Kavli Institute for Theoretical Physics
UC Santa Barbara

# Newsletter

Fall 2015

www.kitp.ucsb.edu

Lars Bildsten, KITP Director.

We have had a very exciting and productive start this year! Synergies between KITP programs are happening, and are nicely described in the article on page 7 by visiting scientist Roger Melko. Science writer and biographer Graham Farmelo was here this spring as a Kavli Foundation supported Writer-in-Residence. His report on page 3 beautifully captures his personal experience and is a wonderful testimony to our efforts to achieve strong synergies at the KITP. A nice science result from Deputy Director Greg Huber is highlighted on page 4 and the fruits of his outreach efforts via the Teacher-in-Residence program are described in page 2.

We are very proud of the achievements of our postdocs here at KITP. Page 5 describes Iair Arcavi's award of the prestigious Karp Fellowship that will allow him to continue his search for supermassive black holes in distant galaxies. As expected, and is part of normal academic life, many of our postdocs are leaving in Fall 2015 for new positions. Jim Halverson has started his junior faculty position at Northeastern University, Tarun Grover has accepted a faculty position at UC San Diego but will stay at KITP for an additional year, Idse Heemskerk will be a postdoctoral fellow at Rice University, Max Metlitski will be at the Perimeter Institute as an assistant professor, Sahand Hormoz will continue his exploration of biophysics at Caltech in the lab of Prof. Elowitz, and Tobias Heinemann will take up a faculty position at the Niels Bohr Institute. Congratulations to all!

There have also been some staff transitions. Our long term housing coordinator, Monica Curry, retired this summer (see article on page 6), triggering the recruitment of James Brill to the KITP. He will continue to house our visitors while also working with me on the Residence planning. James will be the manager of the Residence once it is up and running. One of our long-term IT staff, Shaun Drong, has departed and was replaced by Tim Czerniec, who comes from the College of Letters and Sciences. I also am very happy to report that I have recruited Laura Lambert as KITP's development officer. She has been working with me part-time for over a year and is very familiar with the KITP. Please welcome her and all of our new staff next time you are in Kohn Hall!

KITP programs are known to both strengthen existing collaborations and nucleate new collaborations and ideas. However, once the participants return to their home institutions, it often proves difficult for them to maintain the intellectual momentum gained while in residence at the KITP. Hence, progress on excellent ideas can stall, or, in the worst case, evaporate.  To address this problem, and with new funds from the Kavli Foundation, we are presently experimenting with a new program, called "Follow-Ons" that allows collaborating groups of former KITP program participants to return for an intense 1-2 week working period within 6-18 months of their previous time here. By the end of 2015, we will have hosted an additional 70 visitors under this new program. We are looking forward to seeing the impact of this new modality. I'm also happy to report that I am participating in one myself!

We are well along on our Residence project, please see the back page for some exciting photos. Charlie Munger frequently visits us, both to see the progress but also to continue his strong involvement in design and final interior selections. Thanks again, Charlie!

*– Lars Bildsten, KITP Director*

# Teaching the Teachers

## A new program allows science educators to participate in a cutting-edge information exchange

While many teachers take the summer off, educator JulieAnn Villa uses the time to go back to school. For Villa, summer affords the perfect opportunity to learn ways of enhancing the science research course she teaches at Niles West High School in Skokie, Illinois.

For two weeks in July 2014 she was one of four teachers in residence at KITP. Villa spent her days attending lectures in "The Evolution of Drug Resistance," program and participating in informal discussions and labs with researchers, postdoctoral scholars and professors.

According to Villa, the experience was completely different from any other continuing education program she has attended. "Now I see where science is going," she said. "Watching some of the discussions, it became evident that you really have to be bold."

