

# **KIPAC ANNUAL REPORT 2015**

KAVLI INSTITUTE FOR PARTICLE ASTROPHYSICS AND COSMOLOGY

**Contents**

**3**

**Blandford**



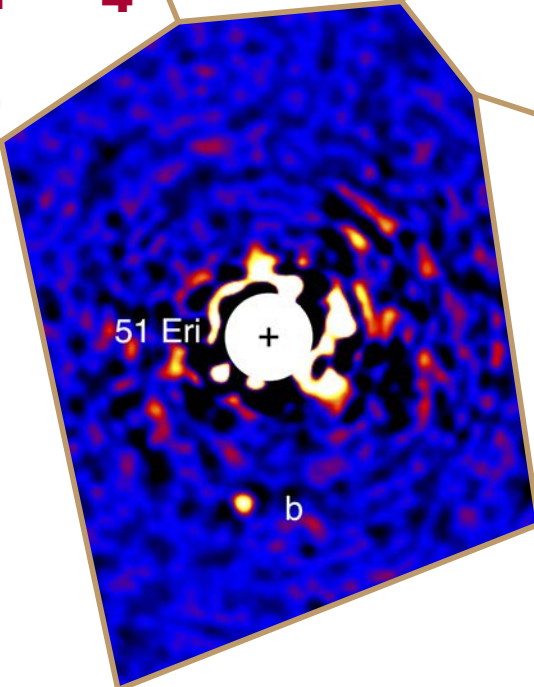
**2**

**Abel**



**4**

**Gemini  
Planet  
Imager**



**Macintosh**

**5**



**Hezaveh and  
Levasseur**

**14**

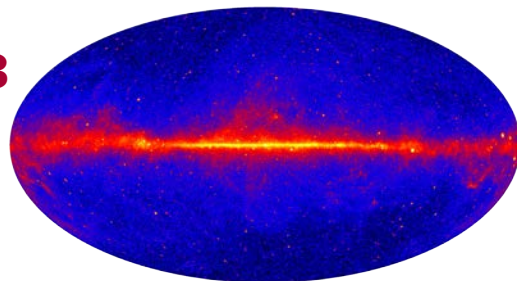


**12 Fermi**



**Pass 8**

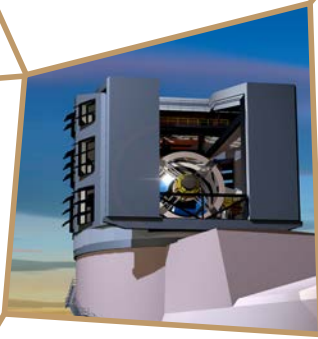
**13**



**7 Wechsler**



**8**



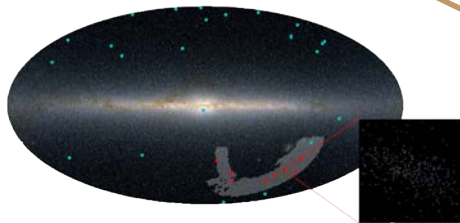
**LSST**

**9**



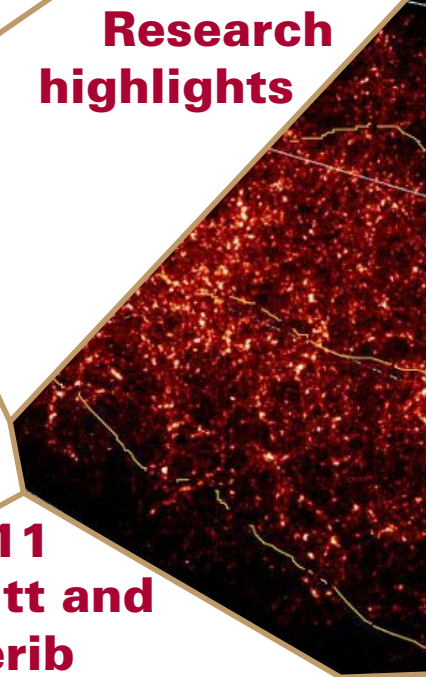
**Dark Energy Survey**

**16**



**18**

**Research highlights**



**10**

**LZ/LUX**



**11**

**Shutt and Akerib**





The Kavli Institute for Particle Astrophysics and Cosmology—KIPAC—was one of the one of the first institutes established by the late inventor, industrialist, and visionary, Fred Kavli, through the foundation that bears his name. I've been privileged to be a part of KIPAC from shortly after its inception. Roger Blandford and Steve Kahn worked tirelessly with all our colleagues in the physics department at Stanford and the faculty, staff and leadership at SLAC to grow the institute into the scientific powerhouse it is today. KIPAC has grown into a vital part of the wider community of astrophysicists, cosmologists, and high energy physicists who are searching for answers to some of the most fundamental questions of our existence, and thus enrich us all.

KIPAC played important roles in ground-breaking experiments such as the Fermi Gamma-ray Space Telescope and the BICEP and Keck arrays that search for signs from the earliest moments of the universe. We've provided critical support to others, such as the Dark Energy Survey and the Cryogenic Dark Matter Survey. Our scientists have been able to use the data gathered by these amazing instruments to shed light on some fascinating questions: Where do cosmic rays come from? Why are there two giant bubbles of energy blowing out from the center of our galaxy?

Our theorists have provided goals for experimentalists to shoot for—or shoot down.

KIPAC has both dark energy and dark matter, two of the biggest questions in physics today, well-covered.

Daniel Akerib and Tom Shutt, dark matter hunters without peer, have joined us from Case Western University to guide the LUX-LZ dark matter hunt. On the dark energy side, KIPAC scientist Steve Kahn is directing the construction of Large Synoptic Survey Telescope, while many of our scientists are deeply involved in designing and building some of the hardware for the telescope, creating the software necessary to analyze the trillions of bytes of data it will collect, and on the science teams that will analyze that data. Others are currently involved in projects that complement LSST, including the planned Dark Energy Spectroscopic Instrument, for which KIPAC scientist Risa Wechsler has been elected co-spokesperson.

We are also turning our attention a little closer to home (on astronomical scales). Bruce Macintosh, an experienced exoplanet hunter, has joined us from Lawrence Livermore Laboratory. Bruce led the construction of the Gemini Planet Imager.

But if we are to take advantage of all these opportunities to learn more about this beautiful universe of ours, we need help from the next generations of scientists. Young people just beginning their careers, or college students in the middle of their studies, or even children just looking up at the night sky and wondering—they will be the ones to continue on the journey of discovery and KIPAC will be here to help them find the path.

**Tom Abel**

When I became the director of the new Kavli Institute for Particle Astrophysics and Cosmology in 2003, my original intent was to stay in that position no longer than five years. Institutes, like people, need fresh ideas and new experiences to help them grow.

2008 came 'round, and the Fermi Gamma-ray Space Telescope (then called the Gamma-ray Large Area Space Telescope) launched in June. KIPAC, along with our host institutions Stanford University and SLAC National Accelerator Laboratory, were very deeply involved in the design and construction of Fermi's main instrument, the Large Area Telescope, and in processing data.

Several other projects were gathering momentum as well—projects that KIPAC, with our ability to draw on the expertise of both Stanford and SLAC, were uniquely situated to pursue. Our scientists and engineers were coming up with new dark matter detectors for the Cryogenic Dark Matter Survey, and heading to Antarctica to study the cosmic microwave background.

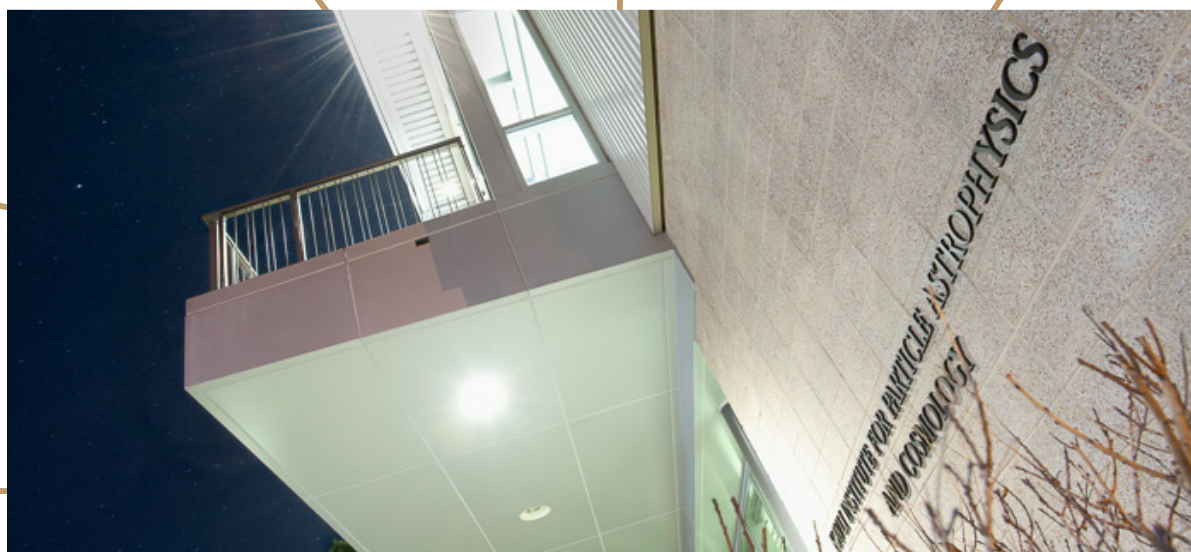
It seemed like a less than optimal time to leave.

But as KIPAC's sixth year, then seventh, then eighth, came and went, I realized that no time was the perfect time. Then I realized I didn't need a perfect time. With important contributions to a wide spectrum of projects such the Dark Energy Survey, X-ray telescopes NuSTAR and ASTRO-H, and the Solar Dynamics Observatory, our own scientists already had the future of the institute well in hand. They were paving the way for KIPAC's leadership positions in the Large Synoptic Survey Telescope and two important experiments searching for dark matter, LZ and SuperCDMS.

I stepped down in 2013, after ten years as Director. Perhaps the best indicator of KIPAC's health is that it survived me for that long. Now, after a sabbatical, I've returned to find KIPAC has changed, as it should, but it remains dedicated to its mission: To bring the resources of modern computational, experimental, observational and theoretical science to bear on our understanding of the universe at large.

To KIPAC's next ten years!

**Roger Blandford**



The Fred Kavli Building, which houses KIPAC on the campus of SLAC National Accelerator Laboratory. Credit: SLAC Communications.

## Far-out photos of extra-solar planets

The image looks nothing like a stereotypical astronomical photo: No vast star fields, no billowing nebulae against the blackness of space. Yet the image of a small orange dot next to a untidy pattern of speckles, all floating on a blue and black background, comes from one of the most advanced scientific instruments to ever be pointed at the night sky.

