in which he authored about 100 papers. Once Quantum Chromodynamics (QCD) was invented, Professor Cornwall's work primarily focused on this area, with occasional excursions to particle astrophysics and high-temperature electroweak gauge theory. Retiring in 1994, Professor Cornwall has remained active in the department and his influential presence can still be felt in the department and the field at-large today. Through this recent planned gift, his impact will be felt for years to come



Howard and Astrid Preston

The **Howard and Astrid Preston Term Chair in Astrophysics** will leave a lasting legacy within the Galactic Center Group, continuing to propel the success of the group in perpetuity. This chair will support the work of the chair holder providing funding for salary, graduate student fellowships, travel and other critical expenses. Since 1990, UCLA alumni Howard and Astrid Preston have embodied the True Bruin spirit of service, philanthropically supporting the Department of Physics and & Astronomy in a variety of deeply meaningful ways from graduate student support to significant research funding. This most recent and largest gift to establish a chair is yet another example of their ongoing commitment to giving back to their alma mater in ways that will positively change the lives of Bruins forever.





For the department as a whole, the gifts of Ben Holmes and Carol Scheifele-Holmes and Ron and Jeryl Abelmann will expand graduate scholarships and graduate student support initiatives. On behalf of our students, thank you very much for your generous support!



This year the Department of Physics and Astronomy received commitments for several impactful endowments:

- **The Julian Schwinger Graduate Fellowship**
- **Mani L. Bhaumik Graduate Fellowship in Theoretical Physics**
- **John M. and Ingrid Cornwall Gift Annuity**
- **Howard and Astrid Preston Term Chair in Astrophysics**
- **John and Lauren Liberati Endowed Graduate Fellowship**
- **Roberto Peccei, Ben Holmes and Carol Scheifele-Holmes Endowed Fund**
- **Rudnick-Abelmann Endowed Fund**

The Impact of Giving

Each of these endowments focus on providing significant student support and making it possible for generations of students to be able to focus much more on their academic experience, exciting research and dedication to innovation than would have otherwise been possible without these generous gifts.

These endowments are each significantly impactful in their own right. However, we are thrilled to share that the Julian Schwinger Graduate Fellowship, the Mani L. Bhaumik Graduate Fellowship in Theoretical Physics, the Roberto Peccei, Ben Holmes and Carol Scheifele-Holmes Fund, and the Rudnick-Abelmann Endowed Fund were each matched by Chancellor Block and the Dean of Physical Sciences, Miguel García-Garibay – tripling their impact!

The Howard and Astrid Preston Term Chair and the John and Lauren Liberati Endowed Graduate Fellowship were matched one-to-one by the Dean of Physical Sciences, Miguel García-Garibay, doubling their impact!

Matching Funds

UCLA Physical Sciences Dean Miguel García-Garibay is matching all endowments of \$100,000 - \$1,000,000 on a one-to-one basis, while funds last, ensuring even greater support for generations of students and educators. Join us by investing in the future by contacting Amber Buggs at (310) 267-5194 or amberbuggs@support.ucla.edu.

Donor List - \$5K+

A special thank you to the following donors to the Department of Physics and Astronomy who have given \$5,000+ between July 2017 and June 2018.

Richard B. Kaplan and Rosamond Westmoreland	Janet E. Marott
Andrea M. Ghez	Robert and Jane Schneider
Mark Heising and Elizabeth Simons	Ken and Eileen Kaplan
James and Lori Keir	John R. Engel
Ralph and Shirley Shapiro	Jason Chai and Millie Young
Gordon and Adele Binder	Lawrence Bender
John B. Wagner	Richard Post
Marc M. Seltzer and Christina Snyder	Tim and Patricia McDonald
David and Patricia Aires	Shirley G. Saxon
	Dorothy P. Wong

Physics & Astronomy RESEARCH HIGHLIGHTS

Physics of Hearing

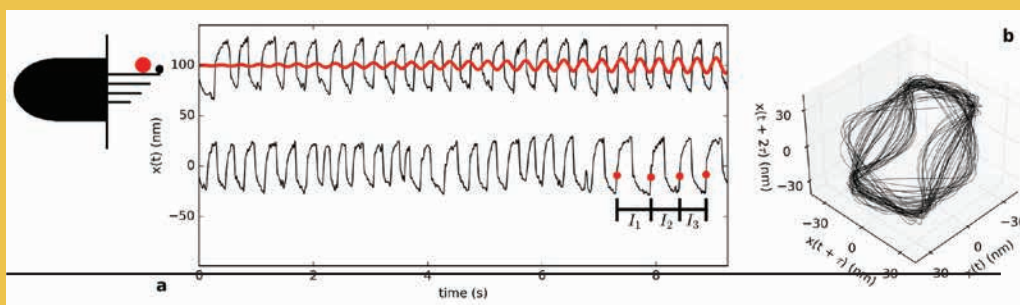
Dolores Bozovic Group

The sense of hearing remains one of the least understood in the field of sensory neuroscience. Despite extensive research, the underlying mechanisms behind its Angstrom-level detection, remarkable frequency selectivity, and sub-millisecond response times are not known. The Bozovic laboratory explores these open questions in auditory neuroscience, combining experimental and theoretical approaches.

In a recent study, we demonstrated that innate oscillations, exhibited by active hair bundles,

display chaotic dynamics. Experiments were performed in vitro, on preparations that maintained the natural activity of the cells. Analysis of both spontaneous and driven oscillations indicated the presence of a chaotic attractor. A number of different mathematical techniques were used to establish this result. For example, Poincaré maps were constructed to characterize the response of the oscillator to drives of different amplitudes. The quasi-periodic transition from a noisy to a perfectly entrained oscillation displayed the

phenomenon known as torus breakdown, one of the signatures of a chaotic system. We furthermore explored, both in theoretical models and experiments on hair cells, how the chaotic regime influences the sensitivity of detection. Our studies show that being poised in a weakly chaotic regime is beneficial, as it enhances the sensitivity of the detector. We believe that chaotic dynamics therefore may be an important and thus far overlooked component contributing to the remarkable properties of auditory detection.



(a) Position of a driven hair bundle (top) and spontaneously oscillating hair bundle (bottom). Red and black traces correspond to the stimulus waveform and the hair bundle response, respectively. (b) Reconstructed attractor of the hair cell system without stimulus, using delayed coordinates.

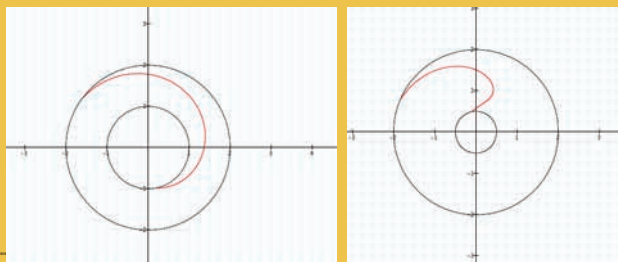
Adiabatic Thermodynamics of Fluids

Christian Fronsdal

Adiabatic Thermodynamics of Fluids, in the works for nearly ten years, is nearing completion and will be published during the current academic year.

The book exists because the theory General Relativity does not (or did not) allow for a coupling of the metric to an extended distribution of matter. An action principle is an absolute requirement, for it is the only way to satisfy the Bianchi identity. The non-relativistic limit is classical hydrodynamics formulated as an action principle. The problem can be and has been resolved by starting from that end. The essence of the solution was found three years ago; at this time some spectacular applications have been completed. The essential feature is the incorporation of a vorticity field to complement the irrotational velocity field introduced by Lagrange in 1760.

- In hydrodynamics, the stability of cylindrical Couette flow has remained an unsolved problem, no longer! Here it was learned that the new velocity field represents an internal stress.



- This first result suggests an application to understand the internal stress in capillaries and menisci, a problem that has never been posed. Work is under way.

- An immediate application to rotating planets led to the surprising discovery that the theory actually predicts the existence of planetary rings.

- The next application to be studied is the phenomenon of lift and drag, as in wind tunnels and in actual flight, a problem that has found no successful theoretical treatment till now. Success cannot be guaranteed at this time, but the additional degree of freedom certainly gives grounds for optimism.