The program's discussion component provides both an arena to debate existing ideas and an incubator for nurturing new ones. "I love the way these brilliant people interact and the way science is done at KITP," said Horatio (Nick) Nicastro, who teaches modern physics at Wachusett Regional High School in Holden, Massachusetts. "I can tell my students that these were the brightest people in their field and they're arguing with each other. They're great friends. There is great collegiality and great respect, which is something I can really appreciate and take back to the classroom."

Nicastro and two other teachers in residence participated in the "Dynamics of Planetary Interiors" program. All of them saw ways to apply parts of what they learned in their classrooms. "Some of it is so high-level that I'm not able to use it in my teaching, but basic ideas about seismology and geodynamics and some of the magnetic field materials I can apply at a basic level to my class," said Nicastro. As an example, he cited Hooke's Law, a principle of physics that states that the force needed to extend or compress a spring by some distance is proportional to that distance. "Instead of using a typical spring and displacement, now I can talk about structures inside the Earth that are stretching."

"At these higher levels, the math and the basic ideas are still things we talk about in an introductory-level class," said Ryan Strickland, who teaches science at Southern California's Idyllwild Arts Academy. "Obviously the math gets more complex and the basic ideas get taken much further, but it still boils down to the same basic principles taught in the beginning. It's interesting to see that it works that way in upper-level physics."

According to Thomas Jacobson, the opportunity to see what researchers are doing provided valuable insight into the application of science and mathematics. "All the math I ever took, they use," said Jacobson, who teaches physics and geophysics at Hinsdale South High School, 20 miles southwest of Chicago. "All the earth science knowledge, they use. All the engineering knowledge, they use. All the physics knowledge, they use."

SPENCER BRUTTIG

KITP's 2014 teachers in residence: JulieAnn Villa, Nick Nicastro, Tom Jacobson and Ryan Strickland.

As part of the KITP program, the teachers visited the nearby Dos Pueblos Engineering Academy (DPEA). DPEA is the brainchild of its director, UCSB alumnus Amir Abo-Shaeer, a MacArthur "genius grant" recipient. "Dos Pueblos was awesome," said Strickland. "I especially liked how engineering and creativity were combined in each project because people often forget that high-level science and engineering require a great deal of creativity. I found the projects at Dos Pueblos to be very applicable for my students."

Villa was impressed with DPEA's marketing and how its students take ownership of different aspects of the program. "Those are key pieces I am missing," she said. "I need to create a school culture and a community culture that understands what my science research class does and celebrates the students' accomplishments."

"Having a small manufacturing background, I find it amazing how much DPEA students get exposure to the process of creating something from beginning to end," Jacobson said. Nicastro agreed. "Programs such as these, driven by teachers, continually renew my faith in an aspiring educational system — even after 42 years of teaching," he added.

The teachers-in-residence program grew out of town hall meetings with participants during KITP's 2013 and 2104 annual teachers' conference led by Director Lars Bildsten and Deputy Director Greg Huber. "High school teachers who attended were themselves the catalysts for this new program," Huber said.

"The goal of our teachers-in-residence program is to expose high school teachers to topics in modern physics," he added. "The complete scope of current physics is very hard to define, but we are uniquely positioned in this respect because KITP's activities are at the forefront of defining what modern physics is."

*– Julie Cohen, UCSB Public Affairs & Communication*

*The inaugural Teacher-in-Residence program was generously funded by the Wyatt Technology Corporation. The KITP plans to do this again in summer 2016.*

# At KITP: report from a writer-in-residence

"Art is I, science is we," wrote the nineteenth-century physiologist Claude Bernard. His aphorism gets to the heart of the difference between the arts and sciences: without Jane Austin, *Pride and Prejudice* would never have been written, though the theory of relativity would have emerged sooner or later even if Einstein had never been born.

No institution better embodies science's communitarian character than the KITP. For the past three decades, I have often heard praise for its sublime location, for its unique atmosphere and above all for the many ways it helps to foster new ideas and collaborations. I ceased to be a practicing theoretician long ago, so I had all but given up hope of visiting this secular Mecca, until former director David Gross approached me. In a long Skype call, he invited me to visit as part of the Institute's writers-in-residence program - "However long you spend here," he concluded with a smile, "you'll regret that you didn't stay longer."