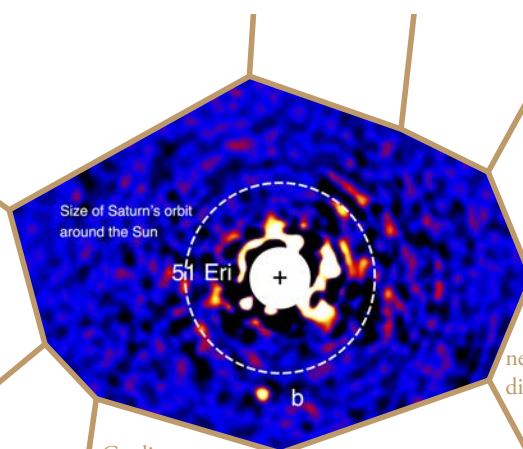
The name of the instrument—the Gemini Planet Imager (GPI), on the eight-meter Gemini South Telescope in Chile—reveals why the image is so extraordinary. That single orange dot is not a star, but a planet—51 Eri b, a Jupiter-like planet circling a star far beyond our own, and the first exoplanet discovered using GPI.

In total, GPI will spend about 900 hours surveying approximately 600 nearby stars for planets between five and 30 astronomical units away from their parent stars. An integral field spectrograph provides information about the temperature, mass, and chemical makeup of the target objects. It saw first light in November 2013 and began its science program about a year later after spending several months imaging known exoplanets to make sure all systems were functioning well.

The technology behind GPI's ability to focus in on tiny dots in the far reaches of our galaxy is called adaptive optics (AO). All AO systems are based on an idea that's simple in concept but devilishly difficult to realize: since astronomers can't make the atmosphere perfectly still, they vary a telescope's mirror to match it.

This is done by constructing the mirror of segments that can be moved independently of each other using tiny instruments called actuators. The greater the number of segments and the faster they can be adjusted, the better the system. GPI's two-square-centimeter silicon mirror with 4000 actuators that can make 1000 corrections each second is currently the most advanced in the world.

GPI targets young gas giants the size of Jupiter or bigger, still warm with the heat of their creation. Add that to its ability to image circumstellar disks of dust and debris, and GPI promises to deliver a treasure trove of information about how planetary systems form.



Credit:  
Processing by  
Christian Marois  
(NRC Canada) and  
Julien Rameau  
(University of  
Montreal)

Image of  
51 Eri b, the first  
new extrasolar planet  
discovered by the Gemini  
Planet Imager. The bright star  
51 Eri (at the location of the cross)  
is blocked by a mask but  
residual light diffracts  
around the edges.

The planet "b" is about twice the  
mass of Jupiter and only 20 million  
years old. GPI obtains a spectrum  
of every pixel element in the field,  
and the spectrum of 51 Eri b shows  
strong methane absorption, similar to  
Jupiter in our solar system.



## Bruce Macintosh

KIPAC faculty member and veteran exoplanet imager Bruce Macintosh led the construction of the Gemini Planet Imager, the first such instrument fully optimized for taking pictures of exoplanets. “GPI is ten times better than previous instruments,” says Macintosh.

Direct imaging is also highly complementary to more established techniques, he adds. “There are almost 2000 known exoplanets and most of them have been found by indirect methods, which misses a lot of planets.” A dip in the total amount of light detected from the parent star, called a light curve, can only reveal a planet that passes in front of its star from our perspective, and radial velocity measurements, or “wobbles,” require at least one orbit, which can take decades.

Macintosh’s own area of expertise is adaptive optics (AO), and he also helped design GPI’s AO system. Macintosh is also looking for non-astronomy applications for the technology he helped create. He sees adaptive optics being used to improve the resolution of X-ray microscopes like SLAC’s Linac Coherent Light Source. “That’s one of the reasons I joined KIPAC,” he says. “Stanford and KIPAC support collaborative, multi-disciplinary work. In fact, a lot of the techniques that people like me use were developed in the electrical engineering department here at Stanford.”

Next on the list is building even more sensitive imagers to find even smaller exoplanets. Macintosh and his students and colleagues are currently at work designing a system that can be mounted on the next generation of giant telescopes, such as the Thirty Meter Telescope under construction in Hawaii and the Giant Magellan Telescope to be located in Chile. “With next-generation adaptive optics on a thirty meter-class telescope, we could see Neptune-sized planets or even Super Earths,” he says.

## A wide-spectrum approach to illuminating dark energy

One of the biggest mysteries in cosmology is a phenomenon called Dark Energy. Discovered fewer than twenty years ago, dark energy is still known only by what it does: cause space to expand at a faster and faster rate, resulting in galaxies that aren't where we thought they should be.

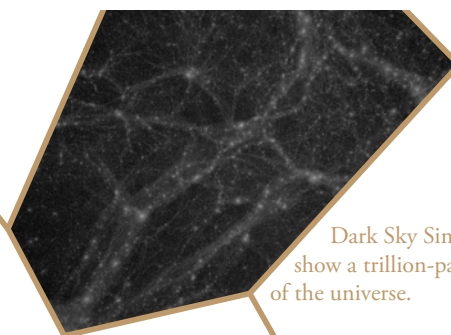
As for what dark energy actually is—the most basic questions, such as “Where does it come from?” and “How does it work?” still remain to be answered. Ultimately, answers to these questions will allow us to answer questions about the fate of our universe in the far, far distant future.

However, before researchers can address such questions, a more precise picture of how dark energy leaves its mark on the universe must be created. By mapping the locations of galaxies in three dimensions across billions of light years, cosmologists can precisely measure the rate of expansion of the universe, and gain understanding of the way in which galaxies cluster over time—both of which provide clues to the nature of the dark energy that is accelerating our universe's expansion.

Astronomical imaging surveys are a first step—for example, the Dark Energy Survey (DES) is currently mapping large numbers of galaxies on the dome of the sky. However, imaging surveys can only get a fuzzy picture of how far away these galaxies are from us. KIPAC scientists are involved in a bold new effort to map galaxies in three dimensions across the largest piece of sky yet surveyed.

The Dark Energy Spectroscopic Instrument (DESI) will map the positions of roughly 35 million galaxies, some as far away as 10 billion light years. Designed for the 4-meter Mayall Telescope on Kitt Peak in Arizona, DESI will point at galaxies—many also studied by DES—using a new spectrograph with 5000 optical fibers. These fibers will collect photons from each galaxy and analyze their wavelengths to get redshifts, which are used to determine the distances of these galaxies from our own Milky Way.

DESI's 3-D maps of the universe will not only pinpoint the distance between galaxies, it will measure their distances away from us more precisely than can be done with an imaging survey alone. Analyzing these intergalactic distances will provide clues about how the expansion rate of the universe has varied over the billions of years since the Big Bang. These clues could provide insight into the nature of the dark energy that is accelerating our universe, and increase our understanding of the universe's contents at its earliest moments.



Dark Sky Simulations (DSS) show a trillion-particle simulation of the universe.



## Risa Wechsler

KIPAC faculty member Risa Wechsler isn't afraid of Big Data. Wechsler is involved in several important large imaging surveys including the Dark Energy Survey (DES) and the upcoming Large Synoptic Survey Telescope (LSST) project. Since 2014 has served as the Co-Spokesperson of the Dark Energy Spectroscopic Instrument (DESI) Collaboration, which will start taking data in a few years. She is looking forward to the massive amount of data that will be produced from these new surveys. "DESI alone will give us about 35 million galaxy and quasar spectra, which is ten times more spectra than exist in the world today, from any project."

In order to interpret these massive data sets, Wechsler creates cosmic simulations, which in essence are computer models of the entire universe. To represent the billions of years and uncounted numbers of galaxies in our universe with enough fidelity to resemble the real thing, such simulations require the resources of some of the fastest supercomputers on the planet. Wechsler is a driving force behind the Dark Sky Simulations, which used Oak Ridge National Laboratory's supercomputer Titan to create two different trillion-particle simulations of the universe (particles are the building blocks of such simulations; each virtual particle maps to many physical particles). The data from these huge simulations have also been made available on the Web to both researchers and the general public.

Wechsler's research group uses these simulations to make predictions of how the universe and the billions of galaxies within it evolve, and then tests these predictions with existing survey data from the Dark Energy Survey—and in the near future, from the LSST and DESI surveys.

## Surveying the southern sky

Everything about the Large Synoptic Survey Telescope (LSST) is big. The telescope's field of view is big: 9.6 square degrees, more than 40 times the area of the full moon. The camera is big: 3.2 gigapixels, or billions of pixels. The sweep of sky it will survey is big: the entire southern sky, once every three nights. And the amount of data it will collect is big: 15 terabytes, or trillions of bytes, every night for ten years beginning in 2022. KIPAC faculty member Steven Kahn is currently serving as director of this immense project, and several other KIPAC scientists are getting ready for the deluge of data or making sure that deluge actually happens.

The LSST will capture so much information about the whole of the southern sky that it will provide valuable data to researchers exploring four different cosmic mysteries:

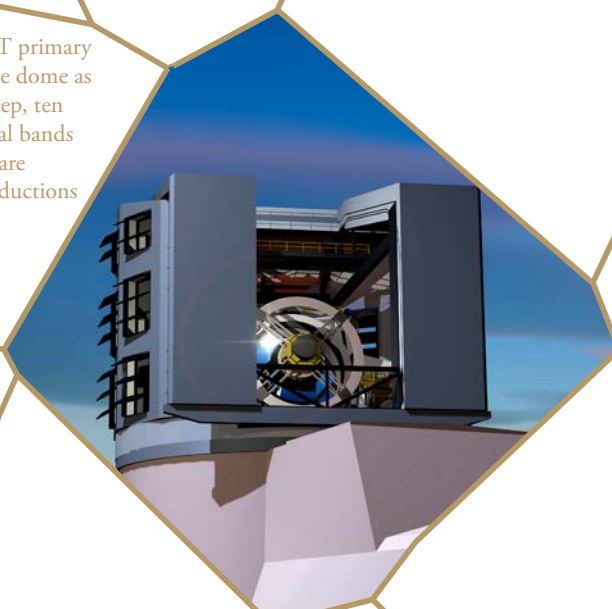
**The Dark Universe:** Researchers will make precise measurements of the effects of dark matter and dark energy on the structure of the universe and on its expansion history using gravitational lensing, galaxy cluster studies, and the clustering of galaxies on the sky.

**The Transient Universe:** Oft-repeated observations of the same areas of the sky means that any changes will be obvious. Data from the LSST will show the evolution over time of fast-moving phenomena like supernovae and gamma-ray bursts. For the first time, researchers will have access to time-lapse movies of the most dynamic objects in the universe.

**The Milky Way:** The LSST will catalogue 10 billion stars in our own Milky Way galaxy and extending into the galactic halo. Researchers can use this data to learn about the structure and evolution of our own galaxy, and, by analogy, galaxies like it.

**Our Solar System:** Objects aren't only faint because they're huge but far away. Objects can be faint because they're close at hand but small. No matter the reason, the LSST will see many more of them, becoming an important tool in the study of dwarf planets at our solar system's edge and an important resource in the ongoing search for near-Earth asteroids.

In this artist's rendition, the LSST primary mirror is seen through the slit of the dome as sunset. The LSST will carry out a deep, ten year imaging survey in six broad optical bands over the main survey area of 18,000 square degrees. Credit: Todd Mason, Mason Productions Inc. / LSST Corporation





The ceremonial Primera Piedra, or First Stone, laid at the site of the future LSST on the summit of Cerro Pachón to commemorate the start of construction. Credit: El Día.

