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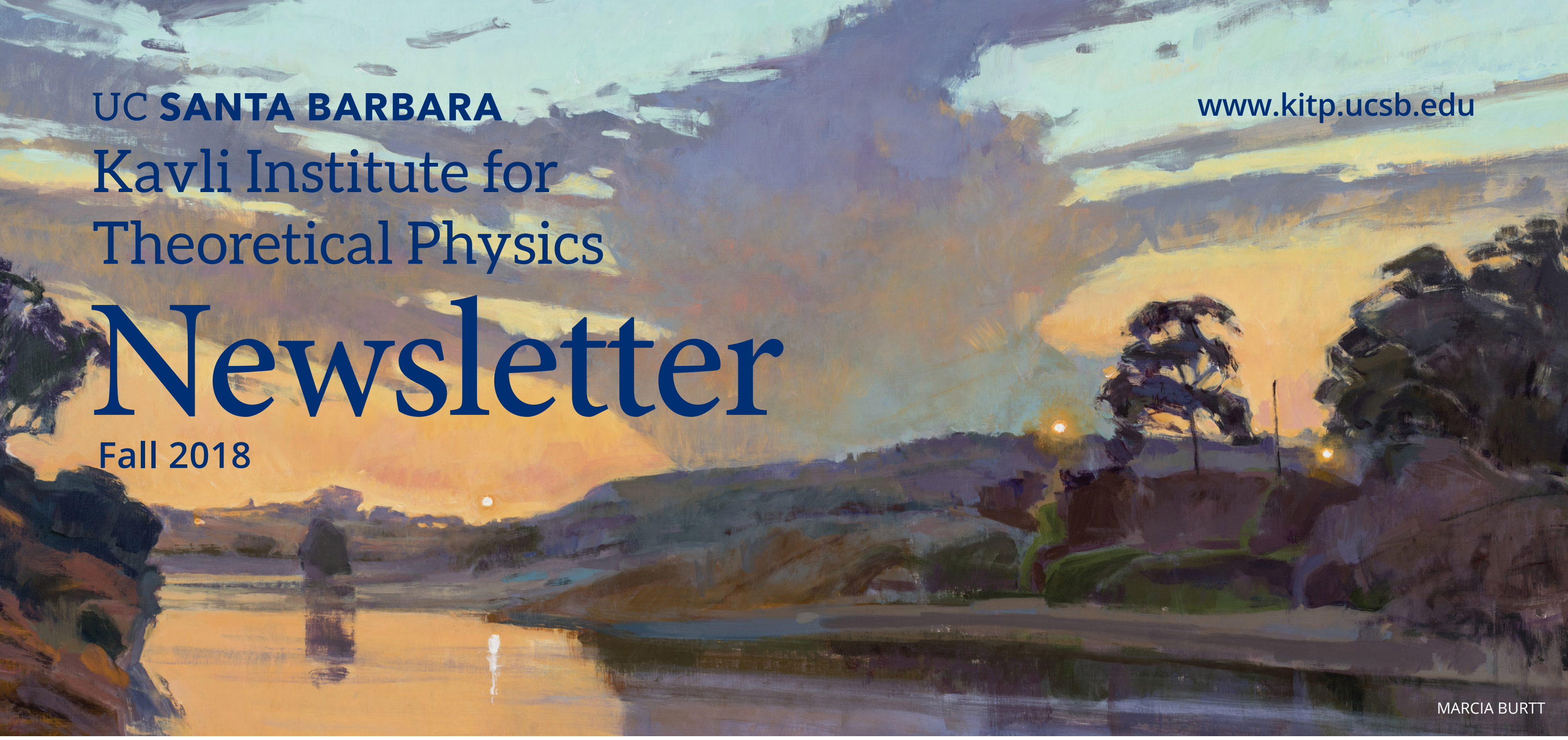
Kavli Institute for Theoretical Physics

Newsletter

Fall 2018



MARCIA BURTT

JAKUB OSTROWSKI

Lars Bildsten

I hope that by now you have seen our 2018 Impact Report, which is the first edition of what will become our annual report to all KITP supporters. In addition to stories highlighting activities at KITP, it also discusses the evolving funding landscape for science research. The monthly magazine Physics Today wrote a thoughtful piece about increasing support from philanthropy and private science foundations for physics research that highlighted KITP's ability to navigate in these new funding waters, and its broad impact across physics. To illustrate this new landscape, in 2018, 60% of our funding comes from the National Science Foundation. The remaining 40% is coming from private foundations (e.g. the Heising-Simons Foundation, the Kavli Foundation, the Gordon and Betty Moore Foundation, and the Simons Foundation) and private philanthropy. Many of you have contributed, and we all thank you for your instrumental support!