The arrangements for my visit were swiftly finalised by director Lars Bildsten, who was eager to support the research for my next book about the relationship between mathematics and theoretical physics. I wanted to meet theoreticians who are working in subjects – notably modern theories of gravity – that are cast in terms of modern mathematical concepts and that also appear to be difficult – or even perhaps impossible – to test experimentally. Are most of these theoreticians really doing 'fairy-tale physics' and indulging in 'recreational mathematics', as many critics have alleged? The KITP's spring 2015 program on the foundations of the quantum theory of gravity was an opportunity to talk with physicists working at the frontiers, and to hear their side of the story. As a bonus, a program on quantum entanglement was scheduled for the same time.

At first, it felt slightly odd to be a licensed interloper. I am used to working alone, but was suddenly a colleague of dozens of top-rate theoretical physicists who would use language and techniques that are only vaguely familiar to me. I did not want to interfere too much with their deliberations but hoped nonetheless that they would grant me a little of their time to help me get a better sense of what they are doing and why they are doing it. At all costs, I wanted to avoid being an irritant or hindrance.

I need not have worried. The participants warmly welcomed me and were generally happy to try to explain their work in plain language. Particularly helpful to me were the lectures. It struck me that the methods used by today's theoretical physicists to present their research – talking at a blackboard, writing academic papers – are essentially identical to those of the very first professional theoretical physicists, notably Rudolf Clausius, a hundred and fifty years ago. But today there are crucial differences. Talks are now routinely broadcast live all over the world and can be made available free to anyone, anywhere at any time. The KITP's policy of making its talks so widely available is hugely helpful to physicists all over the world, and will one day be a priceless resource for historians seeking to understand how solid scientific knowledge emerged from the confusing mush of the past.

Those first professional theoretical physicists would have been nonplussed, or even mystified, if they could have heard the deliberations at the quantum gravity meeting. For those scientists, gravity was a phenomenon that Newton had pretty much understood, and neither relativity nor quantum theory had been discovered. Today, theoreticians are struggling to find a viable quantum theory of gravity, armed with a host of powerful theoretical and mathematical insights, but precious little new data to give guidance from Nature. In all the talks I attended, I heard only one reference to an experimental measurement. Otherwise, most of the talks focussed on attempts to understand better the currently favoured theoretical framework for addressing the problem. This framework is extremely impressive – and is underpinned by the vast experimental support for quantum theory and relativity – though it still cannot give a rigorous account of processes such as the flow of information across the event horizon of a black hole.

Graham Farmelo

It was a great privilege for me to talk in detail with several of the leaders in this field about the challenges facing their field. Steve Giddings, one of the program's coordinators, was open-minded about the current state of the quantum gravity research. He speculated that much of the theoretical speculation may ultimately prove to have been on the wrong track. Like many of his colleagues, he believes progress can be made using pure thought but longs for the subject to be enriched by experimental input. In separate conversations, KITP's Joseph Polchinski and Stanford University theorist Eva Silverstein went out of their way to emphasise that their aim is to understand nature better, certainly not to advance knowledge of mathematics. These conversations and many others gave me the impression that, contrary to popular opinion, most leading quantum-gravity theorists have their feet very much on the ground and are not given to whimsical speculation or to mathematical adventurism.

One exceptionally pleasant memory was the sight of the physicists from the quantum gravity and entanglement programs intermingling and exchanging ideas in the KITP's courtyard. There were even introductory talks on key subjects in both subjects, including one for entanglement experts 'who don't know what a metric is'. Best of all, the groups were on common ground during discussions of new ideas on how space and time might, in some sense, have emerged from bits of quantum information. In the corridors and over afternoon tea, I sensed exciting new, inter-disciplinary collaborations taking shape.