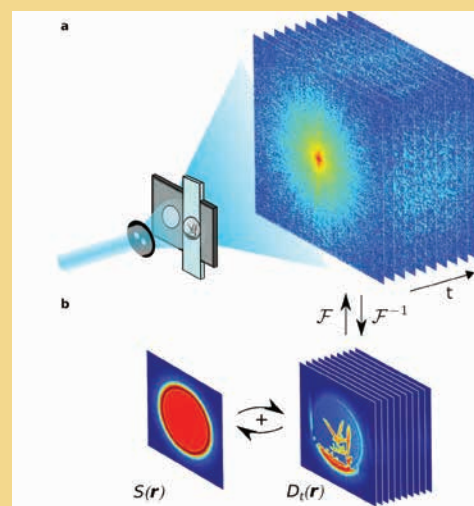


Coherent Diffractive Imaging (CDI)

Miao Group

Coherent diffractive imaging (CDI), pioneered by Miao in 1999, has been widely applied in the physical and biological sciences using synchrotron radiation, X-ray free electron lasers, high harmonic generation, electrons and optical lasers. One of CDI's important applications is to probe dynamic phenomena with high spatio-temporal resolution. Recently, Miao and Professor Chris Regan along with graduate students Mike Lo, Arjun Rana, Jared Lodico, postdoc Marcus Gallagher-Jones and collaborators have developed a general in situ CDI method for real-time imaging of dynamic processes in solution (Lo et al., Nat. Commun. 9, 1826 (2018)). By introducing a time-invariant overlapping region as a real-space constraint, they show that in situ CDI can simultaneously reconstruct a time series of

the complex exit wave of dynamic processes with robust and fast convergence (Fig. 1). They validate this method using numerical simulations with coherent X-rays and performing experiments on a materials science and a biological specimen in solution with an optical laser. Numerical simulations further indicate that in situ CDI can potentially reduce the radiation dose by more than an order of magnitude relative to conventional CDI. As coherent X-rays are under rapid development worldwide, it is anticipated that in situ CDI could be applied to probe dynamic phenomena ranging from electrochemistry, structural phase transitions, charge transfer, transport, crystal nucleation, melting and fluid dynamics to biological imaging.



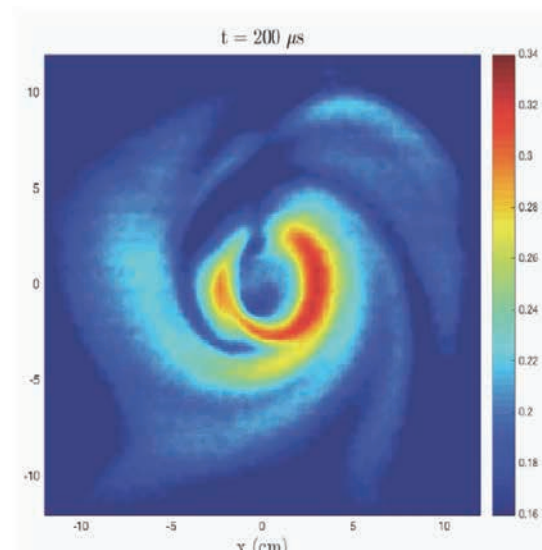
Schematic layout of an experimental geometry and the phase retrieval of in situ CDI. (a) A coherent wave illuminates a dual-pinhole aperture to create a static and a dynamic region. A sample in the dynamic region changes its structure over time and a time series of diffraction patterns are collected by a detector. (b) By using the static region as a powerful time-invariant constraint in real space, the in situ CDI algorithm iterates between real and reciprocal space and simultaneously reconstructs a time series of complex exit waves of the dynamic processes in the sample with robust and fast convergence, and represent the fast Fourier transform and its inverse.

Nonlocal Transport By Extreme Events In Magnetized Plasmas

George Morales

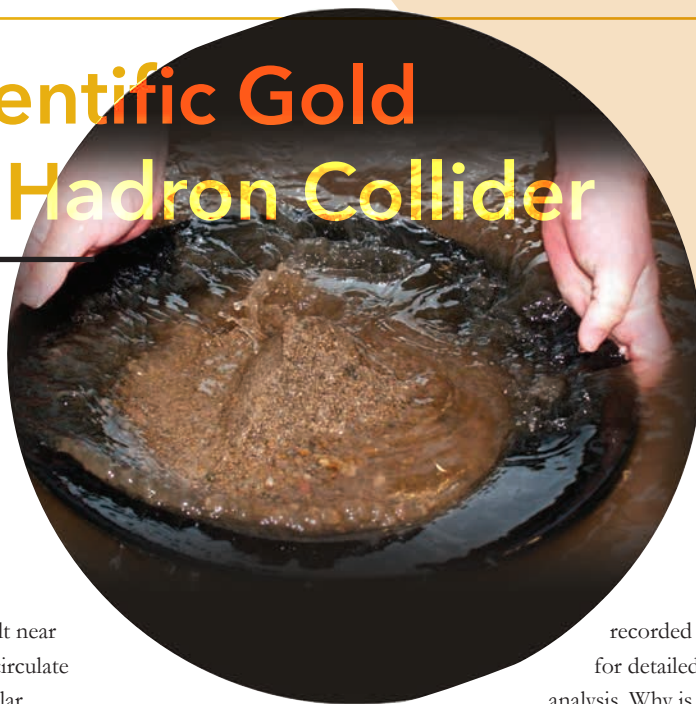
A coordinated experimental, theoretical and modeling project involving Dr. Bart Van Compernelle, graduate student Matt Poulos, and undergraduate student Suying Jin, led by Professor George Morales is investigating extreme transport events that can arise spontaneously in magnetized plasmas subjected to conditions that result in large gradients in temperature, density and ambient flows. Such phenomena can appear in naturally occurring plasmas, as in the Earth's magnetosphere and on the surface of the sun, as well as in laboratory plasmas subjected to strong heating and compression. The extreme plasma events display structures analogous to those encountered in geophysical environments, but

in addition to the intrinsic fluid nonlinearities their dynamics is governed by the complexities of the electrodynamics of plasmas in a magnetic field. The associated transport of heat and mass is nonlocal in the sense that the fluxes do not satisfy Fick's law; what occurs at one location can have global consequences. The phenomena can take the form of intermittent avalanches, tornados, and catastrophic collapses of the plasma pressure profile. Figure 1 provides an example of a tornado-like structure measured in a heating experiment performed in the Basic Plasma Science Facility (BaPSF) at UCLA and whose behavior has been modeled using a Braginskii transport code that includes spiral flows.



Panning For Scientific Gold At Cern's Large Hadron Collider

**Michalis Bachtis,
Robert Cousins,
Jay Hauser, and
David Saltzberg**



In the Large Hadron Collider (LHC), built near Geneva, Switzerland, beams of protons circulate in opposite directions within a large circular ring, and collide head-on with each other at the center of huge particle detectors. By studying these collisions, high-energy physicists from two experiments known as CMS and ATLAS found the Higgs boson in 2012, leading to Nobel prizes in 2013 to the theorists who predicted the existence of this particle. However, only about a half of one hundredth of a percent (0.005%) of all proton-proton collisions in the LHC are

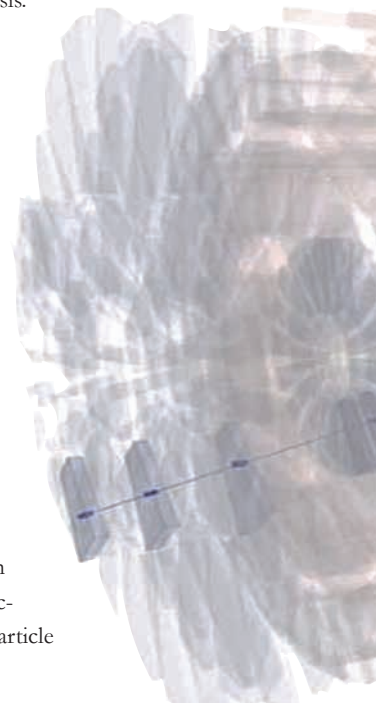
recorded for detailed analysis. Why is this fraction so small, and

how is this a big opportunity for UCLA physicists?

CMS is much like a custom-built digital camera that takes scientific “snapshots” of each proton-proton collision with almost 100 million detector pixels. A heavy dose of data compression reduces the information to about one megabyte per event. However, since proton-proton collisions occur 40 million times per second in the LHC, and the experiment runs for months on end, it is impossible to store all of the data for detailed analysis. Instead, CMS relies on a quick pre-selection of about 1000 out of the 40 million proton-proton collisions per second, a factor of 40 thousand reduction, before recording events for further analysis. This selection is called the trigger of the experiment. In a way, the process is like panning for gold in the stream of LHC data.

Rather than looking for a yellowish gleam at the bottom of a pan, the physicists usually look for very energetic particles of several types. Highly prized are electrons, photons, and more exotic objects well-known only to high-energy physicists: muons, taus, jets, and indirectly detected neutrinos. These can be well identified if they have high energy, typically above 20 to 200 billion electron-volts. Proton-proton collisions produce a lot of pion and kaon particles, averaging less than 1 billion electron-volts. The discovery of the Higgs particle

Great efforts are made to optimize the trigger, and thus maximize the yield of “scientific gold.” Muons are the most clearly identified of all the interesting objects, and all of the professors in the UCLA group have developed or are now developing high-speed electronics for the Level 1 trigger for muon particles.



in 2012 was made using a combination of collisions containing energetic muons, electrons, and photons.