Fall is the time of transition. We have recently bid farewell to our founding manager of the Munger Residence, James Brill, who moved to Ohio to pursue his passion for guitars as a writer for the venerable guitar parts supplier, StewMac. James did a remarkable job at establishing the operational model for the Residence, and worked tirelessly to engage all of our visitors. His successor, Carlos Marquez, started this October. Carlos has been with UC Santa Barbara housing for many years, and we are very fortunate to have him! We also said goodbye to IT Director Kevin Barron, who retired this year after more than two decades of service to the institute. My thanks to both for their dedicated service to KITP's mission.

October also marks Chief Administrative Officer Lisa Stewart's first full year with us. In addition to leading all of our staff, she also launched KITP's twitter account @KITP_ UCSB in January. It has taken off rapidly, with over 1,000 followers in less than a year! Read Lisa's article on the back cover to get some insights into how Twitter is working as a new tool for outreach and science collaboration.

In other staffing news, I am pleased to announce that Mark Bowick has agreed to continue to serve in his important role as Deputy Director, and I look forward to continued collaboration with him on our important scientific programs and outreach efforts.

Six of our postdoctoral scholars have moved on to new positions across the world: Gábor Halász to Oak Ridge National Laboratory, Tim Hsieh to the Perimeter Institute in Canada, Jianpeng Liu to Hong Kong University of Science and Technology, Michael McCourt to Invoca, a Santa Barbara start-up, Vlad Rosenhaus to the Institute for Advanced Study, and Chiara Toldo to Ecole Polytechnique, both in Paris and CEA-Saclay.

We have eight new postdoctoral scholars arriving at KITP this academic year, their research ranging from condensed matter and soft condensed matter to particle theory, astro, and high energy physics. David Aasen and Thomas Kupfer come to us from Caltech, Isabel Garcia Garcia from Oxford University, Adam Jermyn from Cambridge University, Noah Mitchell from University of Chicago, Benny Tsang from UT Austin, and Huajia Wang and Tianci Zhou both from University of Illinois, Urbana-Champaign. Most have arrived and are already engaged with all that's happening at KITP!

It's been a busy year for outreach. Locally, we have continued our tradition of Public Lectures and Friends of KITP Chalk Talks at Kohn Hall, and KITP postdoc Eyal Karzbrun also gave an intriguing Café KITP talk (see page 2) describing how the folds of the brain form. Additionally, we have initiated a new tradition of events in New York City. Our salon in May featured recent Kavli Prize-winner James Hudspeth of Rockefeller University speaking on the physics of hearing at the home of KITP supporter Michael Coyle. It was a special evening for me, as I had just learned of my election to the National Academy of Sciences that morning! Well-deserved accolades also came to Leon Balents, who was elected to the American Academy of Arts and Sciences this year, described on page 3.

We are pleased to feature two articles from KITP program participants Doug Jerolmack (page 4) and Jodi Cooley (page 5) who both share about experiences at KITP and their research.

Finally, it's rare when theoretical physics makes front-page news. It's even more rare when it appears on the cover of a top academic journal like Nature magazine! KITP postdoc Yan-Fei Jiang achieved just that with his research on the enigmatic properties of the envelopes of massive stars. This result was found via one of the largest supercomputer simulations ever done for this type of astronomical object, and the 3D images are fascinating. A summary of his research and accompanying images are on page 6.

The image above is from a painting by Marcia Burtt in the Lounge of the Munger Residence. Marcia's art hangs throughout the building for the enjoyment of all our visitors.

~ Lars Bildsten, KITP Director

A New Wrinkle in Physics

Postdoctoral scholar pushes beyond the boundaries of physics with his Café KITP talk on the brain's physical structure

MEGAN TURLEY

KITP Postdoctoral Scholar Eyal Karzbrun presents to a packed room at SOhO Restaurant & Music Club

We spend a lot of time worrying about and attending to the wrinkles and creases that appear on our skin as we age, but there's one body part where wrinkles are a good thing: our brains.

"Having wrinkles on the brain is advantageous for you," said postdoctoral scholar Eyal Karzbrun, during his talk for Café KITP on June 26th, a KITP-hosted after-hours event held at SOhO Restaurant & Music Club in downtown Santa Barbara.

People filled the house for physics as Karzbrun gave a presentation titled "How the Brain got its Wrinkles," a subject that pushes the boundaries of physics into neurobiology. Moderated by KITP Permanent Member Boris Shraiman, Susan F. Gurley Professor of Theoretical Physics and Biology, a vigorous question-and-answer period allowed for the audience to learn even more after the talk.