As I prepared to leave KITP, I realised that David Gross had been right – I wished I had been able to stay longer. But it was time to return home, to concentrate on the lonely 'I' of writing, nourished and enlightened by six weeks of 'we'.

*– Graham Farmelo is author of "The Strangest Man," a biography of Paul Dirac, and of "Churchill's Bomb" (Basic Books)*

# Biology Meets Geometry

## KITP deputy director Greg Huber collaborates with colleagues to describe the geometry of a common cellular structure

Architecture imitates life, at least when it comes to those spiral ramps in multistory parking garages. Stacked and connecting parallel levels, the ramps are replications of helical structures found in a ubiquitous membrane structure in the cells of the body.

Dubbed Terasaki ramps after their discoverer, they reside in an organelle called the endoplasmic reticulum (ER), a network of membranes found throughout the cell and connected to and surrounding the cell nucleus. Now, a trio of scientists, including KITP Deputy Director Greg Huber, describe ER geometry using the language of theoretical physics. Their findings appeared in the Oct. 31, 2014 issue of Physical Review Letters.

SONIA FERNANDEZ

Greg Huber, KITP Deputy Director.

A 3D-printed model using data from actual endoplasmic reticulum sheets.

"Our work hypothesizes how the particular shape of this organelle forms, based on the interactions between Terasaki ramps," said Huber. "A physicist would like to say there's a reason for the membrane's shape, that it's not just an accident. So by understanding better the physics responsible for the shape, one can start to think about other unsolved questions, including how its form relates to its function and, in the case of disease, to its dysfunction."

The rough ER consists of a number of more or less regular stacks of evenly spaced connected sheets, a structure that reflects its function as the shop floor of protein synthesis within a cell. Until recently, scientists assumed that the connections between adjacent sheets were like wormholes — that is, simple tubes.

Last year, however, it was discovered that these connections are formed by spiral ramps running up through the stack of sheets. According to lead author Jemal Guven of the Universidad Nacional Autónoma de México, this came as a surprise because spiral geometries had never previously been observed in biological membranes.

Attached to the membrane, ribosomes, which serve as the primary site for protein synthesis, dot the ER like cars populating a densely packed parking structure. "The ribosomes have to be a certain distance apart because otherwise they can't synthesize proteins," Huber explained.

"So how do you get as many ribosomes per unit volume as possible but not have them bump up against each other?" Huber asked. "The cell seems to have solved that problem by folding surfaces into layers that are nearly parallel to each other and allow a high density of ribosomes."

Different parts of the ER have different shapes: a network of tubes, a sphere that bounds the nucleus or a set of parallel sheets like the levels of a parking garage. The smooth ER consists of a tubular network of membranes meeting at three-way junctions. These junctions are also the location of lipid (or membrane) synthesis. As new lipids are produced within the smooth ER, they accumulate in these junctions, eventually cleaving apart the tubes meeting there.

In the rough ER, the parallel surfaces or stacks are connected by Terasaki spiral ramps. In some cases, one ramp is left-handed and the other right-handed — the parking-garage geometry — which is what Terasaki and colleagues (including Huber) found last year.

"We propose that the essential building blocks within the stack are not individual spiral ramps but a 'parking garage' organized around two gently pitched ramps, one of which is the mirror image of the other — a dipole," said Guven, who was assisted in his research by one of his students, Dulce María Valencia. "This architecture minimizes energy and is consistent with the laminar structure of the stacks. It is also stable."

In physics, these helical structures, which connect one layer of the ER with the next, are called defects. That word, Huber noted, carries no negative connotation in this context. "When you look at this through the eyes of physics, there are certain mechanisms that suggest themselves almost immediately," Huber said. "The edge of an ER sheet is a region of high curvature because the sheet turns around and bends. The bend is actually the thing that's forming the helix."

