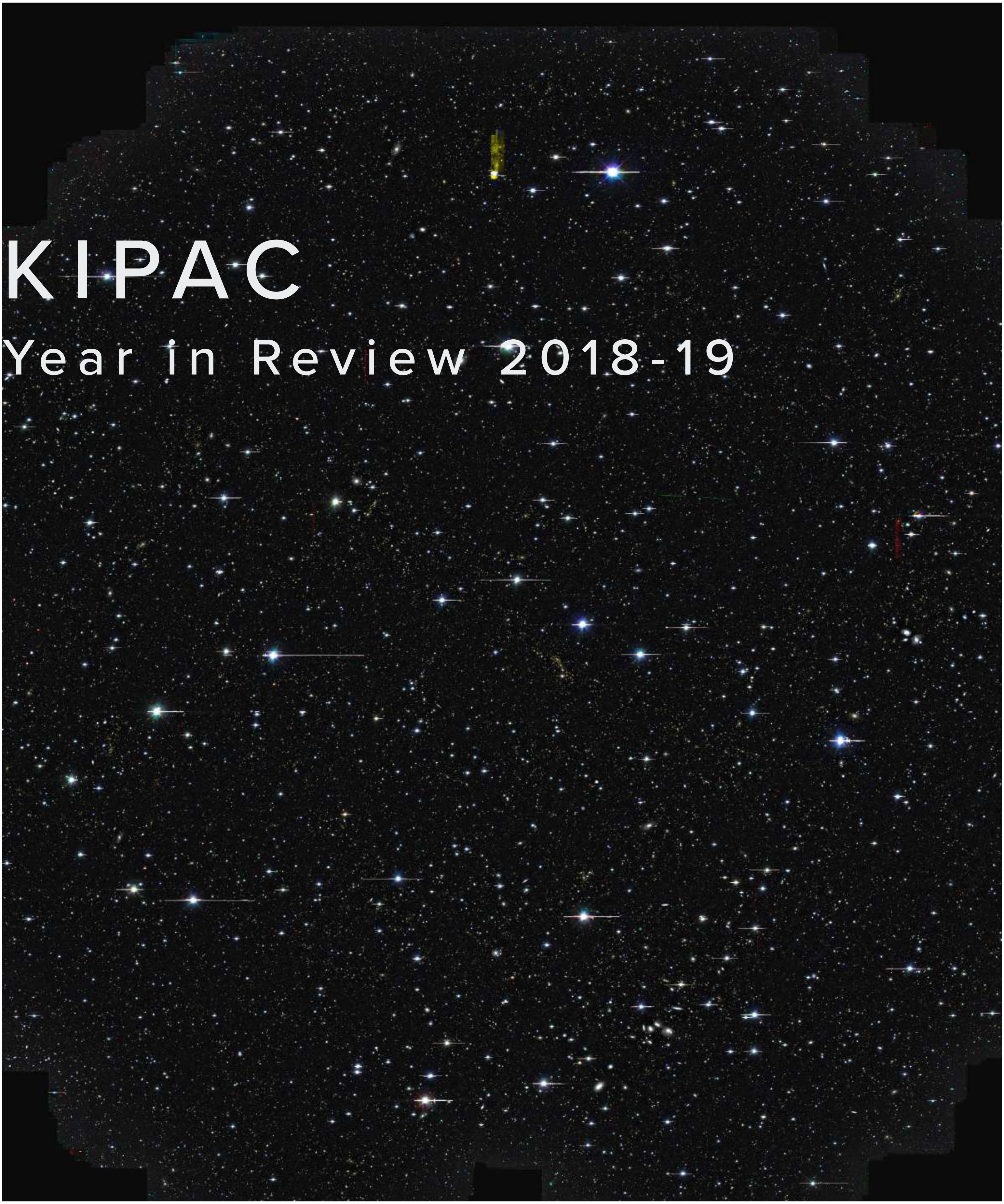
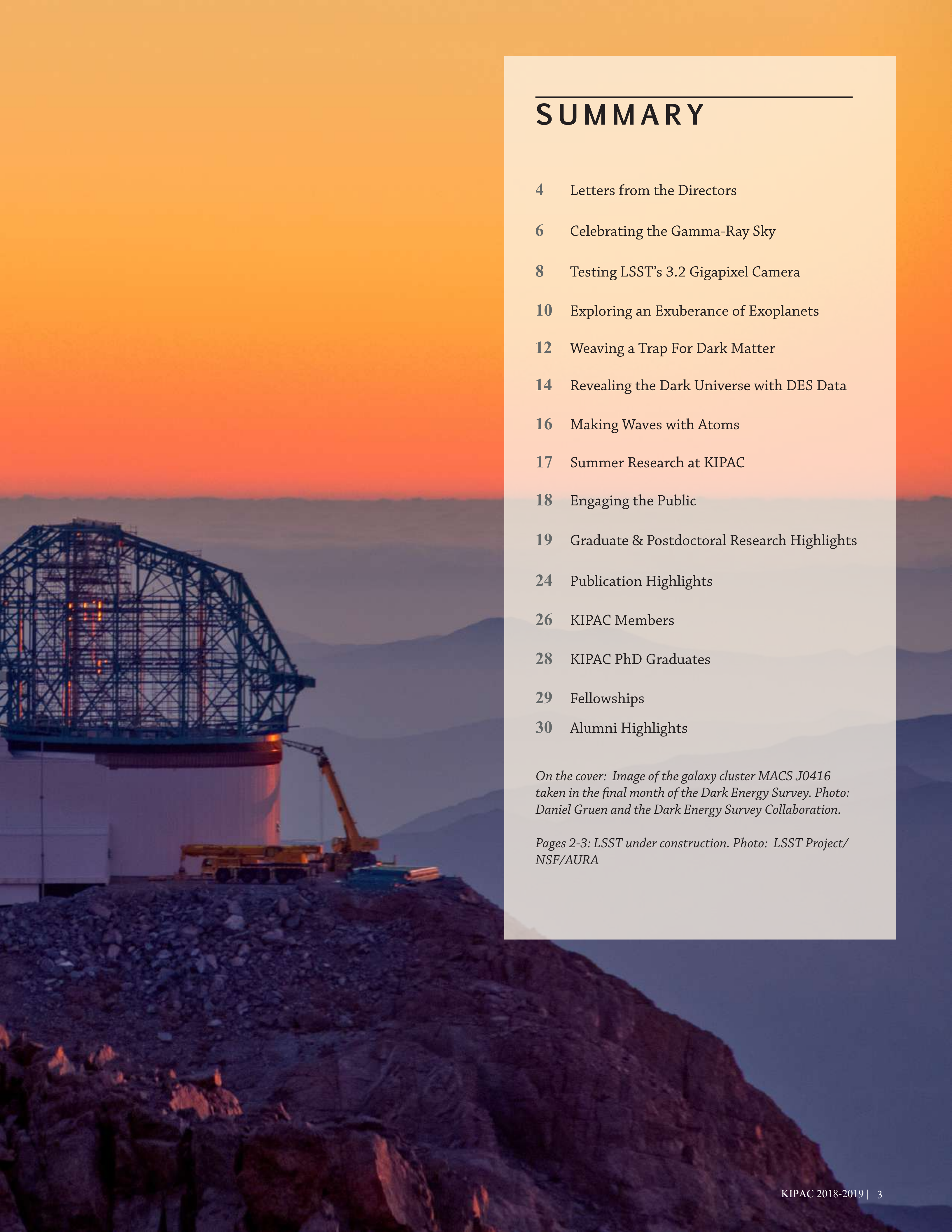