## Milestones

A major milestone for LSST in April, 2015 was literally a stone—Primera Piedra, a ceremony celebrating the laying of the First Stone, equivalent to a ground-breaking ceremony in the US but without the gold shovels.

The start of construction on the summit of Cerro Pachón in Chile's Andean foothills is only the most visible of milestones for the project. A major milestone for the telescope's optics was also achieved in 2015: polishing was completed on the combined primary-tertiary mirror and it's now in storage awaiting further testing and a trip to Chile.

Work on the camera has also seen notable progress with successful tests of camera CCDs and electronics at Brookhaven National Laboratory and a successful test of the refrigeration system that will keep parts of the camera chilled to 140 K.

## Covering the dark matter bases

Two major experiments are currently underway to search for dark matter, that most mysterious of substances thought to make up 85 percent of the mass in the universe, and KIPAC scientists are at the forefront of both. The two experiments are LZ (for LUX-ZEPLIN, a combination of the names of two current experiments that are merging to create it), which is scheduled to start collecting data in 2019, and the Super Cryogenic Dark Matter Search-SNOLAB (SuperCDMS), which should start in 2018.

Dark matter earned the name because we literally cannot see it. It doesn't reflect light or even interfere with light headed our way, so there's no such thing as a dark matter shadow. It has no electric charge and it doesn't glow when—indeed, if—it gets hot. Currently the only evidence of its presence is from the gravitational effect dark matter has on regular matter, like stars, planets, and us, but that evidence is very compelling. Scientists know there's a there, there, but beyond that they need to keep their options open.

LZ and SuperCDMS will help them do just that. Both experiments will be located deep underground in former mines to shield them from cosmic rays that could lead to spurious results. Both experiments will search for the same prize—a form of dark matter called Weakly Interactive Massive Particles (WIMPs)—but they'll use very different methods, which will enable them to team up to cover more possibilities.

LZ uses liquid xenon as a detector. Xenon is a noble gas, and, like other noble gases such as neon and argon, doesn't like to combine with other elements to form compounds. Instead of “noble,” think “snobbish.”

It's hard to believe one of the most standoffish elements could detect the shyest form of matter, but xenon's tendency to rebuff all comers is what makes it so useful. As dark matter particles stream through the seven metric tonnes of extremely pure liquid xenon filling LZ's detector, the occasional WIMP will collide with a xenon nucleus. The much bigger nucleus will absorb some of the energy from the collision and emit it as photons—a flash of light that can be detected. The number of photons is a marker of the momentum, and thus mass, of the dark matter particle, and the xenon molecules are sensitive to a wide range of masses.

SuperCDMS uses stacks of detectors made from disks of germanium and silicon kept at temperatures of less than one kelvin, about absolute zero. Again, the intent is to capture the effect of a collision with an atomic nucleus, but in the very cold crystals the result is waves of vibrations called phonons that ring through the crystal's structure as though it were a bell. SuperCDMS will use special sensors to detect that ringing that are sensitive to WIMPs of much smaller mass than LZ could find.

The LZ water shield, which currently houses the LUX experiment. Credit: Lawrence Berkeley National Laboratory.





## Daniel Akerib and Thomas Shutt

KIPAC's two newest faculty members, Daniel Akerib and Thomas Shutt, arrived at KIPAC's SLAC National Acceleration Laboratory facility with big plans to turn an unused experimental hall at the former particle physics lab into a place where they could build and test equipment for their underground dark matter experiment.

"We want to make our test facility a focal point of the collaboration," Akerib says. "We want to be able to bring collaborators here to test their prototypes and instruments."

But the growing use of noble gases like xenon and argon in experiments convinced them to think even bigger. "When we came to SLAC to make a pitch for building a test platform for our noble gas detector at the lab, we were clear that we wanted to build a test platform that could serve other noble gas experiments as well," Akerib says. "And it's happening."

"The world-leading test platform," Shutt adds. "There's nothing else like this anywhere."

They cite two experiments that have already expressed interest: Fermilab's Deep Underground Neutrino Experiment will use a liquid argon detector, and the Next Enriched Xenon Observatory will use liquid xenon in its detector. Both will study neutrinos.

There's another reason besides room to grow that a laboratory with a history of particle physics discoveries makes a good place to construct a dark matter experiment, Shutt says. "We're building a type of detector called a time projection chamber, which is really a tool from particle physics. But until recently we haven't had a lot of people in the collaboration who have backgrounds in building particle physics detectors," he says. "Now we do and it's been fun."

"There's a cosmological reason to search for dark matter," he adds, "but the actual experiment could be a poster child for a particle physics experiment. KIPAC, through both SLAC and Stanford, has both."

## Getting better every year—the Fermi Gamma-ray Space Telescope

The Fermi Gamma-ray Space Telescope (Fermi), launched June 11, 2008, has spent the past seven years studying the entire sky in gamma rays, the most powerful type of electromagnetic energy. The observatory orbits the Earth every 90 minutes and scans the entire sky eight times per day, and, based on data gathered during its thousands of orbits thus far, Fermi has created the most detailed map of the gamma-ray sky ever, adding thousands of new gamma-ray sources to previous lists.

In addition to discovering deep-space sources such as the spinning neutron stars called pulsars, particles accelerated in clouds of hot gas from stellar explosions, and the roiling hearts of galaxies containing giant black holes at their centers, Fermi has seen the sun blast out powerful gamma rays and tracked emissions from thunderstorms on our own planet.

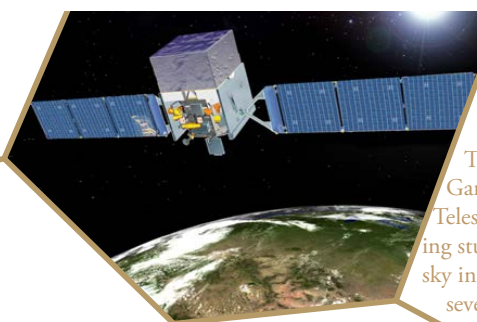
Fermi's main instrument, the Large Area Telescope (LAT), has depended on KIPAC scientists from design, through launch, to data analysis. KIPAC scientists have helped make its seventh year of service as scientifically rich as its first, with contributions to a comprehensive upgrade, called Pass 8, of the algorithms used to reconstruct and analyze LAT data.

Recent discoveries aided by this upgrade include a number of previously unknown pulsars. The LAT is also better able to detect and follow up on the sudden, brilliant flares called gamma-ray bursts, and the rate of discovery for these bursts has already increased. The comprehensive catalogue of more than 3000 sources published in 2015 by the LAT collaboration will be deepened and extended to lower and higher energies based on Pass 8 data.

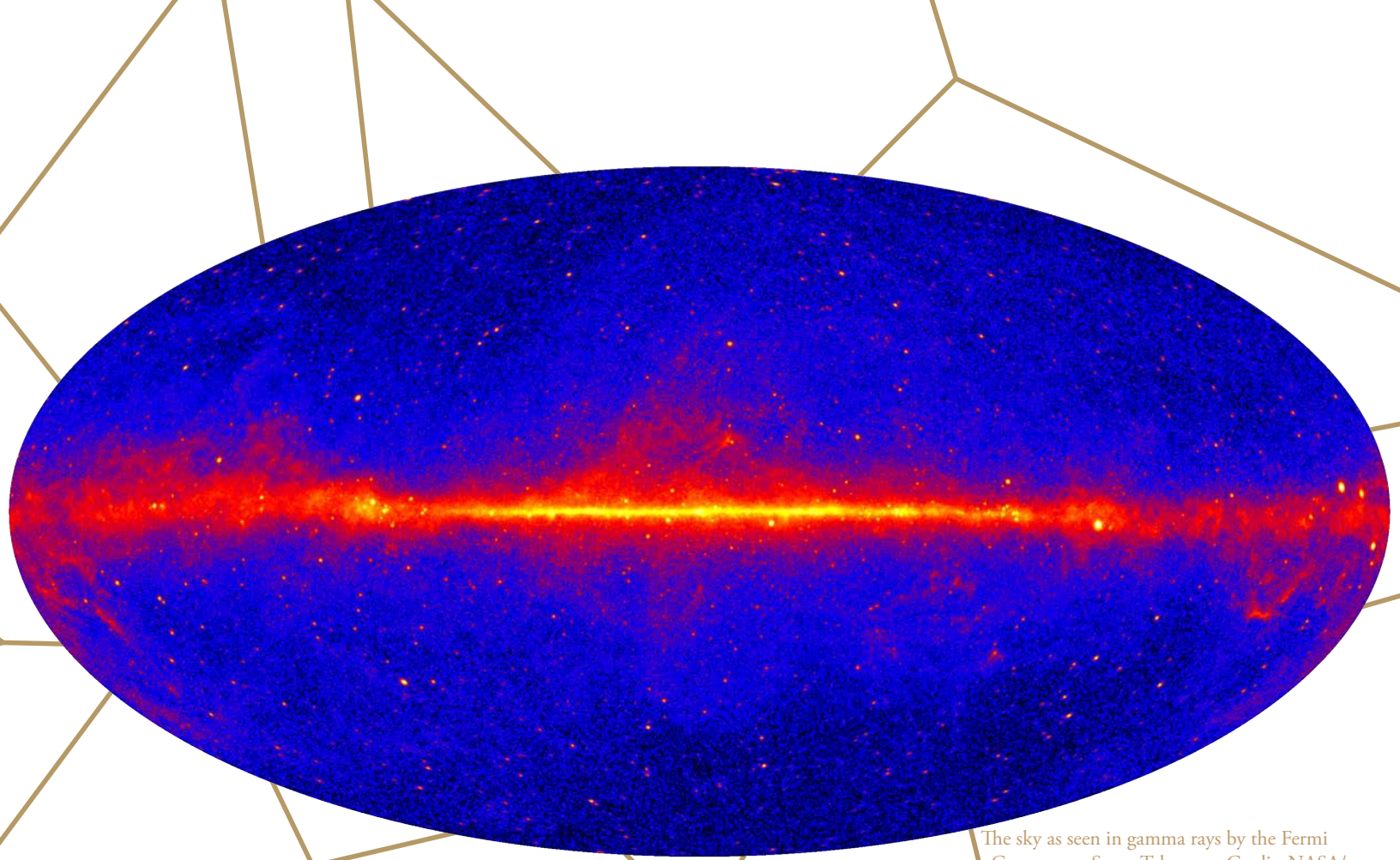
The observatory also is one of the best tools available today in the hunt for dark matter. Several dark matter models call for dark matter particles to produce gamma rays when the particles interact destructively in what is called self-annihilation. The LAT has been searching likely places for such signs, and currently the center of our own galaxy appears to produce more gamma rays than naively expected by known processes.

Dwarf spheroidal galaxies are another prime target. Such galaxies are tiny balls of stars thought to be swimming in dark matter. Unlike the center of the Milky Way, these dwarf galaxies have very few sources of gamma rays to drown out any faint signals from dark matter annihilations.