In CMS, the data is selected in two trigger stages. The first stage, called Level 1, is a set of custom-built electronics that selects only 1/400 of the collisions in about 3 millionths of a second, whereupon 100 kHz of collisions data is sent over a high-speed local network to a large farm of computers. In the second stage, called the High Level Trigger, this computer farm selects 1/100 of the collisions that passed the first stage of selection, within about one hundredth of a second, and the net output rate of 1000 Hz of collision data is written onto storage disks.

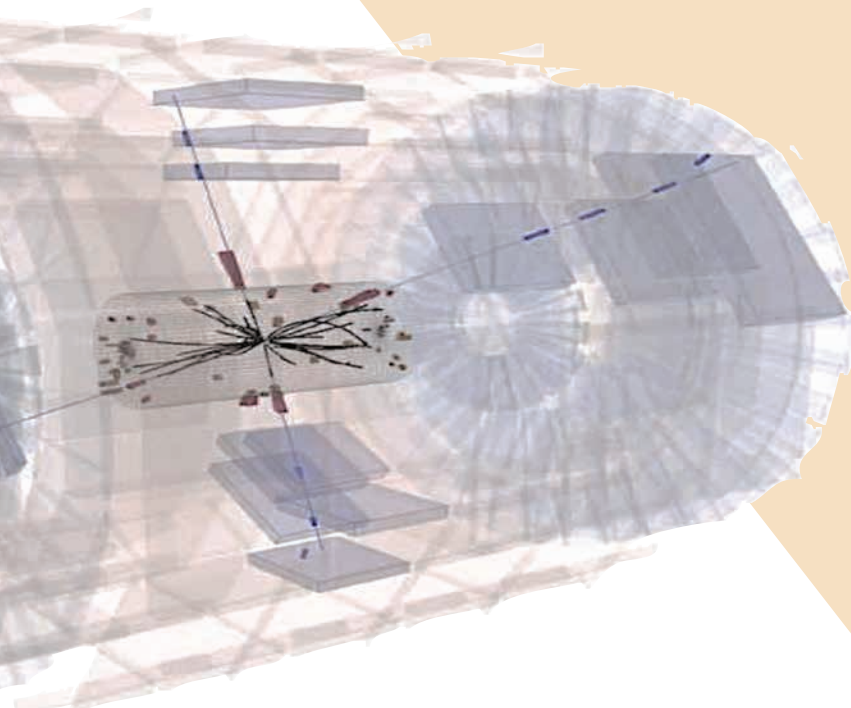
Great efforts are made to optimize the trigger, and thus maximize the yield of “scientific gold.” Muons are the most clearly identified of all the interesting objects, and all of the professors in the UCLA group (with their group members) have developed or are now developing high-speed electronics for the Level 1 trigger for muon particles.

Many years ago, the UCLA group developed electronics that find high-momentum muons that pass through detectors known as Cathode Strip Chambers or CSC. These have been vitally important in the Higgs discovery and most of the physics measurements and new particle searches of CMS. This year, the group is building improved electronics to cope with a higher rate of collisions expected in the future for CSC detectors as well as a new type of CMS muon detector known as Gas Electron Multipliers. The group has also improved the Level 1 trigger for particles crossing the muon detectors known as Drift Tubes. Part of the Level 1

The UCLA group is also working on a physics analysis to isolate any collisions with pairs of non-prompt muons, with the goal being either a discovery or limits on the rate of their production, by early 2019.

trigger connects short segments of the muon track into an overall trajectory. An algorithm known as a Kalman Filter is the ideal tool for this, but requires extensive matrix computation and is normally run on computers. Previously, no one had dreamed that it could be run in the 0.2 millionths of a second available in the Level 1 trigger. By clever linearization approximations and using GPUs built into the existing programmable electronics, the UCLA group managed to squeeze the algorithm into the time available, and program it into the electronics used by CMS. Now the momentum measurement of the Level 1 muon trigger is better, and the efficiency is increased.

Several new theories of physics beyond the standard model predict particles that are very massive and travel away from the point of proton-proton collision before they decay to “non-prompt” muon particles. Some of these theories contain exotic additional Higgs particles, and some contain particles known as dark photons. This type of muon was not foreseen when CMS was designed, and so the CMS trigger may have been routinely throwing away collisions that contain them. This year, the UCLA group changed the trigger in order to collect events with two non-prompt muons with high efficiency. The UCLA group is now preparing further improvements to the Level 1 muon trigger in order to collect collisions containing one or more non-prompt muons efficiently during the next LHC run in 2021-2023. The UCLA group is also working on a physics analysis to isolate any collisions with pairs of non-prompt muons, with the goal being either a discovery or limits on the rate of their production, by early 2019.



A collision containing a Higgs particle decaying to four muons (straight lines).

Planets and Exoplanets

About 15 students took Margot's SETI course and used the Green Bank Telescope to search for technosignatures near Sun-like stars in the plane of the Galaxy. Students wrote Python programs and searched terabytes of data for evidence of ex-traterrestrial civilizations. Their first results have been published in the *Astronomical Journal*. You can get involved in the search and read about our progress at <http://seti.ucla.edu>.

We will offer this course again in Spring 2019.

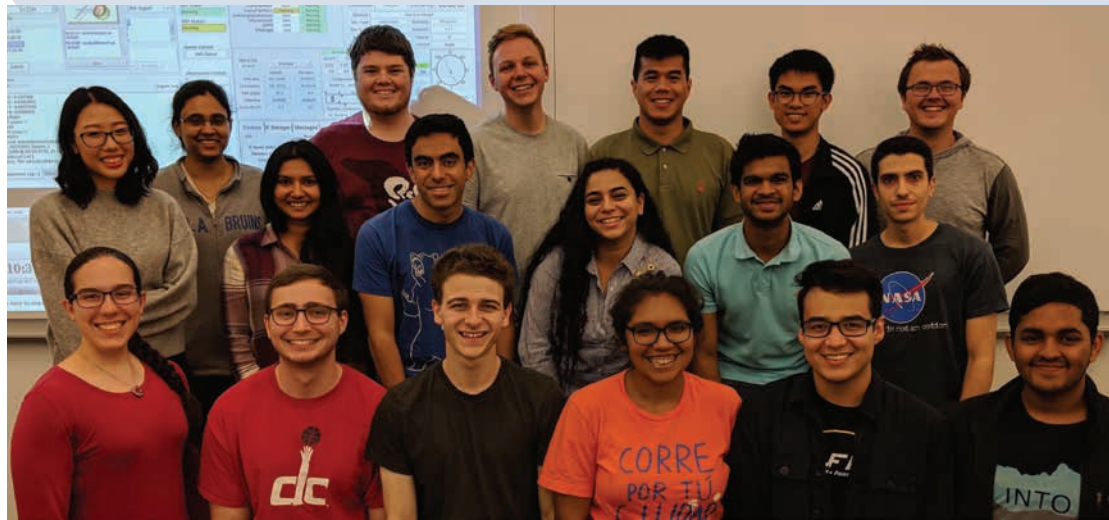
Our research group members measure the spin states, sizes, shapes, gravity fields, and orbits of planetary bodies with a variety of telescopes and spacecraft.

Our radar observations of binary near-Earth asteroid 1999 KW4 in May 2017 at the Arecibo Observatory were seriously degraded by the aftermath of Hurricane Maria, which was the tenth most intense and third costliest Atlantic hurricane on record and which took an estimated 3000 lives. Despite the low signal-to-noise ratio, we are able to measure the positions of the

Jean-Luc Margot

secondary with respect to the primary, which will allow us to quantify the evolution of the mutual orbit since our observations in 2001 and 2002.

With UCLA alumnus Nathan Myhrvold, our team has started an extensive re-analysis of the WISE observations of asteroids. The WISE mission produced superb all-sky coverage of the infrared sky. The analysis of asteroid observations was handled by a JPL team and several aspects of the analysis need improvement. Our goal is to deliver better asteroid parameters that will serve asteroid researchers for many years to come.



Students who took Margot's SETI course.