The bend creates a U shape that looks like half of a tube. Huber and his colleagues applied the principles of differential geometry to this curved membrane. Pulling the halves of a tube apart creates a flat region spanning the two U-shaped halves, which then become part of a sheet.

"The geometrical idea is that one can actually get a sheet by pulling apart a network of tubes in a certain way," Huber explained. "Imagine that each of the U-shaped edges wants to bend, but when you try to connect those two U shapes together, each one is now bent. That's what the color figure is trying to show. A tube can generate a sheet if the edges come apart and they're allowed to bend in space."

According to Huber, this theoretical work provides a deeper story and richer vocabulary for discussing the shapes found in cell interiors. "One suspects that their shape is related to their function," he concluded. "In fact, scientists know that the shape of the ER can be an indicator of abnormal functions seen in certain diseases."

*– Julie Cohen, UCSB Public Affairs & Communication*

# A Black Hole Enigma

## Physics postdoctoral scholar Iair Arcavi will use the Harvey L. Karp Discovery Award to learn more about supermassive black holes

The mass of supermassive black holes is almost beyond imagining. They can be millions, even billions of times the mass of our sun. While scientists aren't clear about how such entities could exist, these behemoths apparently inhabit the center of almost all galaxies.

And Iair Arcavi wants to learn more.

SONIA FERNANDEZ

Iair Arcavi

Arcavi, a joint postdoctoral scholar at UC Santa Barbara's Kavli Institute for Theoretical Physics (KITP) and the Las Cumbres Observational Global Telescope (LCOGT), will be able to do just that as the recipient of the 2015 Harvey L. Karp Discovery Award. Funded through a $48,000 gift from international business leader and entrepreneur Harvey Karp, the award is intended to support the innovative research of exceptional early career postdocs in UCSB's Division of Mathematical, Life and Physical Sciences.

"I was really excited — and surprised — to receive the Karp award," Arcavi said. "After all, black holes are so esoteric. But I'm happy that curiosity-driven research like mine is being recognized and supported."

In order to form a more complete picture of supermassive black holes, Arcavi will use the award to advance his latest research project, "Seeing the Invisible: A New Tool for Discovering and Studying Supermassive Black Holes."

Lars Bildsten, director of KITP, nominated Arcavi for the award. "I have given Iair a large amount of freedom to define his own projects and explore, which he has done with vigor," Bildsten said. "His publication record speaks to his broad involvement in many distinct activities, and this project is in the prime field where Iair intends to make a distinctive mark."

To contribute to the science of supermassive black holes, Arcavi and colleagues at LCOGT will look for tidal disruption events in very specific types of galaxies. Tidal disruption occurs when a star orbiting a massive black hole makes a close approach and is pulled apart by the black hole tidal forces.

The idea of tidal disruption events originated in the 1970s, but it wasn't until 2012 that scientists reported witnessing one of these rare events. In 2014, three more were described in a paper led by Arcavi using data from the Palomar Transient Factory, a Caltech-led transient survey. Arcavi also published new data on a fourth event found by an Ohio State University-led survey called ASAS-SN and linked two other events in the literature to this class of tidal disruption events.

All of these events share common properties. In fact, six out of the seven occurred in a very rare type of galaxy called E+A. The E stands for elliptical and the A for A-type stars, which are overabundant in E+A galaxies.

"It's been very exciting and we want to find more because seven is not enough," Arcavi said. "We still don't understand the events themselves and if we want to use them to deduce the mass of a black hole, we first have to understand what's going on when a star gets disrupted."

The project will use the LCOGT's network to track 100 of the most easily observable E+A galaxies, visiting each of them once a month for a year. Images will be compared to determine whether new points of light have occurred. These could represent tidal disruption events.

"No one has ever specifically monitored E+A galaxies in any kind of transient survey so we don't know what we'll find," Arcavi said. "The worst case is we detect nothing in 100 galaxies. Then we can say the rate is not once per year, not even once per 10 years; it's probably lower than once in 100 years. That would set some limits, but the optimistic scenario is that we witness stars being disrupted in these galaxies. We're hopeful — but either way it should be interesting."