KIPAC scientists analyzing LAT data continue to work with other researchers (some also from KIPAC) to look at gamma-ray sources in other wavelengths, such as radio waves, to glean even more information about the objects. Such teamwork has discovered far more gamma-ray pulsars than anticipated—nearly 200 thus far—and almost half of them belong to a special class of pulsar called millisecond pulsars. Such information is invaluable for studying pulsar evolution.



The Fermi Gamma-Ray Space Telescope has been providing stunning views of the sky in gamma rays for seven years. Credit: NASA



The sky as seen in gamma rays by the Fermi Gamma-ray Space Telescope. Credit: NASA/DOE/Fermi LAT Collaboration

## Pass 8

Perhaps the biggest milestone for Fermi's Large Area Telescope in 2014–2015 was the implementation of Pass 8, a comprehensive upgrade of the software used to analyze LAT data. "It's a really big thing that improves the instrument and is directly related to the science," says KIPAC faculty member Peter Michelson, who leads the LAT collaboration. "Pass 8 greatly increases the scientific return from the LAT, especially at higher energies. It's almost like a new instrument."

According to Michelson, when Fermi launched, Pass 8 was already just over the horizon. "We had schedules to meet, so we focused on what are called Level 1 requirements," or the list of what must be accomplished to make a mission a success.

The observatory went up with all Level 1 requirements met, Michelson says. "What we launched with was pretty darned good." But at the same time they learned about the gamma-ray sky from the LAT, they learned about the LAT itself. "We learned more about its operating environment and we developed better algorithms for detection and reconstruction of gamma rays."

In a sense, Michelson says, work on Pass 8 began the day Fermi launched. "Afterwards we had breathing space," he says. "We could improve the software to support even bigger goals."

## Complementarity in action: Laurence Perreault Levasseur and Yashar Hezaveh

This year, a new post-doctoral researcher is joining KIPAC. Her name is Laurence Perreault Levasseur, and after bachelor's and master's degrees at McGill University in Montreal, Canada, she earned her PhD at the University of Cambridge. Levasseur's interests include the birth and early development of the Universe, and what that can teach us about fundamental physics.

The first person to welcome Levasseur will be Yashar Hezaveh, KIPAC researcher, Hubble Fellow—and Levasseur's husband.

One might assume physics played matchmaker for the petite French-Canadian and the lanky Canadian of Persian origin, but one would be wrong. Or, at least not entirely right. After all, Levasseur is a theorist, while Hezaveh is a data analyst. Inflation vs. strong gravitational lensing. Pencil and paper vs. supercomputers.

The two did meet in college. Hezaveh was a graduate student in the physics department at McGill University when Levasseur arrived and they even took a class together, though lightning didn't strike then. It wasn't until they were both teaching assistants for the same lab that the two got to know each other.

"She was late to class once," Hezaveh recalls.

"He gave me a lot of attitude for that," Levasseur adds with a smile. "But then, he always did."

They began dating six months after the course ended, and a scant two weeks after that Levasseur dropped a bombshell: Would he like to meet her in Italy for a two-week, 1000-kilometer bike trip—just the two of them?

Hezaveh wasn't exactly in shape for such a trip, but he said yes. He returned his new telescope, the one he'd been saving up to buy for years, and with the refund he bought a decent bike and a plane ticket and prepared to suffer. "I have never in my life invested so much so soon but I had the feeling she was the one."

"He hadn't really prepared for it at all," Levasseur says. "He even showed up in Bologna without biking shoes—he had forgotten his brand new shoes in Montreal in the spirit of 'packing light'—but even on Day One my approach was to work as a team...because we were in it together."

"After two weeks and more than 1000 kilometers I felt as though I'd lived with her for 10 years," Hezaveh says.

Since that very first trip, teamwork has been key, and not only during their subsequent trips, including a honeymoon spent biking through Portugal. Their complementarity manifests itself in their differing approaches to physics. According to Levasseur, her husband has a knack for coming up with new ways to approach problems—she calls him "a better scientist"—while Hezaveh says his spouse is incredibly tenacious at solving problems. "She's a better physicist," he says.



Levasseur sums it up with one word: “Respect. In my book it’s probably number one. I have a lot of admiration for him as a human being and I really feel that being with him makes me a better human being. He’s really good at pushing me beyond my comfort zone.”

“We know we’re going to face hardships,” Hezaveh says. “We know we’re going to face situations where one person is weak and the other person is strong and vice versa and we have to support each other—we want to support each other. We each know the other has the best intentions so we can face problems together.”

The biggest problem they’ve had to face as a couple is being pulled apart by their careers. “Three years of being separated by the Atlantic Ocean isn’t easy,” Levasseur says. “We thought we’d get used to it but it just got harder.”

“We’re really happy to be together and lucky that KIPAC is equally good for both of us,” Hezaveh adds.

In fact, with both starting three-year appointments, they’re actually in phase. One way the two celebrated their newfound stability? They adopted a dog.

“He’s a mixed Border Collie-Australian shepherd named Spark,” Hezaveh says. “We got him three weeks before we knew what our plans were for the next few years or where we would live, but she loved the dog, so we adopted him. Now I think it’s one of the best decisions we’ve ever made.”

The couple is looking forward to their time at KIPAC, including working on a project together, says Levasseur. “And our next biking trip will be around California.”

She smiles. “I can make sure Yashar brings his shoes.”

## Gamma-rays to dwarf galaxies: Synergies in searches for faint fuzzies

The March, 2015 announcement that nine dwarf galaxy candidates had been uncovered in the first-year data from the Dark Energy Survey (DES) made headlines around the world. Eight of them were included in an analysis performed by members of the DES collaboration, led by post-doctoral researchers Keith Bechtol of the Kavli Institute of Cosmological Physics at the University of Chicago and Alex Drlica-Wagner of Fermilab. (The ninth dwarf galaxy candidate appears in a separate paper from a different group using the same DES data.)

At the same time, another paper reported on the result of efforts by members of the Fermi Gamma-ray Space Telescope's Large Area Telescope (LAT) Collaboration to detect gamma-ray emissions from the newly discovered dwarf candidates. According to some theories, gamma rays could result from the annihilation of dark matter particles, and since dwarf galaxies have very few other potential sources of gamma rays within their borders to muddy the signal, dwarf galaxies are a favorite target of dark matter hunters.

This feat of collaborating collaborations was made possible in a large part because of the positions current and former KIPAC members hold in each collaboration. Bechtol and Drlica-Wagner were both graduate students at KIPAC and members of the LAT team before they joined DES. Once the decision was made within DES to share their data with the LAT team, Andrea Albert and Matthew Wood, two current KIPAC postdocs, spear-headed the gamma-ray analysis.

"The KIPAC connection was essential," says Drlica-Wagner. "KIPAC is involved in both LAT and DES, and the exposure to both experiments was what originally prompted the idea for this project. Additionally, people at KIPAC had just the right combination of expertise to be able to move quickly on the LAT data once the DES discoveries were made."

Considering their previous analysis had been based on 15 dwarf galaxies, the LAT researchers were happy to add the new examples to their sample set, Albert says. "Finding new dwarfs is really exciting and crucial to dark matter searches. Given that you expect the same dark matter signal from all the dwarfs you can stack them to increase the sensitivity."

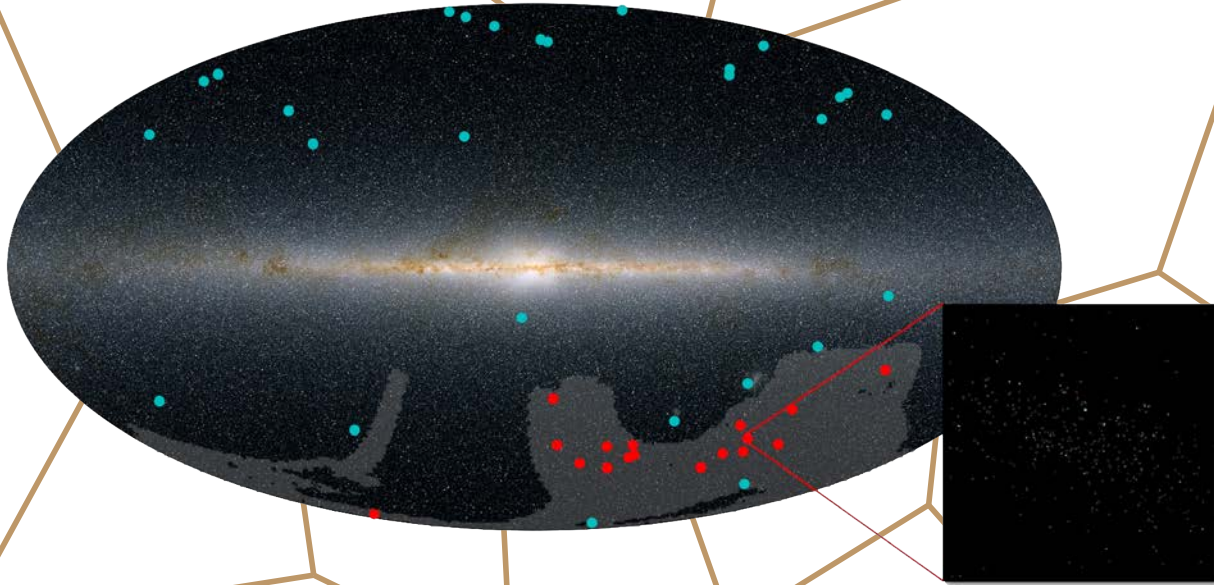
The KIPAC connection goes even deeper. The analysis techniques used to find these "faint fuzzies" in the DES data were adapted from algorithms originally created by KIPAC members searching for something else: KIPAC scientist Eli Rykoff and former KIPAC scientist Eduardo Rozo (now a professor at the University of Arizona) were using very similar methods to search for galaxy clusters in the DES data.

"The main focus of DES is to study dark energy, not dark matter. The DES collaboration is mostly planning to look deep for far-away objects like galaxy clusters," Albert explains. "But Alex and Keith saw the potential in using DES to find new dwarfs."

"Alex and I worked on different areas of Fermi analysis as graduate students, but both of us were very interested in statistical techniques to identify faint gamma-ray sources for which the LAT may have detected only a few individual photons," Bechtol says. "Similarly, when searching for ultra-faint dwarf galaxies, there may be only a few stars detected in the survey images."

Researchers have discovered a set of possible dwarf satellite galaxies (red dots) orbiting the Milky Way. They were found in the area covered by the Dark Energy Survey (gray). Scientists had previously found about two dozen dwarf galaxies (blue dots). Inset: An image of the stars that likely belong to one of the dwarf galaxy candidates.

Credit: Kavli Institute for Particle Astrophysics and Cosmology/SLAC National Accelerator Laboratory/Fermi National Accelerator Laboratory/Dark Energy Survey/Infrared Processing and Analysis Center/California Institute of Technology/University of Massachusetts



According to Drlica-Wagner, the two started discussing the viability of such a project while both were still graduate students at KIPAC, but actual work on it had to wait.