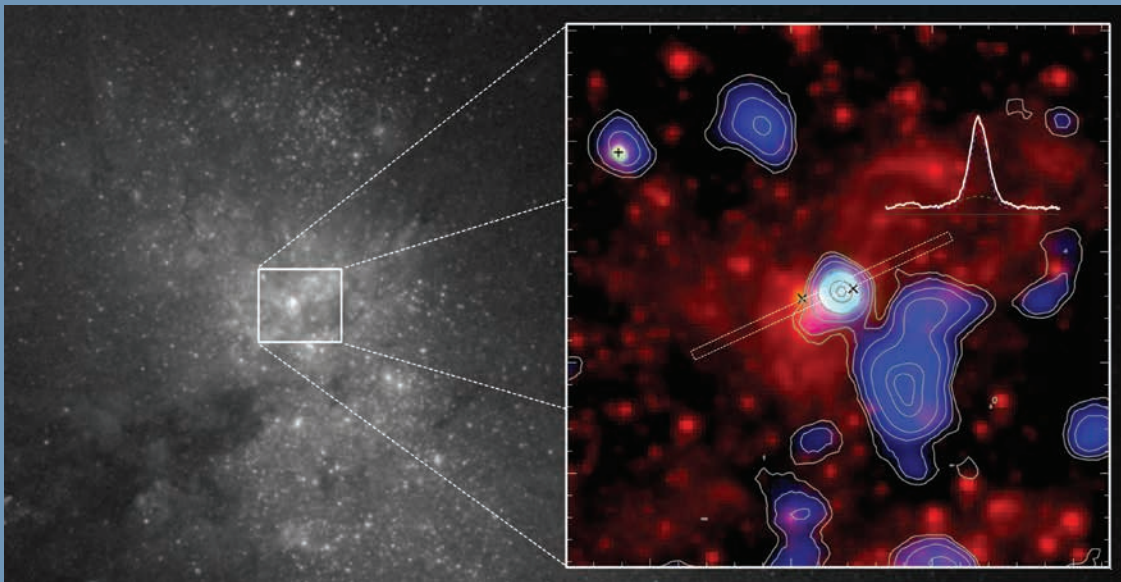
Giant Star Clusters & Feedback in Dwarf Galaxies

Professor Jean Turner and her group are studying the formation and feedback of giant star clusters in local dwarf galaxies. Giant star clusters are the largest objects that are composed of primarily of baryons, not dark matter. Postdoctoral fellow S. Michelle Consiglio, and students Danny Cohen, Dallar Babayan, and Eric Bratton III are using a combination of high resolution near-IR spectroscopy using NIRSPEC on Keck, VLA and ALMA imaging to characterize the dynamics of ionized and molecular gas near forming super star clusters. A highlight of the year was Cohen's paper

on Brackett α emission from the giant cluster in NGC 5253 with data from NIRSPEC behind adaptive optics. This recombination line has a remarkably narrow linewidth considering that the cluster core contains an estimated 2000 windy O stars within its diameter of 20 light years. The lack of mechanical feedback means this cluster can continue to accrete gas, form stars, and grow in size. CO J=3-2 images from the ALMA Telescope also show a narrow line, as published last fall by Consiglio et al. This paper revealed that the super star clusters in this galaxy are forming from

Jean Turner Group

filaments of molecular gas being accreted from outside the galaxy. Turner and Consiglio, with collaborator Sara Beck, have also imaged the CO(3-2) line in the dwarf galaxy Henize 2-10, and find accreting filaments there too, but also a molecular outflow with no apparent infrared, X-ray, radio, or optical source. Both galaxies are likely to be dark-matter dominated; the role of dark matter in shaping the filament accretion and the mysterious outflow source are unclear.



Dwarf galaxy NGC 5253 and its giant young star cluster. To the right is shown a close-up of the giant cluster, with molecular gas in blue, optical continuum light in red, and $2\ \mu\text{m}$ dust emission in light blue. The Keck-NIRSPEC spectrum of $4.05\ \mu\text{m}$ Brackett α recombination line is shown, taken from the slit position centered on the star cluster. Adaptive optics were used; the slit was $0.1''$ in width, or about 6 light years on the source. Adapted from Cohen et al., *Astrophysical Journal*, 860 (2018).

The A-type Stars, the Destroyers of Worlds

Massive stars classified as ‘A-type’ stars are roughly 1.6 to 2.4 times the mass of the Sun and are often found with a stellar binary companion. This companion can strongly affect the dynamical evolution of planets around either star. In a paper led by UCLA graduate student Alexander Stephan (Stephan, Naoz & Gaudi 2018), we showed that these A-type stars tend to destroy their accompanied planets. The companion stars gravitationally influence the orbit of a Jupiter-sized planet, moving it too close to the A-type

stars to eventually be destroyed – either ripped apart by the star’s gravity or swallowed up by the star as it expands beyond the main sequence. We also found a new class of planets, Temporary Hot Jupiters, that form during the post-main sequence lifetime. These Temporary Hot Jupiters orbit on periods of tens to a hundred days and only exist for a few 100,000 years before they are engulfed, but they reach similar temperatures as “classical” Hot Jupiters.

Smadar Naoz Group

HIGHLIGHTS:

SMADAR NAOZ GROUP

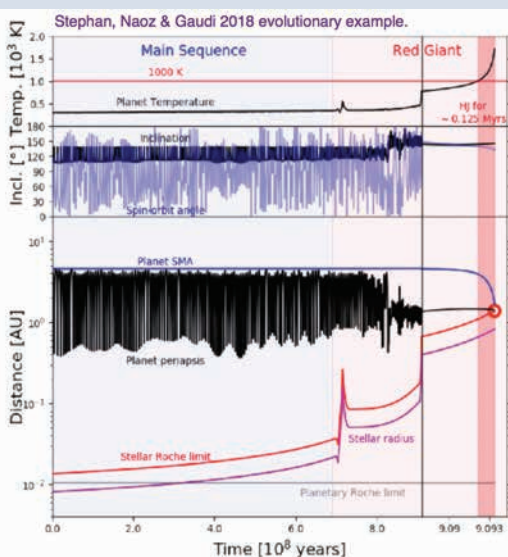
We destroyed worlds: (Stephan, Naoz & Gaudi 2018) - see on the left for more.

We spun up stars by feeding them planets (Qureshi, Naoz & Shkolnik 2018).

We hid friends for planetary systems (Denham et al 2018).

We spun up supersonically-induced gas objects at the early Universe (Chiou et al 2018).

We suggested that stellar binaries can explain many of the puzzles associated with the stellar disk at the Galactic Center (Naoz et al 2018).



Artist's impression of the exoplanet KELT-9b which is too close to its host star. Credit: NASA/JPL-Caltech

Infrared Laboratory Group

The UCLA Infrared Laboratory for Astrophysics (IR Lab group) was founded in 1989 by Professors Becklin and McLean to develop state-of-the-art infrared cameras and spectrometer for astronomy.

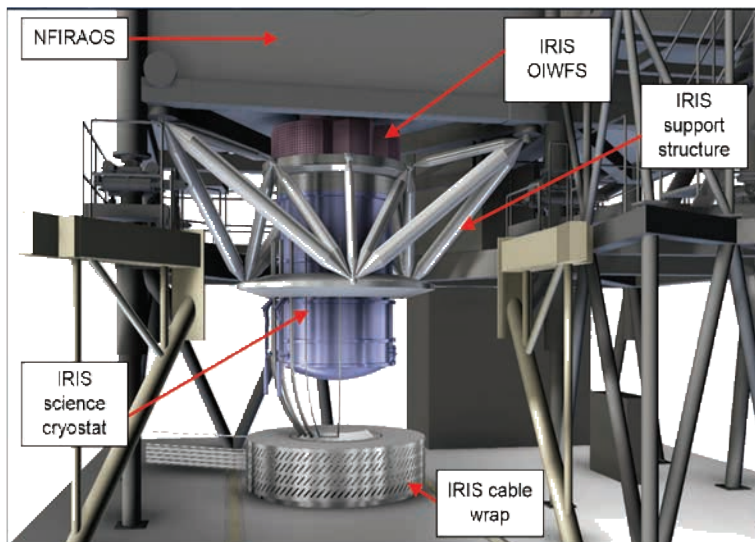
**Ian McLean,
James Larkin,
Mike Fitzgerald**

The UCLA Infrared Laboratory for Astrophysics (IR Lab group) was founded in 1989 by Professors Becklin and McLean to develop state-of-the-art infrared cameras and spectrometers for astronomy. Our initial focus was on the giant twin 10-meter telescopes of the W. M. Keck Observatory (WMKO) on Mauna Kea, Hawaii, which went into operation in 1993 and 1996. Professors Larkin and Fitzgerald joined the IR Lab group in 1997 and 2010 respectively, and have been actively promoting the development of diffraction-limited instruments that take advantage of adaptive optics technology. For almost three decades, the IR Lab group has built and deployed many highly successful instruments. Significantly, graduate students of the IR Lab have gone on to become leaders themselves. Of the four infrared instruments currently in use at the Keck Observatory, three were built under the leadership of UCLA faculty (NIRSPEC, OSIRIS, and MOSFIRE), and UCLA collaborated with Caltech scientists to produce the fourth instrument (NIRC2). Because each instrument is developed for open use in order to maximize scientific return, these instruments have facilitated numerous discoveries, and resulted in many hundreds of research papers across the entire Keck community.

Professor Becklin retired in 2005, but Professor McLean remains Director of the IR Lab. Both were honored by the American Astronomical Society in 2017, with Becklin receiving the Russell Prize and McLean the Weber prize. The formal award presentations took place in Washington D.C. in January 2018.