KIPAC

Year in Review 2018-19

KIPAC KAVLI INSTITUTE FOR PARTICLE ASTROPHYSICS & COSMOLOGY



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On the cover: Image of the galaxy cluster MACS J0416 taken in the final month of the Dark Energy Survey. Photo: Daniel Gruen and the Dark Energy Survey Collaboration.

Pages 2-3: LSST under construction. Photo: LSST Project/ NSF/AURA

FROM THE DIRECTORS

It is a great pleasure and privilege to take on the leadership of KIPAC at this exciting time in its development. I came to KIPAC just a few years after its founding, as a new assistant professor, and since first arriving have been struck by the commitment to building a community that aims for scientific excellence as well as a welcoming, collaborative environment that enables the success of all of its members. It has been wonderful to be a part of KIPAC's growth, to share in the exiting discoveries enabled by our researchers, and to see the first generations of students and postdocs go on and make an impact throughout the community.

In the last year alone, KIPAC researchers have put new limits on the nature of dark matter and dark energy, characterized the properties of extrasolar planets around 300 nearby stars, and made new discoveries about black holes and gamma-ray bursts. The next few years promise to be at least if not even more exciting; we are finishing the construction of the LSST camera and the LZ and SuperCDMS dark matter experiments, expanding the reach of our cosmic microwave background program, and developing new ways to look for high energy phenomenon, extrasolar planets, and dark matter.