“Keith began working on the DES detection techniques after he graduated and left KIPAC for KICP. A year later, I graduated and joined Keith,” Drlica-Wagner says. “I had been working on the Fermi-LAT side of dwarf galaxies as my thesis at KIPAC, so almost all of the gamma-ray algorithms were developed there.”

Bechtol and Drlica-Wagner also noted KIPAC contributions to the theories behind their search: Risa Wechsler, a professor at KIPAC, on the DES side, and former KIPAC scientist Louis Strigari, who is now a professor at Texas A&M University. “Louie’s research helped lead us to the idea that the nearest dwarf galaxies could be among the most important places to search for dark matter,” says Bechtol.

“This project was a cool synergy between experiments operating at much different energy scales,” Albert says. “The gamma rays observed by Fermi are approximately one billion times more energetic than optical photons observed by DES.”

Six months after the initial discovery, data from the second year of the DES became available. The DES team led by Drilca-Wagner and Bechtol found eight new objects, for a total of 17 dwarfs detected in DES data.

“Ultimately, we want to use the optical and gamma-ray data together to make the most sensitive dark matter search,” Bechtol says.

The following excerpts from the KIPAC blog provide just a glimpse of the research being conducted at the institute by its dedicated researchers, including the work of several KIPAC graduate students and postdoctoral researchers. Read the full entries at <http://kipac.stanford.edu/kipac/kipac-blog>. All images courtesy of the respective researchers unless otherwise noted.

## Yashar Hezaveh puts supermassive black holes under a gravitational microscope

<http://j.mp/smbhlensing>

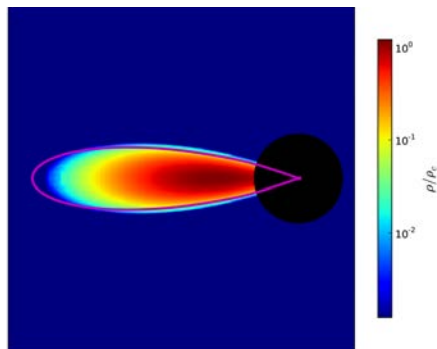
...there are hints that the supermassive black holes (SMBHs) lurk at the hearts of galaxies help determine the growth, maturation, and ultimate fate of their host galaxies. One of the most important steps towards solving how they do this is determining the masses of the central SMBHs in the oldest and furthest away galaxies.

That's where a novel idea by KIPAC astrophysicist Yashar Hezaveh may come in useful: using nearby massive galaxies as gravitational lenses that act like powerful cosmic microscopes for the background galaxies farther behind them...In his work, Hezaveh specifically looked at the prospects for the newly built massive radio telescope array ALMA (the Atacama Large Millimeter/submillimeter Array) to measure the masses of super-massive black holes (SMBHs) in lensed background galaxies in the near future through zooming in on the rotation velocity of gas clouds such as carbon monoxide.

Hezaveh did careful simulations based on a previous observation of the rotation velocities of gas in the disk of a nearby galaxy (NGC 4526, some 55 million light years away) combined with a realistic model distribution of gravitationally lensed distant galaxies. He estimated that we could "zoom in" on up to 20% of those gravitationally lensed galaxies, whose light has travelled more than 12 billion years—from almost the edge of our observable Universe—to reach us. Viewing their internal details in this fashion could significantly increase our knowledge of SMBHs and their masses at these distances.

## William East watches black holes swallow stars

<http://j.mp/blackholeeatingstars>



...When black holes are perturbed by, for example, a star falling into them, they act a little like bells. Like bells, black holes vibrate at specific frequencies which are determined by their masses and how fast they rotate. When you strike a bell, the energy in its vibrations is eventually carried away by vibrations in the air that we hear as sound. Black holes behave similarly, but instead of emitting sound waves, they emit gravitational waves as they settle back down to a stationary state. This process, in keeping with our analogy, is known as "ringdown."

As you might imagine, the strength of the gravitational waves produced by a star colliding with a black hole depends on how much the star is distorted before it collides. If the star is pulled apart as it nears the black hole, it acts more like a series of gentle taps on the black hole bell, instead of one big wallop from the collision of a compact object. East's simulations help reveal how much the strength of the gravitational wave signal is affected by the tidal distortions of the star.

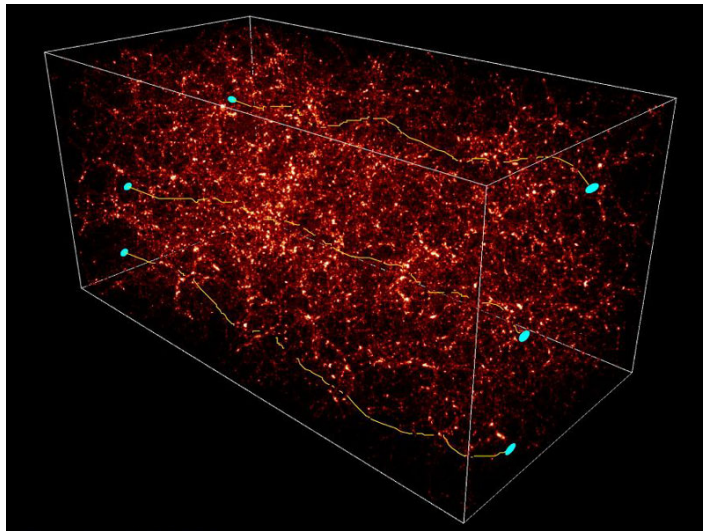
To detect the lower frequency ringdown of supermassive black holes, which have masses a million or more times that of our Sun and reside at the centers of galaxies, would require a space-based instrument. A lot of effort has been put into designing and developing such an instrument, though the funding for such an expensive space laser is still uncertain. However, ground-based gravitational wave observatories are searching for signs of other types of gravity wave-generating phenomena, and a real possibility exists that they'll make their first detections in the near future, thereby inaugurating a completely new type of astronomy. It's a very exciting time to be in gravitational physics!

## Josh Meyers explains how to map out the presence of material we can't even see

...Fortunately, astronomers are clever—and even more fortunately, the Universe has given us a few ways to indirectly map dark matter, including a wonderfully exotic-sounding effect called “weak gravitational lensing.” In a nutshell: As light rays from distant galaxies pass by clumps of matter on their way toward Earth, their trajectories bend a tiny bit. This bending is slightly different for light coming from different parts of the distant galaxy, which subtly distorts the galaxy images when observed with our telescopes.

<http://j.mp/galacticrainbows>

Unfortunately, there's a catch: turbulence in the atmosphere and optical imperfections in the telescope and camera produce distortions much larger than the gravitational signal of interest. However, the Universe has kindly provided a solution to this conundrum as well. The images of stars can be used to learn—exposure by exposure—what the distortions caused by the atmosphere and the optics are; the distortions can then be removed from the images of the galaxies.



Credit: S. Colombi (IAP), CFHT Team

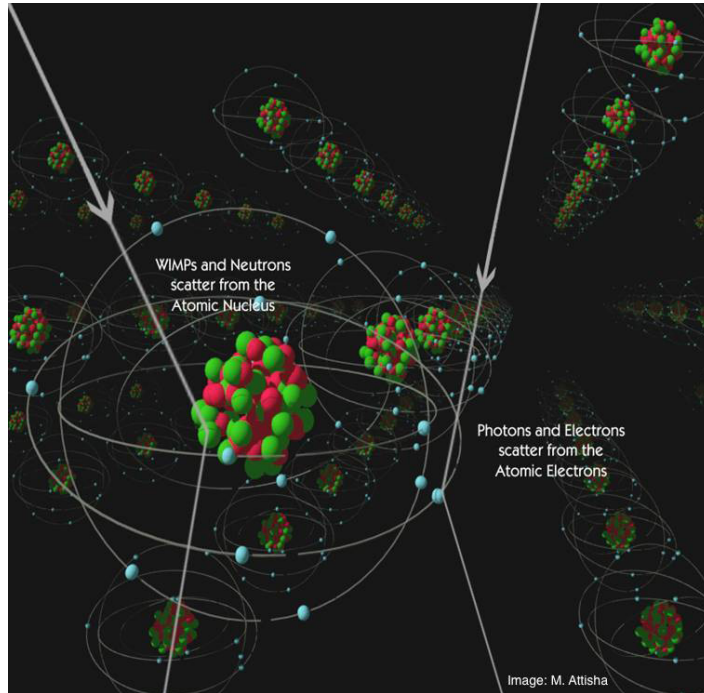
This technique of using images of stars to remove the effects of the atmosphere and optical imperfections on images of galaxies (but, importantly, not the effects of gravitational lensing itself!) has been standard practice for more than a decade now. However, new surveys such as the Dark Energy Survey, currently in its second year of taking data, and especially surveys at future facilities such as the Large Synoptic Survey Telescope, which began construction in 2014, will strain this technique to its limits.

## Kristi Schneck looks for low-mass dark matter particles with silicon detectors

...Detecting dark matter in the lab is a bit like a game of billiards. As the Earth moves through the Milky Way's dark matter halo, it is possible that a dark matter particle will collide with an atom in our detector, as in the figure below. This will cause the atom's nucleus to recoil, much like how you send the eight ball careening towards the pocket at the end of a game of pool.

<http://j.mp/lowmassdm>

Unlike in billiards, though, the masses of the dark matter particle (the cue ball in this analogy) and the target nucleus can be wildly different. As you can imagine, using a ping pong ball instead of the cue ball won't cause the target ball to travel very far, since the light-weight ping pong ball cannot transfer much energy to the target. This means dark matter detectors need to be sensitive to extremely small energy deposits if we want to search for low-mass dark matter. In addition, we would like to use a lighter target element if we're looking for low-mass dark matter: a tennis ball hit by a high-speed ping-pong ball is going to recoil more than a bowling ball would.



Credit: M. Attisha

Image: M. Attisha

The Cryogenic Dark Matter Survey (CDMS) is currently operating 15 germanium detectors 2341 feet below ground in the Soudan Underground Lab in northern Minnesota. The amount of rock between the CDMS detectors and the surface serves to shield the experiment from cosmic rays that hit the earth's surface. Additional shielding protects the detectors from ambient radioactivity and the few cosmic rays that make it deep into the earth.

Even with all this shielding, a few non-dark-matter particles occasionally manage to deposit energy in the detectors, especially at the energies where a low-mass dark matter particle would show up.

One recent CDMS paper used machine learning to teach the computer to recognize the differences between signal and background and remove background events from data taken using the detectors currently operating at Soudan. A second paper developed a sophisticated model of the expected backgrounds in CDMS-II, an earlier version of the CDMS experiment currently in the mine, and performed a likelihood analysis to look for dark matter. Both analyses concluded that what was seen in the detectors was consistent with the expected backgrounds.