"Iair Arcavi is a visionary, and I'm thrilled to see this acknowledged by the Karp Discovery Award," said Andy Howell, leader of the supernova group at LCOGT, which includes Arcavi. "His work lets us see the universe in new ways, and the technology he will develop here will allow us to better understand stars being disrupted by black holes but will be useful for all kinds of research beyond that. He's gambling for big results, but it is built on a safe bet that looking at the sky in a new way is always a winner."

*– Julie Cohen, UCSB Public Affairs & Communication*

*Iair Arcavi is the 10th recipient of UC Santa Barbara's Harvey L. Karp Discovery Award. Including UCSB, Harvey Karp generously supports scientific research and innovation at nine universities across the country.*

# Monica Curry's Legacy

## With her support, visiting scientists hit the ground running upon arrival

After 22 years as KITP's Housing Coordinator, Monica Curry retired in late June leaving a proud legacy of advancing physics by enabling visiting scientists to be immediately productive upon their arrival in Santa Barbara. Curry joined the then-ITP staff in November 1993. At the time, she was a real estate agent, about to be married and knew nothing about the institute. "At the time, I knew nothing about theoretical physics; I knew nothing about ITP," Curry said. "I didn't realize it was world famous, but I could tell whatever they were doing, they took it really seriously."

Monica Curry retires after 22 years at KITP.

Quickly after she was hired, the ITP staff moved into Kohn Hall and Curry has occupied the same office since. While her office hasn't changed, the way she does her work and its scope has. When she started, ITP housed about 200 visitors per year. That number has grown to 700 visitors staying three weeks or longer and about 1,000 total each year with half coming from outside the United States. While arranging their housing, Curry has also helped innovate the systems and databases needed to accomplish this challenging task.

*"I have been able to take the nuances of what make a visit for physicists comfortable and productive, and download that into the new residence and see that carried into the future."*

"The whole philosophy of the KITP staff is to enable a scientist to land here and start doing science as soon as possible with as little bureaucratic entanglement as possible," Curry said of her work. Former Director James Hartle described Monica's accomplishments nicely at her retirement party: "You were of great help to me. I don't think I had to think about housing the whole time I served."

The relationships that Curry has built through the years with the local community and property owners have been pivotal to obtaining this objective. During her tenure, she is proud to share that she has never had to advertise to the community for rentals with each coming from decades-long relationships and word-of-mouth referrals due to the Institute's sterling reputation.

Fantastic community relationships are just an aspect of the great legacy Curry has built at KITP. She was integral to the creation of the Rice Family Fund along with former KITP Development Officer Dr. Sarah Vaughan. The fund was established when Anne Rice donated her home—which was often rented to ITP visitors. The proceeds from the sale now provide extra funding for visiting physicists, particularly female scientists, with unique family issues such as daycare needs.

According to Curry, the biggest highlight of her career at KITP has come recently with the creation of KITP's Residence project. Early in the project's development, the donor, Charlie Munger recognized that Curry's years of experience and knowledge about physicists' housing needs were extremely useful to designing the ideal space for KITP visitors. In a note to Monica for her retirement celebration, Charlie wrote: " Monica is the most important member of our team. She has intelligence plus knowledge, which is a good combination."

"Charlie recognized that my experience of housing physicists for 22 years gave me insights into what their needs are and what would work for them. He has respected that and has incorporated those ideas into the project," Curry said. "So instead of handing off what I have been doing: which are many private arrangements, I have been able to take the nuances of what make a visit for physicists comfortable and productive, and download that into the new residence and see that carried into the future. That is the highlight and that's why I feel like I am leaving a legacy."

Becoming a part of the worldwide physics community has been deeply satisfying for Curry. During her career at KITP, she has seen the development of String Theory and celebrated the awarding of a Nobel Prize to former KITP director David Gross.