During the current reporting period the IR Lab group consisted of three faculty members (McLean, Larkin and Fitzgerald), eight professional staff, and three graduate students. One of our students (Emily Martin) received her PhD in June 2018. Emily played a key role in the upgrade of the NIRSPEC spectrograph at Keck Observatory. Currently, the IR Lab is completing two major instrument upgrades for WMKO; the OSIRIS Imager upgrade and the NIRSPEC detector upgrade. Both projects are led by Professor Fitzgerald. UCLA is also the lead institute on the huge, multinational IRIS integral field spectrograph for the proposed Thirty Meter Telescope (TMT). This project is led by Professor Larkin.

The Infrared Imaging Spectrograph (IRIS) for the TMT (Figure 1) spans the wavelength range from 0.84-2.4 microns. This “first light” instrument for TMT combines a set of on-instrument wavefront sensors, a wide-field diffraction limited camera, and an integral field spectrograph. IRIS is a large international project, with an estimated total budget of \$45 million and major collaborations at UC San Diego, UC Santa Cruz, Caltech, NRC-Victoria, and the National Astronomical Institute of Japan



The IRIS instrument shown in-situ mounted to the up-looking port of NFIRAOS (TMT's facility AO system). IRIS mounts through a set of carbon fiber struts and rotates about its vertical axis to track the rotation of the field. The silver cylinder in the lower portion of the image is the IRIS cable services wrap, which is designed to prevent damage to IRIS cables as the cryostat rotates during operations. For scale, the blue dewar is 1.9 meters in diameter.

(NAOJ). In addition to overall leadership of the project, UCLA also leads the electrical and software systems, and the design of the lenslet array spectrograph. The spectroscopy section of IRIS provides a base resolving power of $R \sim 4,000$ (8,000 in some modes) and comes with four optional image scales (0.004, 0.009, 0.025, 0.050 arcsec per sample). Notice how fine the image scale is at the diffraction limit of a 30-m telescope! The corresponding imaging section of IRIS provides a relatively large 34 arcsec field of view by using a 2×2 grid of 4K x 4K (H4RG) HgCdTe detectors from Teledyne Imaging Sensors. The plate scale for imaging is a remarkable 0.004 arcsec per pixel. IRIS passed a crucial milestone in 2017 when the team successfully completed the 2nd portion of the IRIS Preliminary Design Review. Subsequently, the TMT project office approved IRIS to enter its Final Design phase. This phase is planned to run for three years from November, 2017 to November, 2020.

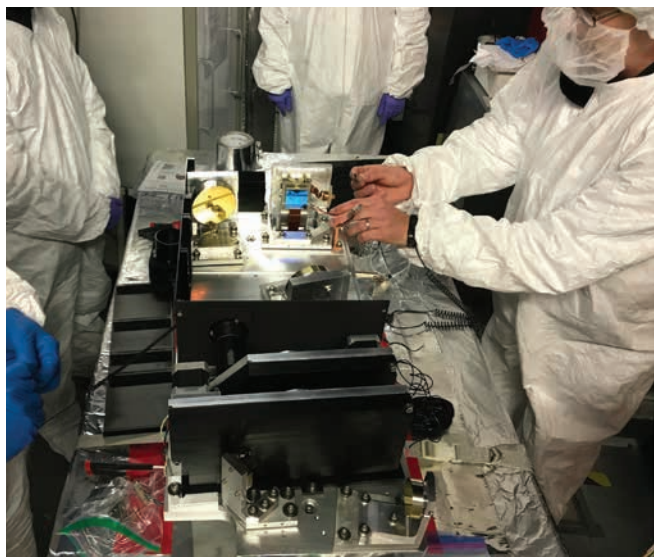
Led by Professor Fitzgerald, the new OSIRIS Imager project is close to completion. Installation at the telescope began late last year (see Figure 2), and detailed on-sky characterization of the new

camera and detector performance is currently underway. Final adjustments are planned for the second half of 2018. The aims of this upgrade project were several. Provide stable imaging over a $20'' \times 20''$ field with fine sampling suitable for astrometry; provide finely sampled PSF references for the spectrometer; improve the sensitivity in the K-band (wavelengths ~ 2.2 micron) over current performance; and enable capabilities for first-light operation of Next Generation Adaptive Optics (NGAO). The Imager upgrade project is primarily funded by the Gordon and Betty Moore Foundation, with cost matching from UCO and UCLA.

Funded by a successful Major Research Instrumentation proposal to the National Science Foundation by WMKO, in collaboration with UCLA, Professor Fitzgerald is also leading the upgrade of NIRSPEC at the Keck Observatory. NIRSPEC was the first cross-dispersed, high-resolution 1-5 micron cryogenic echelle spectrometer on any 10-m class telescope. It was commissioned on Keck 2 in 1999 (PI: Professor Ian McLean). The long-running success of NIRSPEC, followed by the successful deploy-

ment of MOSFIRE on Keck 1 in 2012, together with earlier contributions to CCD and IR array technology, were among the reasons cited for the Weber Award to Professor McLean. The NIRSPEC upgrade has three main goals. Replace the original InSb detector in the spectrograph with a modern HgCdTe array having four times as many pixels; replace the slit-viewing camera optics and detector; and eliminate the obsolete Transputer-based electronics used for both detector and motion control. Delivery and installation of the new detectors began in July of this year (Figure 3), and commissioning will continue in planned phases through the end of 2018 and into 2019. Graduate student Emily Martin played a major role in this project as the instrument scientist, including optical design, detector testing and evaluation, software and team management. She graduated in June 2018 and is currently a visiting research fellow at Keck Observatory before taking up her NSF postdoctoral fellowship at the University of California, Santa Cruz.

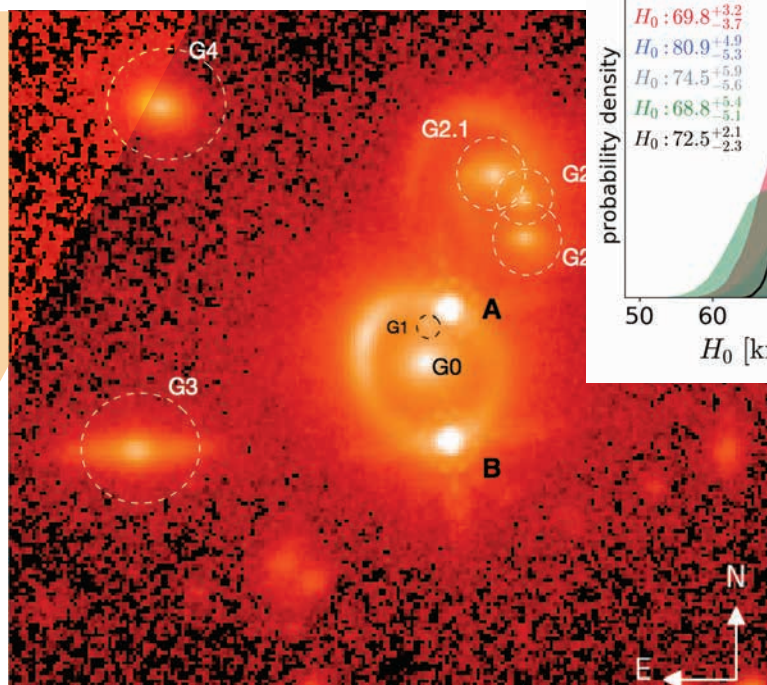
Ian McLean uses the NIRSPEC and MOSFIRE instruments at the Keck Observatory, and the FLITECAM instrument on NASA's Stratospheric Observatory for Infrared Astronomy. He was the principal investigator for all three of these instruments.



Professor Fitzgerald is the lead investigator of the new OSIRIS Imager project which is close to completion. Installation at the telescope began late last year, and detailed on-sky characterization of the new camera and detector performance is currently underway. Final adjustments are planned for the second half of 2018. The aims of this upgrade project were several. Provide stable imaging over a $20'' \times 20''$ field with fine sampling suitable for astrometry; provide finely sampled PSF references for the spectrometer; improve the sensitivity in the K-band (wavelengths ~ 2.2 micron) over current performance; and enable capabilities for first-light operation of Next Generation Adaptive Optics (NGAO). The Imager upgrade project is primarily funded by the Gordon and Betty Moore Foundation, with cost matching from UCO and UCLA.

Tommaso Treu's Group Highlights

- The discovery of a single highly magnified star billion of light years away (<http://newsroom.ucla.edu/releases/a-cosmic-quirk-helps-astronomers-pinpoint-the-farthest-star-ever-seen>).
- A new determination of the expansion rate of the universe H_0 to 3% precision using multiply imaged quasars (Birrer, Treu et al. 2018; see Figure), with profound implications for the nature of dark energy.
- The discovery of a large sample of quadruply imaged quasars (Treu et al. 2018, Shajib et al. 2018b), which paves the way to reach 1% precision on H_0 in the near future (Shajib et al. 2018a) and to characterize the nature of dark matter (Gilman et al. 2018).
- New determinations of the mass of black holes (Williams et al. 2018; in collaboration with Prof Malkan).
- The discovery of two galaxies at the peak of cosmic star formation activity blowing gas out with massive winds (Wang et al. 2018).
- A new determination of the end of the cosmic dark ages (Mason et al. 2018a,b,c).