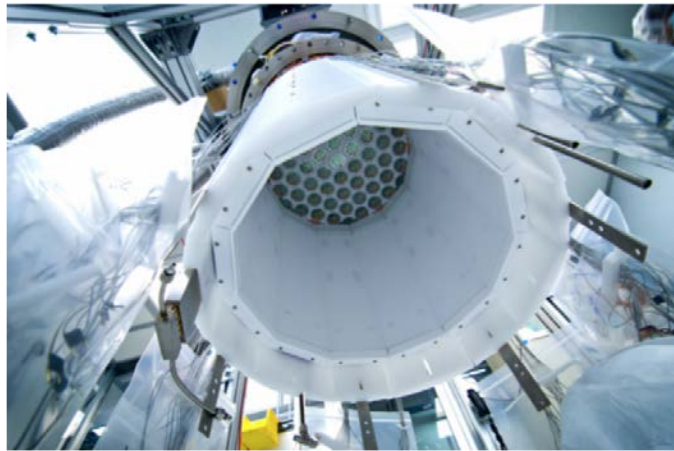
In addition to moving to an even deeper location in a Canadian mine, the planned upgrade to SuperCDMS, called SuperCDMS SNOLAB, will include both silicon and germanium detectors, whereas the currently running experiment uses only germanium. Silicon is particularly sensitive to low-mass dark matter since it has a relatively light nucleus. A low-mass dark matter particle will deposit more energy in a silicon detector than in a heavier germanium or xenon detector, as in the ping pong ball/tennis ball/bowling ball analogy. In addition, one of the possible dark matter signals was seen in silicon detectors, so we would like to test this observation with the same type of target. Combined with the xenon target used by LUX and its planned upgrade called LZ, SuperCDMS SNOLAB will be capable of probing even more of the large region of dark matter parameter space—watch for many more interesting results in the future!

## Christina Ignarra looks for heavier dark matter particles with liquid xenon

...LUX, or the “Large Underground Xenon” Experiment, a portion of whose central containment vessel is pictured below, is a particle detector consisting of hundreds of kilograms of xenon, located deep underground, in which we look for individual scatters from dark matter particles. The detector is a dual-phase liquid/gas xenon time projection chamber (TPC), one of the most sophisticated forms of modern particle detectors. When a dark matter particle (or other particle, for that matter) interacts with one of the xenon atoms in the liquid portion of the detector, it causes the xenon nucleus to recoil. A nuclear recoil in the detector leads to a burst of scintillation light and to the ionization of the surrounding xenon atoms, leading to the liberation of “ionization electrons.” We refer to the initial burst of light as the “S1” signal.

<http://j.mp/luxdm>

The ionization electrons subsequently drift to the top of the detector, driven by an applied electric field, where they encounter the gas-liquid interface. There, they produce a second burst of light through electroluminescence, which we call the “S2” signal. The resultant photons from each burst of light are detected by 122 photomultiplier tubes (PMTs), split between the top and bottom of the detector. The two signals, S1 and S2, are separated by the drift time of the electrons, from



which we can infer the depth of the event. Combining this information with the geometrical patterns produced by the number of photoelectrons detected by each PMT, the three dimensional position can be reconstructed for each event. This position information is vital for discrimination between signal and background since the xenon is self-shielding, meaning most of the background events are concentrated near the walls of the detector. Uniform backgrounds, such as the decays of radioactive elements contaminating the xenon itself, will produce electron-recoils rather than nuclear recoils in the detector. These events can be distinguished from that of nuclear recoils based on the ratios of their S1 and S2 signals.

We report our results in terms of two parameters that would describe WIMPs: their mass and their cross-section, or probability of interaction. We do not know the exact values of these parameters, so we show our results in terms of excluding regions of their potential values. LUX currently holds the world’s best direct dark-matter detection limit for most WIMP masses.

## Devon Powell shows researchers what to look for with dark matter simulations

...Discretizing dark matter on a computer, or simulating it using virtual particles that don’t have a one-to-one correspondence with the dark matter particles themselves, is a standard technique for creating dark matter simulations, but it suffers from one distinct difficulty, which is that we often want to know the density of dark matter at any given point in space.

<http://j.mp/dmphasespace>

What is the density of dots at a particular location in a simulation? The answer is we don't really know, because the locations of the dots don't give us enough information.

But knowing this is important, for instance, in studying the large-scale structures in the cosmos. Dark matter particles, as a general rule, form structures called haloes (clumps that host galaxies), filaments (elongated strands that connect haloes), voids (vast regions of low density), and walls (sheets that separate voids from one another). The consistent identification and classification of these structures in the cosmic web is a topic of ongoing debate.

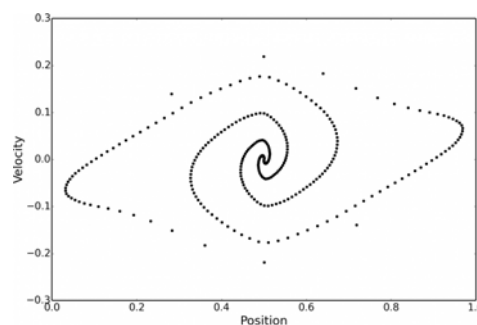
What if it were possible to discretize dark matter on a computer in such a way that the actual density field were known, with no need to use estimators or other tricks? In fact, it is. Since 2011, KIPAC Director Tom Abel and his group at KIPAC (including former KIPAC postdocs Oliver Hahn and Raul Angulo, as well as visualization expert Ralf Kaehler) have been exploring a new method for discretizing dark matter. This method works by respecting something called the phase space structure of the dark matter, which the particle discretization does not. "Phase space" refers to the combined position (position space) and velocity (velocity space) coordinates that a point moving along with the flow of dark matter may have. In our universe, a bit of dark matter has three position coordinates (since we live in 3-D), as well as three velocity components, which give a total of six dimensions for a 6-D phase space.

To illustrate, imagine a 1-D universe in which the positions of dark matter particles can be specified by a single number. A plot of dark matter particle positions in a "1-D halo" might look something like this:



We can see that there is a region of higher density (more points per unit length) in the middle. We could apply a density estimator to just these points if we wanted to. But what if we include the velocity coordinate of each particle on the vertical axis, as well? Now, the particles occupy a 2-D phase space, the space consisting of one position coordinate and one velocity component.

All of a sudden, we see structure! The spiral is a result of "phase mixing," a process by which neighboring particles that orbit the halo at slightly different speeds end up drifting away from one another. The use of phase space coordinates illuminates the physical structure of the particle distribution, which is that particles that are neighbors in physical space are not necessarily neighbors in phase space.

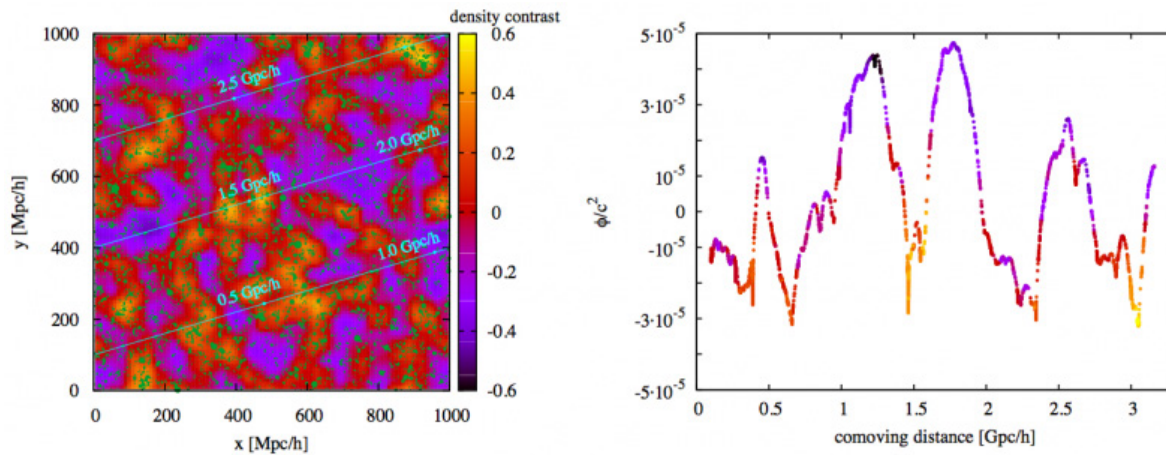


Ultimately this method of discretization leads to a representation of dark matter as a sheet in 6-D phase space vs. as a series of disconnected points. This view provides information about the distribution of dark matter in the universe that is more physically complete than previous view and opens the door to many profoundly exciting prospects for future computational research on dark matter and cosmology.

# Radek Wojtak tests whether we inhabit a special place in the Universe

... A simple test assessing the relevance of the local gravitational redshift on cluster weak lensing can be performed by repeating cosmological fits on simulated SN Ia data generated for the same cosmological model and modified by the local gravitational redshift. Ideally, we would like to know the exact large-scale gravitational potential at the Milky Way's position so that we could simulate the effect of the gravitational redshift as realistically as possible.

<http://j.mp/localunderdensities>



Many independent studies of galaxy counts and cluster counts in the Local Universe suggest that the Milky Way is located in an underdense region. We expect then to experience gravitational redshift rather than gravitational blueshift. Unfortunately, this is probably all that we can deduce from observations, because the current mapping of the Local Universe (out to a few hundred million light-years) is not complete enough for all objects and we cannot ascertain the exact value of the underdensity of our region.

However, instead of referring to observations we can take a more conservative approach and consider a range of all possible gravitational redshifts at locations of Milky Way-like galaxies found in a large-scale cosmological simulation. This range represents the most conservative prior knowledge of the local gravitational redshift permitted by the currently accepted best cosmological model.

It turns out the presence of the local gravitational redshift places a roughly 1% limit on the accuracy of measuring cosmological parameters using SN Ia data. Without trying to judge whether or not this is going to be a dominant effect in future observations, it is really remarkable to see that this weak effect manifests itself in a global cosmological fit.

A natural follow-up question is whether the gravitational redshift can have a similar effect on other cosmological probes such as baryon acoustic oscillations (BAO). This depends on how precisely we know the physical scale of objects used to measure distances. In contrast to SN Ia, the standard ruler of the BAO is precisely fixed by cosmic microwave background physics. This means that cosmological inference in this case does not need to employ any marginalization over the physical scale which turns out to be the main channel of propagating perturbations due to the gravitational redshift to the errors in the measured cosmological parameters. Therefore, our simple expectation is that BAO observations should not be affected by the local gravitational redshift effect. Interestingly, this may have some consequences for the empirical distance-duality

relation based on combining luminosity distances from SN Ia and angular size distances from BAO.

## Krzysztof Nalewajko looks for missing magnetic fields in pulsars

<http://j.mp/blazarflares>

... Recently, a collaboration led by Masaaki Hayashida detected a very peculiar gamma-ray event in the historically well-known blazar 3C 279, which was characterized by a lack of simultaneous activity in the visible wavelengths. These gamma-ray flares are thought to be produced through inverse Compton scattering (where ambient visible-light photons are boosted in energy by interactions with high-energy electrons), and they are generally expected to be accompanied by some level of both visible and radio emissions due to synchrotron radiation (an energy loss mechanism which occurs when energetic electrons spiral around magnetic field lines).

The lack of any significant emissions in the visible light band indicates that the gamma ray-emitting region must have very weak magnetic fields. How, then, are the radiating particles accelerated to the extreme energies required in these blazing jets, since most of the theorized mechanisms to accelerate them rely on substantial magnetic fields confining the particle motions?