"The scientists have shown a large amount of appreciation for not only what I do, but what the entire staff does," Curry said. "I have several that have told me that this is a unique place because there aren't a lot of other places where they can hit the ground running so seamlessly and start doing science immediately. That was the philosophy when I got here and remains the philosophy today."

While Curry is now embarking on retirement, rest and relaxation aren't part of the plan. She will continue to serve the Santa Barbara community through her participation on the Alano Club of Santa Barbara Inc., which houses meetings for local recovery groups. She is also the President of the Board for the Santa Barbara Bird Sanctuary, which provides rescue and housing for parrots that have lost their homes and provides education and outreach for the parrot owning community.

Also on her retirement to-do list will be plenty of hiking, sailing, and further pursuit of her love for afrocuban percussion, specifically the congas.

*– Lisa Skvarla, UCSB Development*

# Entanglement Bridges the Gap at KITP

## Gravity, quantum information, and condensed matter find common ground

This spring, an eclectic group of physicists descended upon the KITP. Representing fields as far-flung as string theory, quantum computing, cold atoms, and condensed-matter experiment, many of these scientists had never imagined gathering together. Yet, a common interest drew them to participate in a program about "entanglement", a topic that has come to lie at the center of quantum physics and technology in the 21st century.

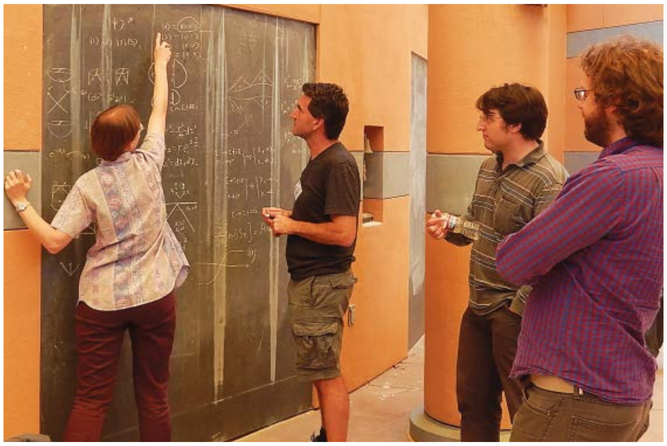
To understand the excitement, we must take a step back and consider that enigmatic wisp of quantum fluff that brought these physicists together. Entanglement is the quantum tie that binds particles across space and time. It occurs when two particles are so closely linked that they essentially share the same reality. For example, particles that are created together can be strongly entangled, allowing one to immediately influence another at some later time, even across a vast distance. This violation of locality—a causal influence at speeds faster than light—so irked Einstein that he famously dismissed entanglement as "spooky action at a distance".

Since those early days of quantum mechanics, entanglement has evolved from a pesky quirk, to an inescapable reality, to its modern role as a powerful resource, providing ways to perform otherwise impossible tasks (such as unbreakable cryptography, ultra-dense data compression, and more). This resource-based view of entanglement is at the root of the modern theory of quantum information science, with the goal (among other things) of nothing less than the construction of the next generation of computers. The algorithms potentially provided by quantum computers include the efficient factorization of large prime numbers—thus effectively breaking the public-key encryption used to secure the world's communication systems. Accordingly, in the last decade there has been an explosion of research on them by our largest institutions; government, military, academic, and information-industrial alike—many with deep ties to UC Santa Barbara.

As evident on KITP's blackboards, a quieter but no less startling revolution is growing in the ranks of theoretical physics, promising a new type of unification of disparate fields under the common (if unfamiliar) guise of entanglement. This union can trace its origins to the observation that most theories of quantum particles in a volume of space, surprisingly, have an entanglement structure that can be encoded on a lower-dimensional boundary. Recently, string theorists led by Maldacena discovered a firm mathematical underpinning to this relationship, conjecturing that the natural curvature inherent in geometric descriptions of gravity can encode quantum mechanics in one lower dimension. This astonishing link suggests a deep "holographic" duality between gravity and quantum theory, that compelled many an excited physicist to stay at work late at KITP, reevaluating their old dreams of a unified theory of quantum gravity in a new light.