Comparing the brain to a traditional computer, Karzbrun, who specializes in biophysics and synthetic biology, drew attention to their architecture — specifically the spatial requirements for computation. While computers use electronic transistors and human brains use neurons, both rely on surface area in particular to lay out the components needed for processing information.

"In many cases, a desktop computer is mostly empty space," Karzbrun said, showing a picture of an open computer case. Most of the actual computing functions, he explained, occur only on the surface of an electronic board, where the central processing unit and memory are laid out. The rest of the open area is for other components, or for more electronic boards for additional computation.

Turns out, the brain determined how to optimize those spatial requirements a long time ago. As humans evolved, brains developed more folds and wrinkles in an effort to create more surface area for more neurons to carry information.

In addition to more surface area, however, proximity between neurons is desirable for fast computation, so rather than having smooth broad surfaces or a large volume brain, wrinkles make it possible to have a large surface area.

"In order to be computationally strong and quick, what your brain does is take a lot of surface area and put it in a small volume," Karzbrun added. And the only way to do it, physically, is to have wrinkles. Other factors, including the relatively small sizes of the neurons in the brain, also optimize the organ for performance.

To understand how the brain wrinkles, however, Karzbrun turned to analogues, such as gels, which have that soft, brain-like consistency. If you take a flat gel and engineer it to grow more rapidly from its edges when you put it in water, the result will be a structure with wavy edges, he said.

"We learn that if you have a brain that wrinkles during growth, it must mean that it grows more on the outside," he said.

Taking the concept to a more sophisticated, more biological stage, Karzbrun then turned to a three-dimensional ball of cells, cultured in a lab.

"The way biology works is through a big system that is made of a lot of small, active components," he explained. Through the collective actions of each component, the entire system can take different shapes. From a random assortment of cells, the ball first self-organized, rearranging into a pattern.

In fact, he continued, the ball of cells not only organized, but the surface began to wrinkle due to the individual actions of each cell located at the surface of the ball. Through the phenomenon of differential growth, Karzbrun noted, the rates of growth of the outer cells became faster than the ones closer to the core of the ball. And because of that, he added, the only shape they can take is in the form of wrinkles.

Watching the biological system do its work was an eye-opener for Karzbrun, and probably for many physicists who explore disciplines on the boundaries of their own.

"It's surprising because we as physicists are used to looking at systems that go from an organized, ordered state, into a disordered state," Karzbrun said. "But active, biological material can go in the other direction, from a disordered system to an organized system.

"If we want to understand living systems," he added, "we have to come up with new physics."

~ By Sonia Fernandez, UCSB Public Affairs

Lars Bildsten elected to membership in the National Academy of Sciences


MATT PERKO

KITP Director, Lars Bildsten

Nobel Prize laureate David Gross wanted to be the first to break the news to KITP Director Lars Bildsten. So, with apologies for the early hour, he phoned his colleague at 6:30 a.m. on May 1, 2018 to congratulate him for being elected a member of the National Academy of Sciences (NAS).

Bildsten, who was in New York City and already awake, was thrilled. "That was wonderful news," he said. "It's a rare honor that provides an occasion to celebrate. The acknowledgement is quite profound."

"We are proud and delighted to congratulate Professor Lars Bildsten on his election to the National Academy of Sciences," said UCSB Chancellor Henry T. Yang. "Election by one's peers to this most prestigious academy is not only a milestone achievement but also a deeply meaningful recognition of years of hard work, pioneering research and exceptional contributions. Through his original and influential work on the structure, life and death of stars, as well as his visionary leadership of our Kavli Institute for Theoretical Physics, Professor Bildsten is helping to advance the field of stellar astrophysics and deepen our understanding of the universe."

This accolade from NAS, Bildsten said, has only boosted his momentum, adding that he is eager to continue his theoretical research in time domain astrophysics, a field dramatically enabled by many new space and ground-based telescopes, especially the Zwicky Transient Facility and the Las Cumbres Observatory.