The observation suggests a complete destruction—if only locally—of the jet's magnetic fields. Or perhaps there was a gap in the jet that was filled by surrounding interstellar gas. Or something completely different—perhaps an extra source of matter polluting the jet, perhaps from a large, unlucky star that straggled too close (such an interaction is thought to lead to at least a partial destruction of the star).

In fact, this is not the first case of extreme gamma-ray flares from blazars. Probably the first example was observed in blazar PKS 1510-089 and described by Shinya Saito and collaborators in 2013. However, in that case there were no visible light/infrared observations made that could constrain the counterpart luminosity. Such extreme gamma-ray flares may be rare, and we may have even overlooked some of them in the Fermi data, but we should pay close attention to them because they are ultra-luminous and because they tell us something new about the physics of particle acceleration.

In short— there is a real mystery here that we have yet to unravel.

*You can read more about KIPAC's science at <http://kipac.stanford.edu/kipac/researchlist>, and follow us on Facebook at <https://facebook.com/KIPAC> and Twitter at <https://twitter.com/KIPAC1>*



# KIPAC members

## Faculty

Tom Abel  
Daniel Akerib  
Steve Allen  
Roger Blandford  
Elliott Bloom  
Patricia Burchat  
David Burke  
Bob Byer  
Blas Cabrera  
Sarah Church  
Savas Dimopoulos  
Lance Dixon  
Francis Everitt  
Peter Graham  
Giorgio Gratta  
Kent Irwin  
Shamit Kachru  
Steve Kahn  
Renata Kallosh  
Aharon Kapitulnik  
Mark Kasevich  
Chao-Lin Kuo

Andrei Linde  
Bruce Macintosh  
Peter Michelson  
Michael Peskin  
Vahe Petrosian  
Roger Romani  
Aaron Roodman  
Philip Scherrer  
Rafe Schindler  
Leonardo Senatore  
Stephen Shenker  
Tom Shutt  
Eva Silverstein  
Peter Sturrock  
Leonard Susskind  
Sami Tantawi  
Robert Wagoner  
Risa Wechsler

## Faculty Alumni

Stefan Funk

## Faculty Emeriti

David Caldwell  
Tune Kamae

## Staff

Ron Adler  
Luca Baldini  
Eugenio Bottacini  
Iryna Butsky  
Rob Cameron  
Eric Charles  
Mandeep Gill  
Kirk Gilmore  
Charlottee Hee  
Karen Heidenreich

Todd Hoeksema  
Ralf Kaehler  
Grzegorz Madejski  
Stuart Marshall  
Philip Marshall  
John Mester  
Glenn Morris  
Igor Moskalenko  
Nicola Omodei  
Troy Porter  
James Russell  
Eli Rykoff  
Owen Saxton  
Stephen Tether  
Jana Thayer  
Keith Thompson  
Brian Van Klaveren  
Daniel Van Winkle  
Anthony Waite  
Lori White  
Matthew Wood  
Ki Won Yoon

## Administration

Christine Aguilar  
Chris Hall  
Jeff Heckathorn  
Ziba Mahdavi  
Sara McCardle-Blunk  
Jan Olson  
Dorrene Ross  
Martha Siegel  
John Skinner  
David Stricker  
Dora Taumalolo  
Dana Volponi  
Jeff Wade

## Postdocs

Zeeshan Ahmed  
Hongjun An  
Matthew Becker  
Rebecca Canning  
William East  
Frederic Effenberger  
Katherine Follette  
Anna Franckowiak  
Amy Furniss  
Yashar Hezavehe  
Sarah Kernasovskiy  
Ji-hoon Kim  
Ashley King  
Matthew Kistler  
Elisabeth Krause  
Ranjan Laha  
Philipp Mertsch  
Joshua Meyers  
Krzysztof Nalewajko  
Andrew Norton  
Walter Ogburn

Fatima Rubio da Costa  
Luigi Tibaldo  
Giacomo Vianello  
Zvonimir Vlah  
Christopher Williams  
Irina Zhuravleva  
Jonathan Zrake

## Research Associates

Andrea Albert  
Tomasz Biesiadzinski  
Christina Ignarra  
Ethan Karpel  
Dmitry Malyshev  
Elena Orlando  
Wing To  
Marco Viero  
Anja von der Linden  
Norbert Werner  
Radoslaw Wojtak

## Students

Alice Allafort  
Richard Anantua  
Michael Baumer  
Rosie Bramante  
Saptarshi Chaudhuri  
Dongwoo Chung  
Chris Davis  
Joe DeRose  
Harry Desmond  
Simon Foreman  
Bryant Garcia  
James Grayson  
Jae Hwan Kang  
Wei Ji  
Sowmya Kamath  
Stewart Koppell  
Chang Lee  
Matthew Lewandowski  
Tony Li  
Yao-Yuan Mao  
Warren Morningstar  
Anna Ogorzalek  
Devon Powell  
Jean-Baptiste Ruffio  
Kristi Schneck  
Matt Sieth  
Adam Snyder  
Charles Titus  
Sam Totorica  
Ondrej Urban  
TJ Whitis  
Adam Wright  
Wai-Ling Wu  
Yajie Yuan  
Zhang Zhang

## Staff Alumni

Edward Baltz  
Deborah Bard  
Bill Craig  
Eduardo do Couto e Silva  
Gregory Dubois-Felsmann  
Johnny Ng  
Pat Nolan  
John Patterson  
Olaf Reimer  
Anita Reimer  
Jack Singal

## Research Associate Alumni

Michael Busha  
Carlos Cunha  
Jonathan Granot  
Francesco Mazzaro  
Eduardo Roza  
Louis Strigari

## Postdoc Alumni

Markus Ackermann  
Marco Ajello  
Shizuka Akiyama  
Mark Allen  
Marcelo Alvarez  
Raul Angulo de la Fuente  
Matteo Barnabe  
Peter Behroozi  
Silvia Bonoli  
Melanie Bowden  
Marusa Bradac  
Daniel Brandt  
Rolf Buehler  
Jennifer Carson  
Chao Chang  
Teddy Cheung  
Johann Cohen-Tanugi  
Jody Cooley-Sekula  
Luigi Costamante  
Peter den Hartog  
Kiruthika Devaraj  
Teruaki Enoto  
Andres Escala  
Andrei Frolov  
Steven Fuerst  
Brian Gerke  
Daniel Green  
Ming Gu  
Oliver Hahn  
Masaaki Hayashida  
Stephen Healey  
Mark Hertzberg  
Stefan Hilbert

Julie Hlavacek-Larrondo  
Wynn Ho  
Patrick Ingraham  
Yoshiyuki Inoue  
Saurabh Jha  
Tobias Jogler  
Junichiro Katsuta  
Stelios Kazantzidis  
Ryan Keisler  
Matthew Kerr  
Daniel Kocovski  
Judy Lau  
Yu Lu  
Maxim Lyutikov  
Jonathan McKinney  
Simona Murgia  
Masamune Oguri  
Jeff Oishi  
Akira Okumura  
David Paneque  
John Peterson  
Dmitry Prokhorov  
David Rapetti  
Masao Sako  
Miguel Sanchez-Conde  
Tim Schrabback-Krahe  
Neelima Sehgal  
Marina Shmakova  
Aurora Simionescu  
Samuel Skillman  
Anatoly Spitkovsky  
Lukasz Stawarz  
Mutsumi Sugizaki  
Anna Szostek  
Takaaki Tanaka  
Kathleen Thompson  
James Tolan  
Yasunobu Uchiyama  
Justin Vandenbroucke  
Leif Wilden  
Nadia Zakamska  
Weiqun Zhang

## Student Alumni

Akshit Aggarwal  
Mustafa Amin  
Karl Andersson  
Doug Applegate  
Keith Bechtol  
Bijan Berenji  
Aurelien Bouvier  
Chihway Chang  
Anirban Chatterjee  
Daniel Chavez-Clemente  
Qingrong Chen  
William Chickering

Helen Craig  
Lixin Dai  
Karl Drlica-Wagner  
Yvonne Edmonds  
Steven Ehlert  
Nils Engelsen  
Conrad Hutcheson  
Fabio Iocco  
Niklass Karlson  
Julian Kates-Harbeck  
Patrick Kelly  
Rajiv Krishnakumar  
Joshua Lande  
Shiu-Hang Lee  
Peter Lewis  
Adam Mantz  
Evan Million  
Warit Mitthumsiri  
Eric Morganson  
Martin Mueller  
Rebecca Nie  
Stephen Osborne  
Matt Pyle  
Dominik Rastawicki  
Yasser Rathore  
Rachel Reddick  
Kevin Schlaufman  
Michael Shaw  
Paul Simeon  
Lance Simms  
Maximilian Swiatlowski  
Matt Turk  
Adam Van Etten  
Patricia Voll  
Peng Wang  
Ping Wang  
Kyle Watters  
John Wise  
Edward Wu  
Hao-Yi Wu  
Qi Yang  
Qi Zeng  
Fen Zhao  
Chen Zheng  
Jialu Zhu  
Yan Zhu

*KIPAC's collaborative environment has benefited from many people who have made great contributions but whose names may not be included on this list.*



## KIPAC projects

### CDMS

Tsuguo Aramaki  
Makoto Asai  
Anders Borgland  
Paul Brink  
Blas Cabrera  
Concetta Cartaro  
Matt Cherry  
Kent Fouts  
Gary Godfrey  
Mike Kelsey  
Noah Kurinsky  
Matt McCulloch  
Stuart Metcalfe  
Dave Nelson  
Marco Oriunno  
Richard Partridge  
Mike Racine  
Kristi Schneek  
Astrid Tomada  
Dennis Wright

### LSST

#### Data Management

Jacek Becla  
John Gates  
Fabrice Jammes  
Kian-Tat Lim  
Fritz Mueller  
Nathan Pease  
Vaikunth Thukral  
Daniel Liwei Wang

#### Camera

Frank O'Neil  
Mark Arndt  
Joanne Bogart  
Anders Borgland  
Gordon Bowden

Craig Brackett  
Jim Chiang  
Seth Digel  
Richard Dubois  
Karl Flick  
Warren Focke  
Thomas Glanzman  
Gunther Haller  
Patrick Hascall  
Diane Hascall  
Sven Hermann  
Michael Huffer  
Walter Innes  
Tony Johnson  
Heather Kelly  
Joe Kenny  
Nadine Kurita  
Travis Lange  
J. Langton  
Allan Lazarus  
Hok Leung  
Darren March  
Regina Matter  
Homer Neal  
Martin Nordby  
James Panetta  
Andrew Rasmussen  
Kevin Reil  
Aaron Roodman  
Rafe Schindler  
Roma Singh  
Gregg Thayer  
Max Turri  
Richard Van Berg

### LUX/LZ

Daniel Akerib  
Thomasz Biesiadzinski  
Rosemary Bramante  
Christina Ignarra

Wei Ji  
James Krebs  
Steffen Luitz  
Marie Elena Monzani  
Kimberly Palladino  
Blair Radcliff  
Tom Shutt  
Wing To  
Jaroslav Va'vra  
Thomas Whitis  
William Wisniewski