The holographic duality of entanglement was a focal point of this program. It served as a conceptual pivot, around which a relativist might propose a calculation to a computational physicist; or, a theorist working on high-energy particles could frame an idea to her low-energy condensed-matter counterpart. In some cases, the duality makes striking connections; for example, between entanglement in a microscopic model of electrons on a lattice, and the geometrical structure of a classical gravity theory. Most remarkably, since such models apply to real matter and materials at extremely low temperatures, this connection is not restricted to the realm of theory. As the centerpiece of the program, a handful of talks by experimentalists showed, for the first time, how entanglement can be detected in real measurements on delicate crystals of atoms, held in quantum states near absolute zero.

From this springs the optimism that the new common language of entanglement may someday soon provide predictions for table-top experiments in the laboratory, ushering in new tests of our deepest theories of quantum mechanics, space, and time. More practically, these seemingly abstract theories are birthing a powerful paradigm for quantum matter, which promises, for example, to employ entanglement to identify exotic quantum states, such as the so-called topological phases. As pioneering work right here at UCSB has shown, these topological phases may be our best candidates for the building blocks of future quantum computers.



Visiting physicists debating entanglement.

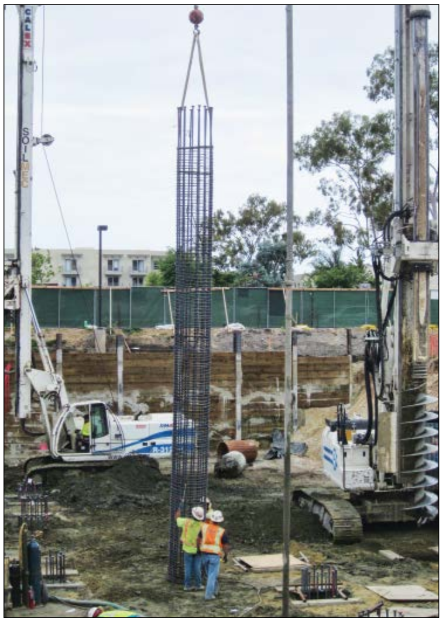
It seems remarkable that the first technological application of the union of information theory, gravity, and condensed-matter physics might be the next stage of evolution of humankind's artificial thinking machines. Yet other, less tangible, consequences of this new synergy are still unfolding in workshops like that recently held at the KITP, where physicists of every creed and guild can find a common language to share their ideas with one another. On what other paths of discovery this new theoretical structure will lead us is uncertain, but this much is clear: the bridge between fields, built by entanglement, is with us to stay.

*– Roger Melko, Professor, University of Waterloo, and Perimeter Institute, was in residence as a Program Coordinator in spring 2015.*

# Visiting Scholar Residence

## Building Update

LARS BILDSTEN



LARS BILDSTEN

TONY MASTRES/UCSB PHOTO SERVICES

At the corner of El Colegio and Los Carneros Roads, construction of the three-story, 75,000-square-foot KITP Visiting Scholar Residence is progressing. The photo on the upper left shows the steel for the basement grade beams, and the upper right photo shows the emplacement of a steel cage for one of the hundred drilled piers. A complete mock-up of the one bedroom unit is shown on the left.


## Engaging with KITP

There are many ways to contribute to the life of KITP. We urge you to become involved by:

- Becoming a Friend of KITP
- Attending a public lecture or Café KITP event
- Making a Philanthropic Gift

To do so, contact Senior Director of Development Laura Lambert at laura.lambert@ucsb.edu, call (805) 450-9501 or visit our website at www.kitp.ucsb.edu

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