Determination of the expansion rate of the universe H_0 with multiply imaged quasars. Left: Hubble Space Telescope image of the system J1206, showing the main lens galaxy G0 and the two images of the background quasar A and B. The host galaxy of the quasar is lensed into an Einstein Ring. Right: Posterior distribution function of the Hubble constant based on J1206 (green) and on four previously analyzed lenses combined (black). Figures from Birrer et al. (2018).

GRADUATE STUDENT HIGHLIGHTS

- The development of a new technique to determine the evolution of galaxies (Abramson et al. 2018).
- Louis Abramson was awarded a Carnegie-Princeton Fellowship.
- Charlotte Mason completed her PhD and started as a Hubble Fellow at Harvard.
- Graduate student Xin Wang received a dissertation year fellowship.

Treu's group received funding from NSF and NASA to support its research. Treu is also Co-PI of a \$7M award by NSF to upgrade the Adaptive Optics system on the Keck Telescope.

UPSILON LAB: A New Research Club for Undergraduates



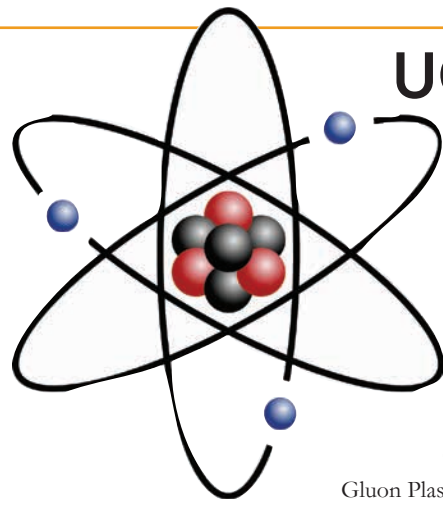
The Upsilon Lab was started by two recent physics graduates to provide undergraduate physics and astronomy majors the opportunity to learn valuable skills to succeed in their future endeavors, whether in research, engineering, or other fields. In Upsilon Lab's first 6 months there were 79 students working on 10 projects plus 3 others including Founder-Presidents, workshop presenters and skill guide authors. The projects included a pilot waves experiment drawing analogies between classical and quantum phenomena, a noise-reducing enclosure for a quantum computing experiment, and a Froot Loop dispenser used to learn how rats react to virtual reality environments.

For more information please visit upsilonlab.pa.ucla.edu.

UCLA Nuclear Physics Group Huan Huang Group

UCLA Nuclear Physics Group
is a founding member of the

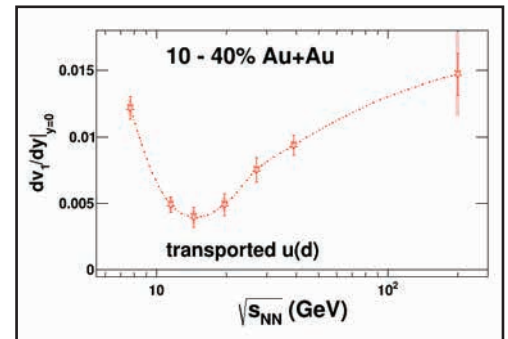
STAR Collaboration at Brookhaven National Laboratory (BNL).



Our research activities center on studying properties of a new state of matter, the Quark-Gluon Plasma (QGP), created at BNL Relativistic Heavy Ion Collider (RHIC). We published intriguing measurements of the directed flow (v_1) for ten particle species (π^\pm , p , anti- p , Λ , anti- Λ , ϕ , K^\pm and K^0_S) from Au+Au collisions at eight beam energies ranging from $\sqrt{s_{NN}} = 7.7$ to 200 GeV [1, 2]. The directed flow reflects a collective deflection of bulk nuclear matter in the early stage of the collisions. Hydrodynamic calculations [3, 4] proposed that a first order phase transition between hadronic matter and the QGP may present a minimum in the net-baryon directed flow as a function of beam energy.

Our measurements indicated a minimum in the slope of directed flow variation as a function of rapidity (dv_1/dy) at an energy between 10 and 20 GeV. To distinguish different interpretations, we used a quark coalescence model to evaluate the directed flow of the constituent quarks. We statistically separate quarks into “transported” quarks (u/d quarks from the colliding nuclei) and “produced” quarks (u/u-bar, d/d-bar and s/s-bar pairs created during the collision) [2]. The v_1 slope of transported quarks (see Figure) can be estimated after removing contributions of the produced quarks. Our measurement is consistent with the softening of EOS with a minimum at $\sqrt{s_{NN}} \approx 14.5$ GeV though alternative scenarios cannot be ruled out. We expect to increase the statistics by an order of magnitude with data from the phase II of the RHIC beam energy scan program, which will commence in 2019.

In July 2018, the National Academies released a report concluded that the science that could be addressed by an Electron-Ion Collider (EIC) is compelling and would provide answers on the nature of nuclear matter and its quark/gluon degrees of freedom. The UCLA group has been working on a new electromagnetic calorimeter detector technology for EIC since 2011. With a new national EIC facility in the coming decade, the future of nuclear physics to study properties of quark/gluon degrees of freedom in nuclear matter is very bright.



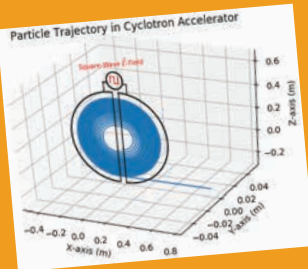
[1] L. Adamczyk et al. (STAR Collaboration), Phys. Rev. Lett. 112 (2014) 162301.

[2] L. Adamczyk et al. (STAR Collaboration), Phys. Rev. Lett. 120 (2018) 62301.

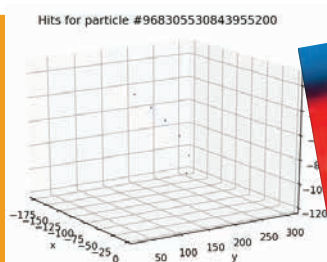
[3] D. H. Rischke et al., Heavy Ion Phys. 1 (1995) 309.

[4] H. Stocker, Nucl. Phys. A 750 (2005) 121.

PICTURES FROM THE LAB



Cyclotron Motion in a Square-Wave Electric Field



Locations where one particle hit the detector within one event. Each event corresponds to a particle collision. Each event leads to thousands of such paths.



Hydrodynamic Pilot Waves



THE BOX

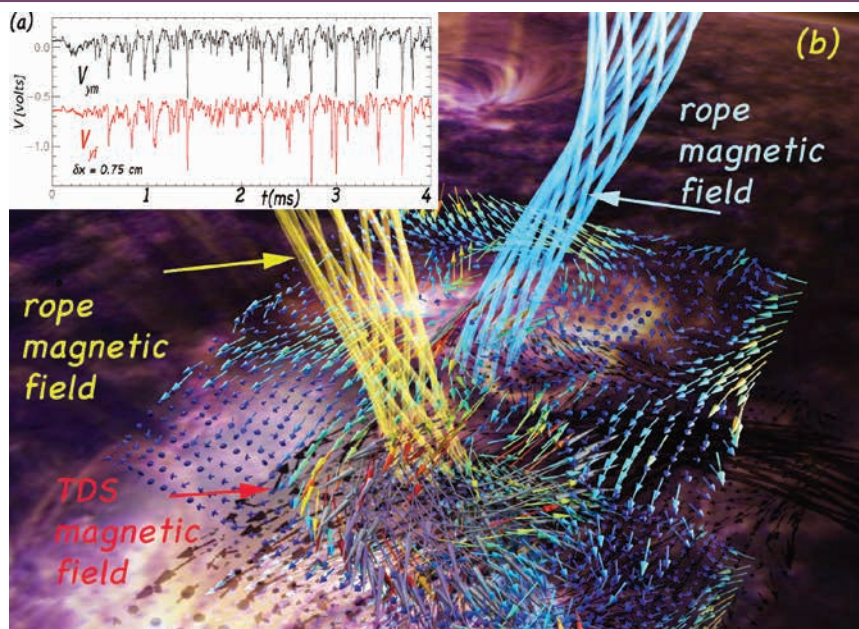


Figure 1. (a) Potential pulses recorded by two probes 0.75 mm apart. Analysis shows the spikes are moving close to the plasma sound speed. (b) Measured magnetic field of the two flux ropes. The ropes move and periodically collide causing reconnection. The arrows show the reconstructed magnetic field of a single spike. The background is a UV image of the sun.