*The above people have been contributing to active projects, the scientific results of which will provide new research opportunities at KIPAC. We apologize if any names have been inadvertently left out.*

## KIPAC visitors 2014-2015

Akos Bogdan  
William Abbett  
Eric Agol  
Marcelo Alvarez  
Douglas Applegate  
Camille Avestruz  
Vanessa Bailey  
Guillermo Barro  
Jacob Bean  
Peter Behroozi  
Andrei Beloborodov  
Bradford Benson  
Sebastian Bocquet  
Dominique Boutigny  
Philippe Bruel  
Jack Burns  
Iryna Butsky  
Andrea Caliendo  
Damiano Caprioli  
Regina Caputo  
Gianpaolo Carosi  
Emanuele Castorina  
Matteo Cataneo  
Renyue Cen  
Sukanya Chakrabarti  
Joseph Clampitt  
Jorge Luis Cervantes  
Cota  
Luiz da Costa  
Maria Giovanna  
Dainotti  
Neil Dalal  
Tijmen de Haan  
Mattia di Mauro  
Benedikt Diemer  
Josh Dillon  
Eduardo do Couto e Silva  
Karl Alex Drlica-Wagner

Richard Ellis  
Glennys Farrar  
Simone Ferraro  
Andreu Font-Ribera  
Anne-Mette Frejsel  
Daniel Gruen  
Yicheng Guo  
Masaaki Hayashida  
Adam Hill  
Florian Hofmann  
Philip Hopkins  
Ryosuke Itoh  
Karsten Jedamzik  
Sonia Karkar  
Kazumi Kashiyama  
Stavros Katsanevas  
Hongsu Kim  
Robert Kirshner  
Ralf Klessen  
Mark Krumholz  
Wlodek Kluzniak  
Brian Lacki  
Astrid Lamberts  
Yu-Hsiang Lin  
Michael Liu  
Jurek Loebell  
Jessica Lu  
Andrew MacFadyen  
Simone Maldera  
Allison Man  
Jacqueline McCleary  
Evan McDonough  
Maura McLaughlin  
Marius Millea  
Jon Miller  
Warit Mitthumsiri  
Lorenzo Moncelli  
Harvey Moseley  
Michael Mulhearn  
Norman Murray

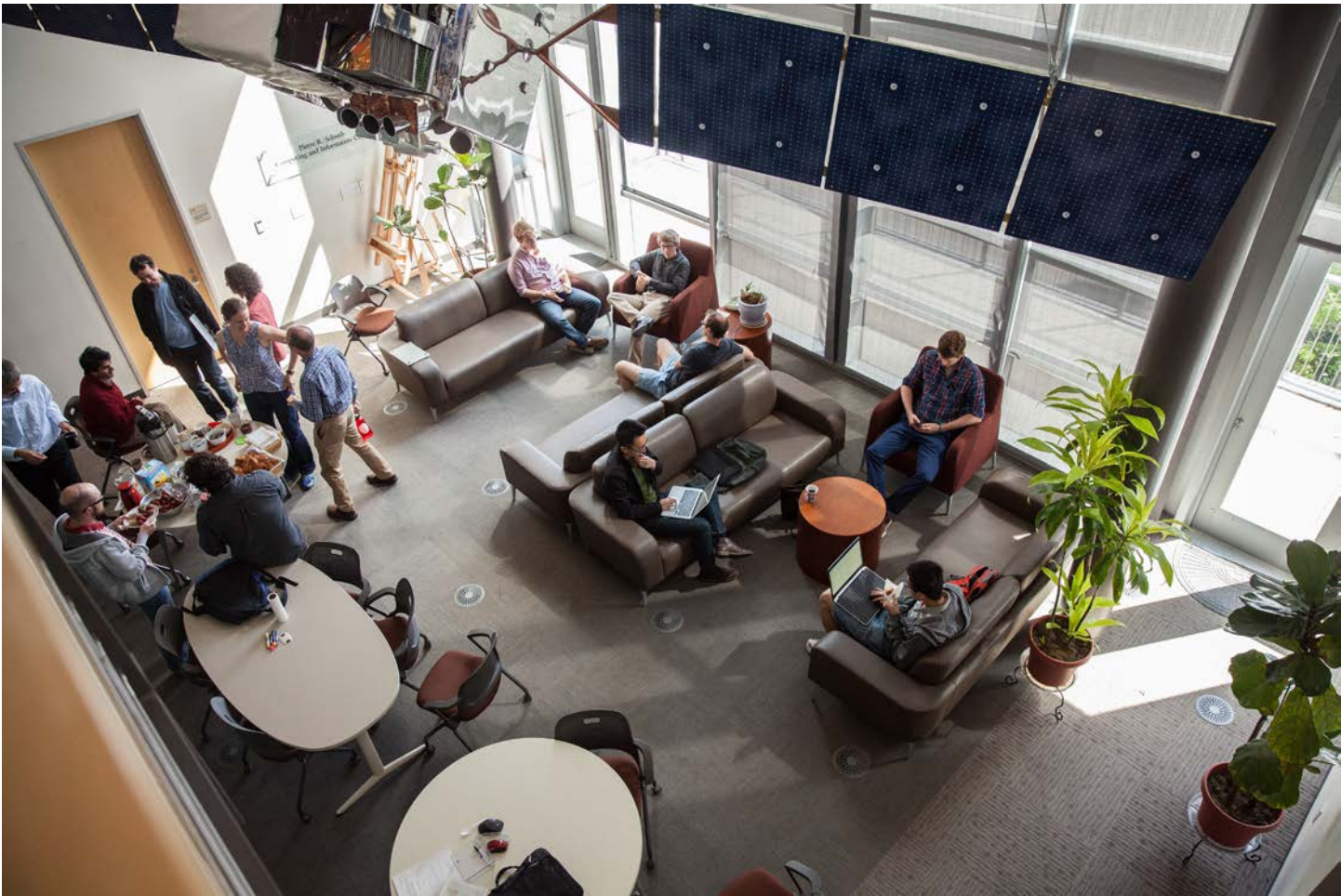
Toshiya Namikawa  
Eric Neilsen  
Georgiana Ogrea  
Peng Oh  
Christian Ott  
Casey Papovich  
Kyle Parfrey  
Dheeraj Pasham  
Melissa Pesce-Rollins  
Kara Ponder  
Francisco Prada  
Laurent Puyeo  
Roman Rafikov  
Scott Ransom  
David Rapetti  
Martin Rees  
Alexandre Refregier  
Beth Reid  
Eduardo Roza  
Michael Schneider  
Erin Sheldon  
Blake Sherwin  
Brooke Simmonds  
Alessandro Sonnenfeld  
Kyle Story  
Andra Stroe  
Christopher Stubbs  
Sasha Tchekhovskoy  
Cora Uhlemann  
Keith Vanderline  
Mei-Yu Wang  
Doug Watson  
Christoph Weniger  
Michael Wood-Vasey  
Nadia Zakamska  
Fabio Zandanel  
Michael Zmccov

Steve Kahn at the ground-breaking of LSST in Chile.

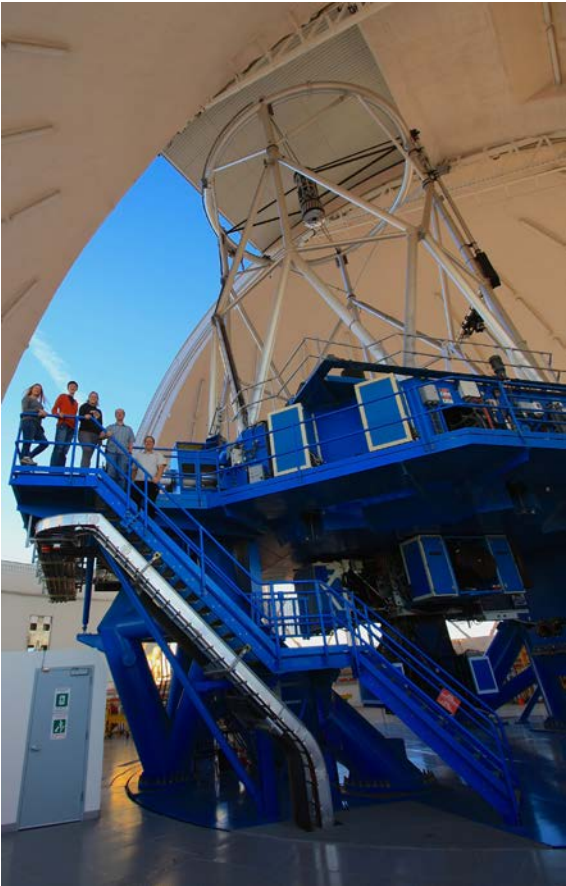


Bruce Macintosh at the Gemini Observatory in Chile.

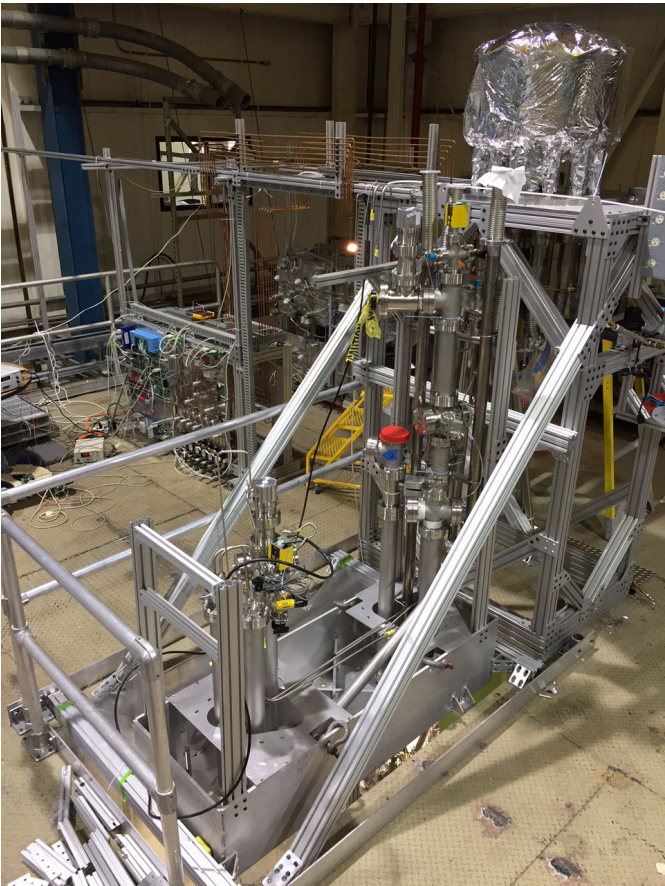




Tea time at the Kavli Building at SLAC National Accelerator Laboratory



KIPAC researchers Ashley Chontos, Vanessa Bailey, Kate Follette, Bruce Macintosh, and Eric Nielsen at the Gemini Observatory



The LZ test platform at SLAC

The web-like structure in the background of this report is called a Voronoi tessellation and is used as a mesh for calculations of dark matter distributions, early star formation, and other astrophysical and cosmological phenomena.



**SLAC**



Production: KIPAC  
Outreach Committee  
Text: Lori White  
Design: David Harris