~ By Julie Cohen, UCSB Public Affairs

Leon Balents Elected to Membership in the American Academy of Arts and Sciences

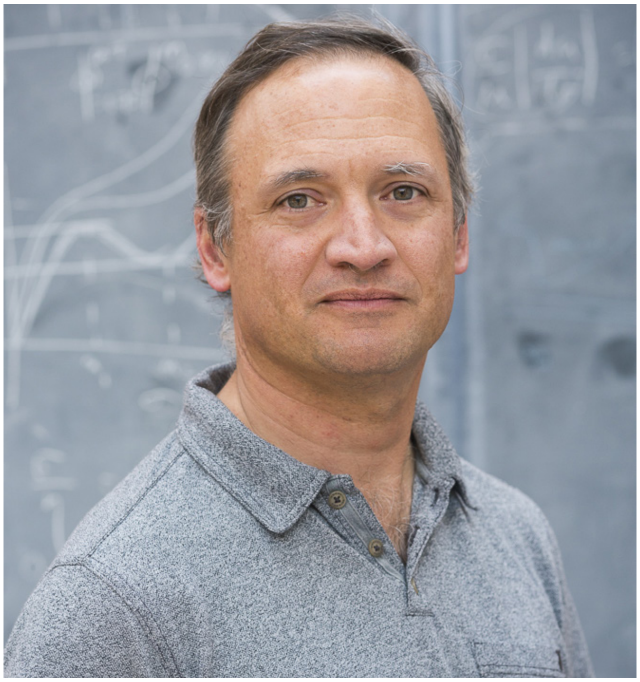
Professor Leon Balents was elected as a member of the 238th class of the American Academy of Arts and Sciences in April of 2018. His selection, along with two additional UCSB professors, brings the total number of UCSB faculty members named to the American Academy of Arts and Sciences to 37.

"We are very proud to congratulate Professors Balents, Hawker and Telles, our three newest members of the American Academy of Arts and Sciences," said UCSB Chancellor Henry T. Yang. "This election by their peers is a prestigious and meaningful career distinction, attesting to their leadership in advancing research, their devotion to teaching and inspiring others, and their commitment to making a significant contribution to our society."

Balents, who holds the Pat and Joe Yzurdiaga Chair in Theoretical Physics at UCSB is a permanent member of the KITP. His research focuses on the quantum physics of matter and its implications. His work explains unique phenomena such as magnetism and superconductivity, and guides the search for new materials and their applications to quantum technologies.

"The intellect, creativity and commitment of the 2018 class will enrich the work of the academy and the world in which we live," said Jonathan Fanton, president of the academy.

~ By Andrea Estrada, UCSB Public Affairs


MATT PERKO

KTTP Permanent Member, Leon Balents

Physics of Dense Suspensions and the Montecito Debris Flows

Dense suspensions are liquids that contain a large proportion of solid particles, and they exhibit a striking range of behaviors. Consider how the flow of water changes with the addition of cement, which is essentially rock powder. The suspension behaves as a solid (or is "jammed") until a large enough force is applied. The viscosity of cement is not only much larger than water, but it also changes with how fast the concrete is flowing. Finally, these properties change over time due to surface-chemistry interactions and settling among the particles. Understanding this rich interplay of physics is at the frontier of the physics of "soft matter", and formed the central theme of the "Physics of Dense Suspensions" program that took place at KITP in Spring 2018.

As a geophysicist, I had come to KITP for sabbatical to gain a deeper understanding of the theoretical physics underlying flows of Earth materials, such as rivers and landslides. Five days after my arrival, the Montecito debris flows occurred. Teams of geologists and engineers, some of them from UCSB, have since documented how this tragic event occurred; following the large Thomas fire which burned vegetation off the hillsides, an unusually intense rainfall triggered mudflows that coursed into the canyons above Montecito. There, these flows combined and picked up boulders from the channels to create powerful debris flows that overwhelmed the downstream channels, and poured out into Montecito with devastating effects. What is not yet understood is why these particular conditions formed the debris flows; without such an understanding, we lack the ability to predict the occurrence and magnitude of future events.

I joined ProfessorTom Dunne (Bren School) and other UCSB faculty on a series of forensic field campaigns to reconstruct the mechanics of the debris flows, from their formation in the Santa Ynez mountains to their growth and acceleration downstream to their deposition in the town of Montecito. At first, this rather applied work was disconnected from the "basic science" activities at KITP. As time progressed, however, the two sides began to inform each other in unexpected ways. On the one hand, I realized that in trying to explain debris-flow dynamics we ran up against the frontier challenges in the physics of dense suspensions that were being studied at KITP. On the other hand, I discovered that program participants – many of them theoretical physicists – were more willing to engage in discussing this "messy" debris flow problem than I had anticipated. These exchanges helped to frame the debris flow problem in a more mechanistic manner: (1) Initiation requires turning a jammed granular solid into a dense suspension; (2) flow depends on how variations in grain size, and cohesive effects from clay and organic material, influence the complex changing viscosity; and (3) formation of a boulder front requires segregation of large particles. I am now conducting research in all three of these themes.