Time domain structures (TDS) and flux ropes

Walter Gekelman, Sean W. Tang, Steve Vincena

Magnetic Flux ropes are structures which litter the solar surface. They are twisted bundles of magnetic field and current. Some can grow quickly in size and morph into Coronal Mass Ejections that leave the sun. If they come close to earth they can wreak havoc with communications, destroy satellites and affect power transmission lines on the earth. We have routinely created magnetic ropes in the LAPD device and used them to study instabilities associated with them as well as events in which magnetic energy is destroyed and instead takes other forms such as heat, plasma waves and flows. This process is called magnetic field line reconnection. We recently discovered narrow electrical and magnetic pulses which emanate from the reconnection region as shown in Figure 1a. Using a novel counting method we were able to reconstruct the magnetic field of one of the TDS shown in Figure 1b. This was recently published in PNAS. TDS is the thesis topic of Sean W. Tang who has advanced to candidacy.

Basic Plasma Experimental Physics

Low Temperature Plasma Physics

Walter Gekelman, Pat Pribyl, Jia Han

Plasma Processing is a multi-billion dollar industry. Without it there would be no computers as we know them, no iPhones, etc. The plasma group has a cooperative program with LAM research corporation, a manufacturer of the tools used to make semiconductors. LAM donated one such tool to UCLA. It was modified for experimental access and a fully 3D probe drive installed. Figure 2 illustrates plasma currents at one instant of time within the etch tool.

In this experiment, the thesis topic of Jia Han, the plasma density, magnetic field, plasma potential, electric field were all measured in full 3D for the first time. The results will be published in Plasma Sources Science and Technology. The UCLA effort is, in part, devoted to improving the performance of manufacturing tools. The experiments also study fundamental processes within the very complicated, multi ion species plasmas.

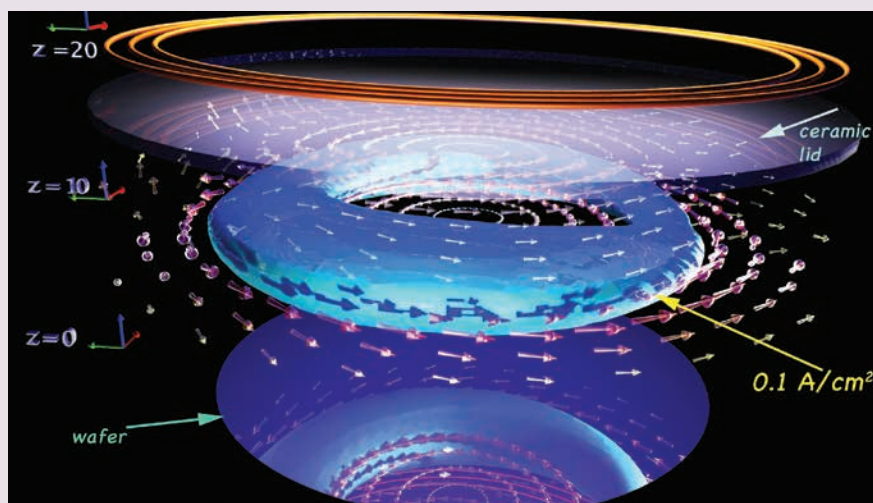


Figure 2. Plasma current derived from measurements of the 3D magnetic field in a plasma etch tool. The arrows show the current on several planes above the reflective silicon wafer on the bottom. The ceramic lid, which forms the top of the vacuum device and the 3 coils used to create the plasma are drawn to scale at the top.

Nonlinear interactions between magnetic flux ropes and shear Alfvén waves

S. Vincena, S.K.P. Tripathi, W. Gekelman, & P. Pribyl

Experiments are being performed on the Large Plasma Device (LAPD) to study the nonlinear interactions between current-carrying plasmas known as magnetic flux ropes and the Alfvén waves. Both flux ropes and Alfvén waves can be found in plasmas ranging from the surface of the sun, through the interplanetary solar wind, to the magnetospheres of earth and other planets. Depending on the current density, the dimensions, and the strength of the surrounding magnetic field, the magnetic flux ropes can become unstable to what is known as a kink oscillation. This is expressed as a dimensionless quantity. When this number is greater than one we have an unstable magnetic rope which kinks as a function of time. The magnetic perturbations of the kink oscillation and the Alfvén wave can both have very large spatial scales and represent energy waiting to be converted into smaller scales—eventually down to scales that are small enough where this energy can be dissipated by the particles and make the plasma hotter. Such an energy transfer is often governed by a nonlinear, three-wave interaction. Evidence for this transfer can also be seen in Figure 3. As the kink oscillation grows, it interacts with a constant-amplitude Alfvén wave launched by an antenna and produces sidebands about the central wave frequency. Although not shown here, these sidebands are measured to have two-dimensional magnetic field patterns that are of increasingly smaller spatial scale. Further experimental and theoretical efforts by our group and collaborators hope to better understand these new, exciting laboratory results.

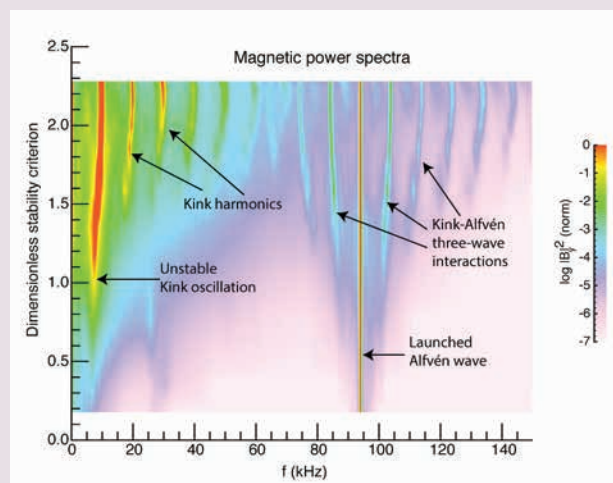
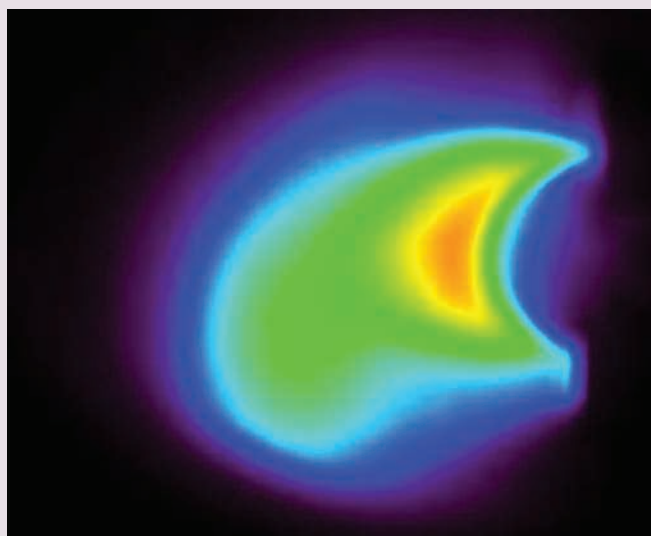


Figure 3. Stability of modes produced when an Alfvén wave interacts with a magnetic flux rope. The dimensionless stability criteria is the ordinate and the frequency of magnetic oscillations the abscissa.

Solar arched magnetized plasma experiment

Shreekrishna Tripathi, Walter Gekelman, and Kamil Krynski



A group of plasma physicists at the basic plasma science facility have devised a laboratory experiment that generates unstable arched magnetized plasmas (see Figure 4) within confines of a large cylindrical vacuum chamber (4.0 m long, 1.0 m diameter). The experiment was built to better understand physics of solar flares and coronal mass ejections. These are extremely intense explosions of arched magnetized plasmas on the Sun that release up to 10^{26} joules of energy (amounting to ten million times greater energy than a volcanic explosion). The laboratory exploration of these phenomena using an appropriately-scaled model is providing a better insight into physical processes that drive solar eruptions. The novel feature of the experiment is its ability to produce tens of thousands of nearly identical eruptions within a day and capture important plasma parameters in three-dimension using automated probes and modular sensors. The experiment has been recently upgraded to improve the performance and reliability of two different hot-cathode plasma sources that form the arched magnetized plasma and the ambient plasma. A three-dimensional probe drive system was also constructed. Results on the excitation of fast magnetosonic waves (identified as intense EIT waves on the Sun) and kink-mode oscillations following the eruption of the arched plasma were presented in scientific meetings. This experiment has generated interest in solar physics community and collaborative efforts are expected in this cross-disciplinary area of research in near future.

Space Plasma Simulation Group

**Jean Berchem, Mostafa El-Alaoui, Robert Richard,
David Schriver, Nicole Echterling (graduate student)**

The Space Plasma Simulation Group (SPSG) has continued to carry out cutting edge research in space physics. The group conducts numerical simulations including global magnetohydrodynamic (MHD), large-scale kinetic (LSK) and particle-in-cell (PIC) simulations. Different techniques are necessary because physical processes in the Earth's magnetosphere occur across vastly different spatial scales and must include wave-particle interactions and large-scale magnetospheric stresses into a single modeling framework. The group achieved this by embedding mesoscale implicit PIC simulations into global MHD simulations. Observations made by NASA spacecraft are used both to initialize and validate the simulations. Measurements from solar wind monitors sunward of Earth are used as input to the MHD simulations while observations near Earth are used to validate their results. The simulation results allow us to put single point spacecraft measurements in a global magnetospheric context and to determine the

physical mechanisms responsible for observed phenomena.