As always, the strength of KIPAC comes from our community, including the amazing ideas of our faculty, staff, postdoctoral fellows, and students and from the ways we learn from each other to innovate and develop new directions. The Universe is full of surprises, and KIPAC is well-positioned to be at the forefront of some of the most exciting discoveries in the coming decade. I am thrilled to have the opportunity to work with all of our members, our supporters, and the broader community to learn more about how the Universe works, and to share what we learn with the public. I can't wait to see what we discover together.

— Risa Wechsler, KIPAC Director

Looking to the Future of KIPAC

In late 2018 I passed the KIPAC Director baton into the very capable hands of my colleague, Risa Wechsler.

Risa is eminently suited to shepherding KIPAC through the next few years. She's been a member of KIPAC for 12 of its 15 years, and she has a deep knowledge of the history and mission of the institute, as exemplified by her own brilliant research into the formation of dark matter haloes and the large scale structure of the Universe. Risa's time as co-chair for the Dark Energy Survey's Simulations Working Group, her service as co-spokesperson of the Dark Energy Spectroscopic Instrument, her position on the LSST Scientific Advisory Committee, and all the help she has given me as a Deputy Director of KIPAC (among many, many other achievements) speak to her administrative and people skills. They also speak to another aspect of Risa that's going to be very, very important: She is one of the most energetic, enthusiastic, and motivated people I know.

Risa will need that energy. Halfway through KIPAC's second decade, many of our projects, big and small, are reaching a critical juncture. Designing and planning is being superseded by building and integrating. From the camera for the Large Synoptic Survey Telescope to the detectors for two different major dark matter direct detection experiments, from equipment for a next-generation cosmic microwave background telescope to a cutting-edge atom interferometer—all these different instruments are coming together at essentially the same time.

Plans to put these instruments to work are also being drawn up, and many KIPAC members have vital roles in those ongoing efforts as well.

Fifteen years on, and KIPAC just keeps getting busier. Our interests expand, and the number of projects with KIPAC involvement increases. It's a big Universe, and there's a lot to be done to figure it out.

— Tom Abel, KIPAC Director 2013-2018

KIPAC turned fifteen in the year 2018. Much has happened since Steve Kahn and I accepted the invitation to guide a major expansion of Stanford's program in astronomy, astrophysics, and cosmology. Those fifteen years saw KIPAC grow enormously in many directions—some of them planned, and others a complete and welcome surprise. That growth has only accelerated as we reach, and pass, our sixteenth birthday.

Thanks to the support of Fred Kavli and the Kavli Foundation, all of Stanford (including SLAC), the federal agencies, and the imagination, initiative and industry of KIPAC members, we are making a large mark in computing, instrumentation, observing and theory. I have been really pleased by the engagement of generations of students and postdocs as well as the loyalty and unsuspected talents of our administration. This is the heart and soul of KIPAC.

The next decade, leading up to our quarter century, should be great. The Fermi Gamma Ray Space Telescope should continue to be crucial to the study of the gravitational radiation from neutron star binaries. The Dark Energy Survey followed by the Dark Energy Spectroscopic Instrument and, especially, the Legacy Survey of Space and Time, to which KIPAC members have contributed so much, will tie down our basic description of the universe and make countless unscripted discoveries. We are hunting for the elusive microwave background B-modes and dark matter. We have a burgeoning program studying exoplanets and creating the next generation of instruments to explore other worlds and seek signs of life. And we produce remarkable explanations of all the wonderful discoveries our telescopes deliver.

I am proud of what KIPAC has become and am looking forward to many more exciting breakthroughs.

—Roger Blandford, Founding Director

Celebrating the Gamma-Ray Sky

2018 marked a decade of discovery by the Fermi Gamma-ray Space Telescope. Fermi's two instruments, the Large Area Telescope (LAT) and the Gamma-ray Burst Monitor (GRB), revealed a gamma-ray sky rife with violent, high-energy events as near to us as lightning in Earth's atmosphere and as far away as young blazars more than 12 billion light years distant.

Along the way, Fermi has mapped thousands of gamma-ray sources, from active galactic nuclei at the heart of giant galaxies to pulsars, to supernovae, to our own Sun.

Fermi has also discovered gamma-ray bubbles ballooning out from the center of the Milky Way, tallied the total amount of starlight produced during 90% of the Universe's existence, and helped inaugurate the era of multimessenger astronomy: first by detecting gamma rays from two merging neutron stars also found via gravitational waves, then by discovering the home galaxy of a high-energy neutrino first detected by IceCube.