DOUGLAS JEROLMACK

Aftermath of the January 9, 2018 debris flow in Montecito

KITP provided an immersive environment for exploring these topics. On a blackboard outside of the Munger Residence, my graduate student and I sketched out the necessary fluid-mechanical properties to produce mudflows capable of lifting boulders and running them out to such long distances from the mountain range. Each week, a talk by a program participant would inspire a series of conversations – often flowing out of Kohn Hall to the grills and foosball tables at the Munger Residence. Many of these led to new ideas or calculations that influenced our work on the debris flows.

A leading light in these discussions always was Bob Behringer; his incredible insight and creativity was matched by his patience, generosity and inclusiveness. His sudden passing in July of this year was devastating for all who knew him. His legacy will live on through all of the science and scientists he has inspired, including all participants at the Physics of Dense Suspensions program. My time at KITP has opened many doors, helping to draw the connections between the frontier problems in physics and those of Earth science.

~ Douglas J. Jerolmack, Professor of Geophysics at University of Pennsylvania

Two KITP Programs Probed the Properties of Dark Matter

During the spring of 2018 particle physicists and astrophysicists gathered at KITP to participate in two complementary programs, one in the field of astrophysics and the other in the field of high energy physics. Both programs were aimed at shedding light on a puzzle that has excited a whole new generation of researchers. Over 80 years ago scientists studying stars within galaxies and galaxies within clusters realized that the motion of these objects could not be explained by the large amount of visible matter and that a large amount of invisible dark matter must be present. Today, with more sensitive instruments, we have established that 84% of the matter in the universe is composed of dark matter – an invisible particle that is a key to extending the Standard Model of Particle Physics and also key to understanding how galaxies form in the universe.

In the last two decades, studies of the relic Cosmic Microwave Background radiation and galaxy clustering have led to a remarkably strong and testable paradigm where the dark matter is a weakly interacting elementary particle that emerged from the early Universe. This scenario, called "Lambda-Cold-Dark-Matter" (LCDM) has developed into a fully mature theory, where detailed predictions can be tested by experiments. The predictions for clustering on small scales in the universe made by LCDM have stimulated strong interest from astronomers, astrophysicists and particle physicists. The revealed challenges include the observations of faint galaxies, the presence (and in some cases absence) of density cusps in centers of the dark matter halos surrounding certain galaxies and the surprisingly low amount of dark matter in some nearby dwarf galaxies. There were plenty of debates during the KITP programs discussing the merits, severity and possible solutions to these issues.

Although resolving the small-scale structure challenges is important for LCDM, it is equally important to discover what dark matter is. For several decades experimentalists have been trying to detect the interactions of dark matter in our own galaxy with detectors on Earth or create dark matter particles by colliding particles together in an accelerator such as the Large Hadron Collider at CERN. Dark matter is very elusive, and up to this point, we have not seen any strong evidence of dark matter interacting or being created in any of these detectors. This ignited strong interest in expanding the types of particles and interactions we might consider in our searches and in turn, it also means examining the technologies we need to use or develop in order to search for these new types of dark matter.