Magnetic reconnection is a fundamental process of energy conversion from magnetic energy to plasma kinetic energy, and understanding reconnection at Earth and at other planets, including Mercury, has been a major focus of the group's efforts. Reconnection occurs mainly within planetary magnetospheres at the dayside magnetopause and in the nightside magnetotail. Figure 1 shows an example using our local-global simulation of the Earth's magnetosphere undergoing reconnection on the dayside. The results are used to support the analysis of spacecraft observations from NASA's Magnetospheric MultiScale (MMS) mission. Among other conclusions, the results indicate that the dayside reconnection "line" is fragmented into smaller irregular regions between which magnetic flux ropes are formed.

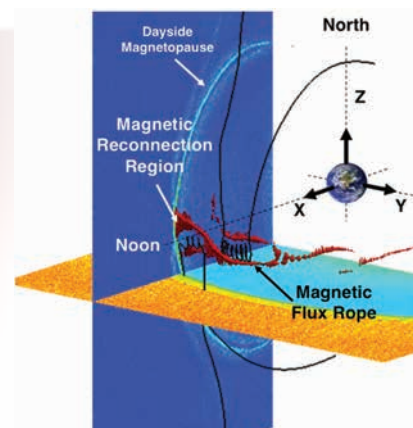


Figure 1. A PIC/MHD simulation of Earth's dayside magnetopause. Red isosurfaces show where reconnection occurs. Magnetic field lines (black traces) indicate that flux ropes are formed between the reconnection regions.

The 13th International School/Symposium for Space Simulations

The 13th International School/Symposium for Space Simulations (ISSS-13) took place on September 6-14, 2018 at UCLA. ISSS-13 was hosted by the UCLA Physics & Astronomy Department and was supported by the UCLA Dean of Physical Sciences, National Aeronautic and Space Association (NASA) and the National Science Foundation (NSF). The International School/Symposium for Space Simulations (ISSS) was first held in Kyoto, Japan in 1982, and for many years was guided by UCLA Physics Professor M. Ashour-Abdalla (USA), Professors H. Matsumoto and T. Sato (Japan), and Professor R. Gendrin (France). Since then the School/Symposium has regularly been held approximately every 2 to 3 years rotating between North America, Asia and Europe, educating generations of young space plasma scientists in numerical simulations.

ISSS-13 adopted the classical scheme of ISSS events starting with the four-day School held September 6-9, 2018, followed by the five-day Symposium September 10-14, 2018. Continuing in a long-term tradition of the ISSS meetings, the program was devoted to teaching of space plasma simulation techniques and sharing of state-of-the-art simulation advances and results with students, post-docs and researchers in plasma physics. ISSS-13 brought together the most recent theoretical advances, numerical simulations and spacecraft observational results to address outstanding problems in space and astrophysical plasma physics.



The winners of the ISSS-13 prize for best student posters were from left to right in the photo, Camilla Harris (University of Michigan), Hannes Arnold (Georgia Institute of Technology) and Takeshi Nogi (Kyoto University). Ms. Harris received her Bachelor's Degree in Physics from UCLA in 2015.

NEW FACULTY

Thomas Dumitrescu



Professor Thomas Dumitrescu recently joined the theoretical elementary particle physics group within the Mani L. Bhaumik Institute for Theoretical Physics in the Department of Physics and Astronomy. An expert on quantum field theory, supersymmetry, and strongly-coupled systems, Dumitrescu is widely known for having developed new tools for studying strongly-coupled systems. He is the first holder of the Mani L. Bhaumik Presidential Term Chair in Theoretical Physics and previously held a five-year position at Harvard University.

IN MEMORIAM

Rubin Braunstein



May 6, 1922 – June 9, 2018.

The department sadly notes the passing of Professor Rubin Braunstein, an experimental condensed matter physicist at UCLA. During his long and varied career, Professor Braunstein used unique techniques to study light scattering in media. He also used spectroscopic techniques to study strand breaks and defects in DNA. He studied a wide range of materials: semiconductors, insulating glasses, high temperature superconductors, and biological macro-molecules. He has been credited with the invention of the first light-emitting diode (LED) while working for the RCA Corporation in the late 1950s.

Edward L. (Ned) Wright receives the NASA Distinguished Public Service Medal



Ned Wright (center) receiving the NASA Distinguished Public Service Medal from Jim Bridenstine and Stephen Jurczyk.

Edward L. (Ned) Wright received the Breakthrough Prize in Fundamental Physics for 2018 as part of the Wilkinson Microwave Anisotropy Probe (WMAP) team. He also received the NASA Distinguished Public Service Medal from NASA Administrator Jim Bridenstine in 2018. This is the highest honor NASA bestows on non-NASA employees. Currently the Wide-Field Infrared Survey Explorer (WISE) is still operating in an extended mission to search for new Near Earth Objects and to characterize known asteroids by infrared radiometry. The Near Earth Object Camera (NEOCam) project, with Wright as deputy PI, is transitioning to a detailed study under the NASA Planetary Defense Coordination Office.

OUTREACH

UCLA
Planetarium

has had another very successful year.

The graduate student-led planetarium hosted 3,308 attendees over the 2017-2018 school year. In addition to the free weekly shows open to the public, private shows were given to 32 educational groups from the Los Angeles area. It played a major role in Exploring Your Universe 2017 and the High School Summer Program.

On November 5, 2017, Astronomy Live! hosted the ninth annual Exploring Your Universe (EYU) open house. This free public event included talks, demonstrations, exhibits, and hands-on activities from the Departments of Physics and Astronomy; Earth, Planetary, and Space Sciences; Atmospheric and Oceanic Sciences; Chemistry and Biochemistry; and Engineering and Applied Sciences; as well as the Center for Environmental Implications of Nanotechnology. Approximately 8,000 visitors attended from all over the Los Angeles area.

In 2018, the UCLA Planetarium and Astronomy Live! hosted the fifth annual Summer Observing Workshop for high school students. Eight juniors and seniors from Los Angeles area high schools were chosen based on their applications. Over the course of 8 weeks, students learned the basics of observational astronomy. They also had the chance to remotely observe using the Nickel 1-meter telescope at Lick Observatory, a research-grade telescope at an active astronomical observatory. Each student completed an independent data analysis project on a particular astronomical object using analysis guides and custom software developed by UCLA graduate students. The program culminated in a final presentation from each student showing the results of their research. We plan to continue holding this workshop in future years.

SCIENCE FOR KIDS OUTREACH PROGRAM

Professor Ni Ni stated that "It sounds weird to hold a scientific outreach in a busy mall, but we want to reach out to kids from a broad spectrum of backgrounds and diversities. I was worried that we may not get enough kids, since parents come to the mall for shopping rather than science, but it turned out to be a great success."

On August 18th 2018, the UCLA Department of Physics and Astronomy put on an outreach event entitled Science for Kids at the Westfield Mall in Culver City under the direction of Professor Ni.

Children from all ages were welcomed to tour the enclosure that was packed with different interactive demonstrations. The event had a superconducting ping-pong game, a station dedicated to making jelly from water-absorbent polymers, a thermoelectric cooler, a waterpark of hydrophobic surfaces, and a mini-internet communication with optical fibers.

All the demonstrations were aimed to help the kids understand how the discovery of new materials and their functions have shaped our everyday life.

UCLA DEPARTMENT OF PHYSICS & ASTRONOMY

INTERNAL RESEARCH EXPERIENCE FOR UNDERGRADUATES

The Department hosted an internal Research Experience for Undergraduates program during summer 2018. It was a 10-week immersion in research for physics and astrophysics majors. In total, 12 of our own physics majors were able to participate in the program. Our increasing number of majors and an increased demand for research opportunities led us to prioritize our in-house students who are not always able to find research slots in our department during the academic year. In addition to the individualized research projects supervised by faculty mentors and their group members, the program included a variety of academic activities – faculty seminars, a seminar on scientific ethics, a research methods workshop, a graduate admissions workshop, and mid-term and final oral presentations to give undergraduate students the opportunity to learn to communicate their research results. All these activities serve the purpose of giving the participants skills generally useful in basic science and in graduate school. It was a great success, as demonstrated by the fact that many of the participants will now continue doing research with their summer advisor during the academic year. All the students were grateful for the opportunity to explore what research is all about, and as a result of this experience many will decide to pursue a graduate education. Participating in research is increasingly recognized as a critical component of a STEM education, so these contributions have had a particularly high impact on the education of these 12 students. We hope to continue this internal program in the years to come.

The UCLA Department of Physics & Astronomy internal Research Experience for Undergraduates program was funded through a generous donation from the Robert A. Rasmussen and the Enrichetta, Beverly & Anthony Gangi endowments.



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