Although Fermi has been in orbit for only two-thirds of KIPAC's existence, the conception, design, and construction of the telescope was already well underway when KIPAC began sixteen years ago. In fact, the telescope destined to become Fermi had been given the green light by NASA in 2000 and shortly thereafter was named the highest priority for medium-sized space-based missions in the 2001 Decadal Survey, *Astronomy and Astrophysics in the New Millenium*.

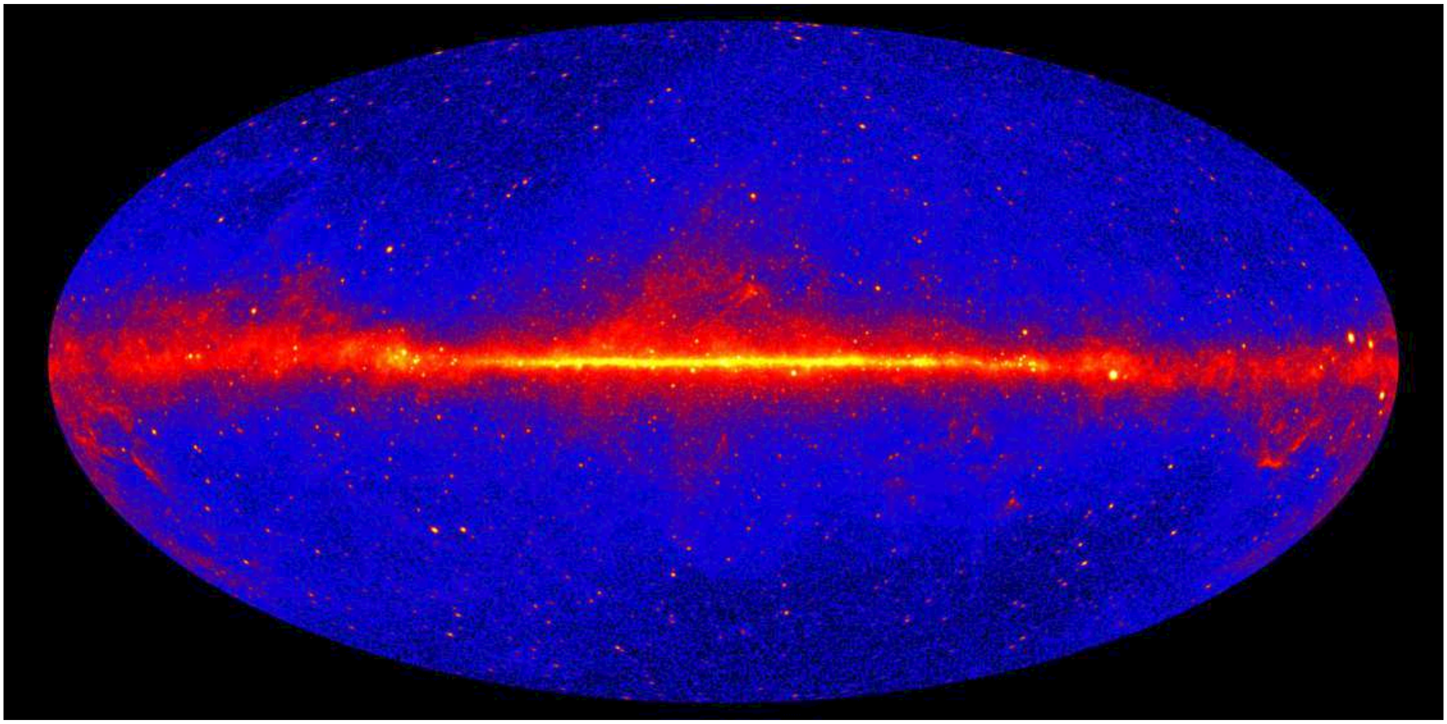
With Stanford professor Peter Michelson as Principal Investigator, a role he still holds, and the Department of Energy's SLAC National Accelerator Laboratory providing the particle detector expertise needed to build the LAT, the synergy between the mission and the institute was inevitable.

Both the chair and vice chair of the Panel on High-Energy Astrophysics from Space, the decadal survey committee that recommended that Fermi go forward, are familiar names to friends of KIPAC. Committee Chair Roger Blandford left CalTech to become the first KIPAC director, while Committee Vice Chair Steve Kahn made the trek west from Columbia University and now directs the construction of the Vera C. Rubin Observatory, the home of the Legacy Survey of Space and Time.