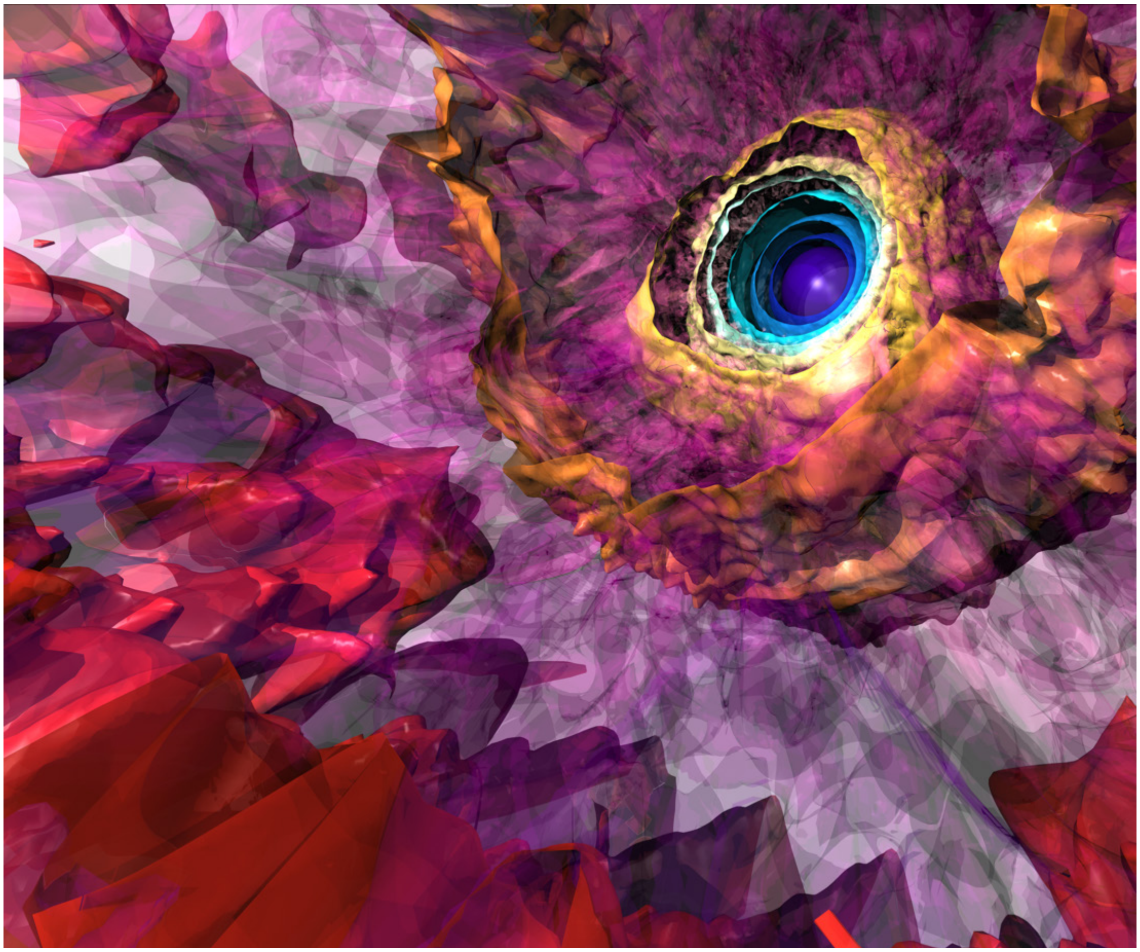
LISA STEWART

Professor Jodi Cooley records her segment for Public Radio International's Science Friday

One of the most anticipated events to occur during these two programs was the announcement of new results from one year of data taking from the XENON1T dark matter detector. At KITP, program coordinator Laura Baudis of the Physik Institut of the University of Zurich, who is also a leader in the XENON1T experiment, presented the exclusion of new dark matter parameter space at a special seminar. The additional constraints provided by the XENON1T experiment further fueled the excitement to consider new dark types of dark matter and this excitement extended beyond the walls of KITP. On June 8, 2018 KITP program participant Flip Tanedo and I had a chance to discuss some of the new types of dark matter that theorists and experimentalists are exploring on Science Friday with host Ira Flatow and Gizmodo science writer Ryan Mandelbaum. It was a great way to wrap-up an exciting visit to KITP.

~ Professor Jodi Cooley, Southern Methodist University

Listen to the Science Friday segment recording at: https://www.sciencefriday.com/segments/dark-matter-eludes-particle-physicists/



3D simulation of a Luminous Blue Variable star visualized by Joseph Insley from Argonne Leadership Computing Facility (ALCF)

Superstars' Secrets

Supercomputing power and algorithms are helping astrophysicists untangle giant stars' brightness, temperature and chemical variations.

Since the Big Bang nearly 14 billion years ago, the universe has evolved and expanded, punctuated by supernova explosions and influenced by the massive stars that spawn them. These stars, many times the size and brightness of the sun, have relatively short lives and turbulent deaths that produce gamma ray bursts, neutron stars, black holes and nebulae, the colorful chemical incubators for new stars.

Although massive stars are important to understanding astrophysics, the largest ones – at least 20 times the sun's mass – are rare and highly variable. Their brightness changes by as much as 30 percent, notes Lars Bildsten. "It rattles around on a timescale of days to months, sometimes years." Because of the complicated interactions between the escaping light and the gas within the star, scientists couldn't explain or predict this stellar behavior.

But with efficient algorithms and the power of the Mira IBM Blue Gene/Q supercomputer at the Argonne Leadership Computing Facility, a Department of Energy (DOE) Office of Science user facility, Bildsten and his colleagues have begun to model the variability in three dimensions across an entire massive star. With an allocation of 60 million processor hours from DOE's INCITE (Innovative and Novel Computational Impact on Theory and Experiment) program, the team aims to make predictions about these stars that observers can test. They published the initial results from these large-scale simulations – linking brightness changes in massive stars with temperature fluctuations on their surfaces – in the September 27th issue of the journal Nature.

Yan-Fei Jiang, a KITP postdoctoral scholar, leads these large-scale stellar simulations. They're so demanding that astrophysicists often must limit the models – either by focusing on part of a star or by using simplifications and approximations that allow them to get a broad yet general picture of a whole star.

The team started with one-dimensional computational models of massive stars using the open-source code MESA (Modules for Experiments in Stellar Astrophysics). Astrophysicists have used such methods to examine normal convection in stars for decades. But with massive stars, the team hit limits. The bodies are so bright and emit so much radiation that the 1-D models couldn't capture the violent instability in some regions of the star, Bildsten says.

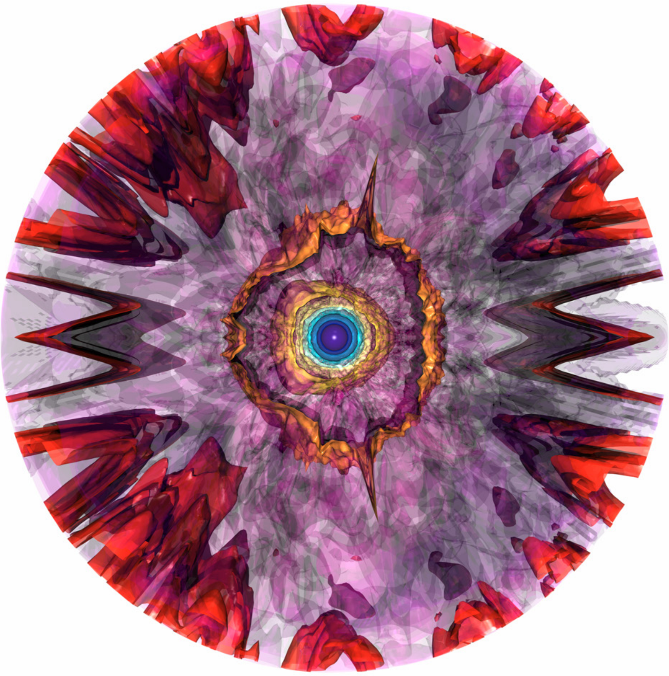
Matching 1-D models to observations required researchers to hand-tune various features, Jiang says. "They had no predictive power for these massive stars. And that's exactly what good theory should do: explain existing data and predict new observations."

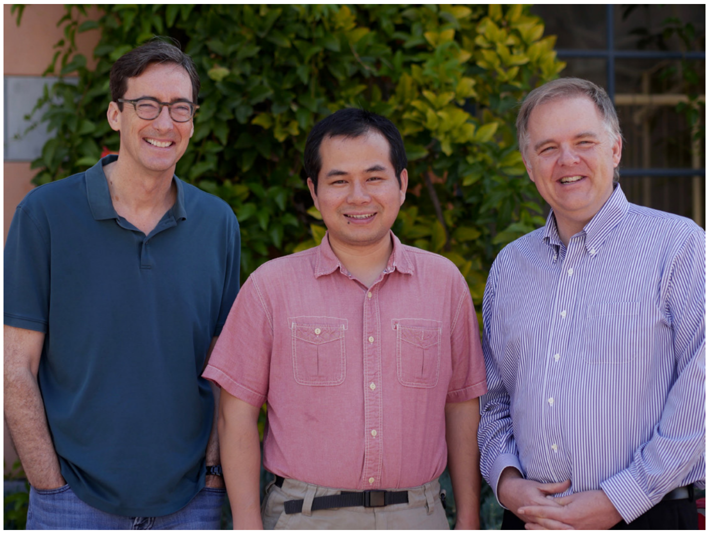
To calculate the extreme turbulence in these stars, Jiang's team needed a more complex three-dimensional model and high-performance computers. As a Princeton University Ph.D. student, Jiang had worked with James Stone on a program that could handle these turbulent systems. Stone's group had developed the Athena++ code to study the dynamics of magnetized plasma, a charged, flowing soup that occurs in stars and many other astronomical objects. While at Princeton, Jiang had added radiation transport algorithms. That allowed the team to study accretion disks – accumulated dust and other matter – around the edges of black holes, a project that received a 2016 INCITE allocation of 47 million processor hours. Athena++ has been used for hundreds of other projects, Stone says.

Stone is part of the current INCITE team, which also includes UCSB's Omer Blaes, Matteo Cantiello of the Flatiron Institute in New York and Eliot Quataert, University of California, Berkeley.

In their Nature paper, the group has linked variations in a massive star's brightness with changes in its surface temperature. Hotter blue stars show smaller fluctuations, Bildsten says. "As a star becomes redder (and cooler), it becomes more variable. That's a pretty firm prediction from what we've found, and that's going to be what's exciting to test in detail."

Another factor in teasing out massive stars' behaviors could be the quantity of heavy elements in their atmospheres. Fusion of the lightest hydrogen and helium atoms in massive stars produces heavier atoms, including carbon, oxygen, silicon and iron.





CRAIG KUNIMOTO

UCSB and KITP scholars, from left, Omer Blaes, Yan-Fei Jiang and Lars Bildsten

When supernovae explode, these bulkier chemical elements are incorporated into new stars. The new elements are more opaque than hydrogen and helium, so they capture and scatter radiation rather than letting photons pass through. For its code to model massive stars, the team needed to add opacity data for these other elements. "The more opaque it is, the more violent these instabilities are likely to be," Bildsten says. The team is just starting to explore how this chemistry influences the stars' behavior.

The scientists also are examining how the brightness variations connect to mass loss. Wolf-Rayet stars are an extreme example of this process, having lost their outer envelopes containing hydrogen and instead containing helium and heavier elements only. These short-lived objects burn for a mere 5 million years, compared with 10 billion years for the sun. Over that time, they shed mass and material before collapsing into a neutron star or a black hole. Jiang and his group are working with UC Berkeley postdoctoral scholar Stephen Ro to diagnose that mass-loss mechanism.

These 3-D simulations are just the beginning. The group's current model doesn't include rotation or magnetic fields, Jiang notes, factors that can be important for studying properties of massive stars such as gamma ray burst-related jets, the brightest explosions in the universe.

The team also hopes to use its 3-D modeling lessons to improve the faster, cheaper 1-D algorithms – codes Bildsten says helped the team choose which systems to model in 3-D and could point to systems for future investigations.

Three-dimensional models, Bildsten notes, "are precious simulations, so you want to know that you're doing the one you want."

~Sarah Webb, PhD, Senior Science Writer for Krell Institute

This article is reprinted from the original article, https://ascr-discovery.org/2018/09/superstars-secrets/ with permission from ASCR Discovery

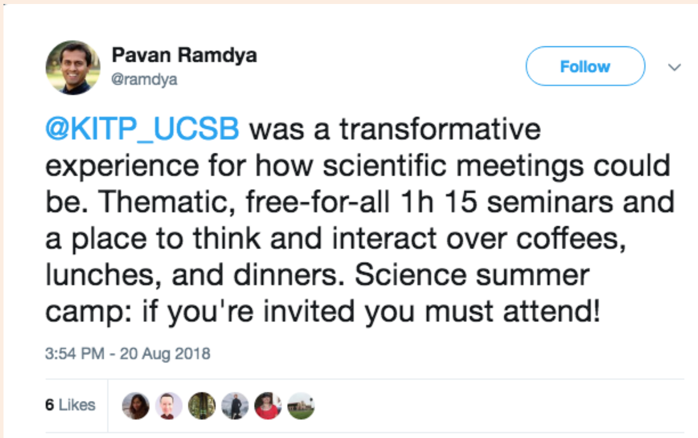
More Ways to Connect: @KITP_UCSB

KITP has fostered connections amongst scientific communities for almost 40 years through well-defined and extended-stay interactive scientific programs, and by allowing space and time for deep and lasting collaborative relationships to develop. On January 1, 2018, we added a new venue for connecting our visiting scientists, the global scientific community, and science enthusiasts when we launched the @KITP_UCSB Twitter account. It has been rewarding to observe the ways in which many of our scientists and friends have actively engaged with us, and with each other, on this platform. By the printing of this Newsletter, we will have over 1,200 followers!

Programs and conference visitors often "live Tweet" sessions for those in the field who may not have been able to attend; they share testimonials about their experiences while visiting, information about upcoming programs and conferences, and publications that resulted from collaborations started while at KITP. For KITP, this has become an additional platform for us to share KITP news, links to upcoming science talks and lectures, program and conference information, KITP history, feature articles or photos, and updates on what's happening at KITP.

We are grateful to see our visitors tagging us in science conversations, sharing positive reviews (and a lot of sunset shots!) and retweeting our announcements. Please follow us and keep up with what's happening!

~ Lisa Stewart, KITP Chief Administrative Officer



Visitors frequently Tweet us about their KITP experiences!

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Engaging with the 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, call (805) 893-6307, email friends@kitp.ucsb.edu or visit our website at www.kitp.ucsb.edu/support-kitp.

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