The telescope also attracted young scientists just beginning their careers. "Some of the original postdocs came to KIPAC because of Fermi," Michelson says. "Lots of students got PhDs on Fermi and now there are Fermi and KIPAC collaborators all over the world."

The Fermi telescope's unique fusion of particle phyics and astrophysics means the project's influence—and KIPAC's, with it—is felt worldwide in other ways.

"With Fermi, one of the great things has been the connections forged between a lot of nations and institutions," Michelson says. "Particle physics led the way in that, and NASA led the way in openness of data by making sure it's been available to everyone."



Fermi gamma-ray space telescope's 10-year view of the sky. Photo: Fermi Collaboration.

IN THE SPOTLIGHT

Mattia Di Mauro: Making Fermi Data Accessible

In 2018 former KIPAC postdoc Mattia Di Mauro joined the Fermi team at the Astroparticle Physics Laboratory at NASA's Goddard Space Flight Center. Half of Di Mauro's time is spent analyzing Fermi data, where he's an expert at tracking down the origins of the diffuse gamma ray background that fills the spaces between the stars. The other half of his time, Di Mauro carries on a project that started with a former KIPAC postdoc, Matthew Wood: support for Fermipy, an open-source software "wrapper" that provides an easier-to-use interface for the Fermi data analysis tools provided by NASA.

One of the legacies of the Fermi Gamma-ray Space Telescope is its publicly available data. Anyone, including the LAT and GBM collaborations, small research groups, and even undergraduate physics classes, can download and analyze Fermi data. This openness is courtesy of NASA and is an established practice, especially for projects with government support.

However, all the downloaded data in the world is of no use if it can't be analyzed. NASA has also made analysis tools available but, says Di Mauro, the NASA-provided Fermi science tools are somewhat cumbersome. Extracting the necessary data for a particular analysis can be time-consuming and labor intensive.

Finding an easier way to get a peek into Fermi data was Wood's original motivation, but colleagues enthusiastically adopted the new tool. Now Fermipy is a robust wrapper for the Fermi science tools that increases the scope, reach, and ease of use of the official Fermi science tool set. Di Mauro says, "People like me can make more precise and more detailed analyses using Fermipy, while enabling analyses that would otherwise be impossible for less experienced users, like a professor and their students."

Di Mauro credits Wood's clever use of Python, a popular programming language known for its flexibility, to harness the science tools. "For example, determining the angular extension of a source is very repetitious using just the science tools. You have to fit your data to a point-like template with an extension, then find the probability that it's the correct template, then try other point-like templates with other extensions and compare all the probabilities by hand." In contrast, the Fermipy wrapper enables a researcher to determine the angular extent with a single procedure call.

Di Mauro says that before joining KIPAC, "I was struggling to use the science tools. Then Matthew and [staff scientist] Eric Charles introduced me to Fermipy and in one month I had completely switched."

Testing LSST's 3.2 Gigapixel Camera

An engineer checking one of the science rafts comprising LSST Camera's focal plane. Photo: Travis Lange, SLAC

A mountaintop in the Chilean Andes is the remote, windswept target of high-tech components arriving from around the world. Huge mirrors from Tucson, a mount from Spain, Italian trusses for the dome, special equipment to apply optical coatings from Germany. This equipment and more has either arrived or will soon arrive at Cerro Pachón as components of the Simonyi Survey Telescope, which is scheduled to begin a deep, comprehensive survey of the southern sky in 2023 from its vantage point at the Vera C. Rubin Observatory.

Taking shape at SLAC National Accelerator Laboratory is a vital part of the new telescope: a giant CCD camera that will convert light from billions of distant galaxies into data. When complete, the 3.2 gigapixel camera will have the size and heft of a small car; it's already filling up a dedicated cleanroom.

What's happening now in that cleanroom: 21 science "rafts," the name given to the 3x3 arrays of CCD chips backed by their attendant electronics, cabling, heat exchangers, and other infrastructure, are being tested one by one in a cryostat that will keep them at a chilly -100°C, then linked together into the giant camera.

> *"It's good to support an effort like this to answer some of the really important questions of the universe."*

Engineer Scott Newbry has been in charge of designing two crucial pieces of equipment: the Bench for Optical Testing (BOT) stand for testing the performance of the camera as the rafts are integrated into the camera's focal plane, and the Camera Integration Stand, where all the pieces are being put together and tested to make sure they work.

First the BOT got a workout. KIPAC researchers including Newbry and Yousuke Utsumi tested the performance of the rafts and how they fit into the camera cryostat. Then the cryostat went through rigorous testing, and now the rafts are being installed in the cryostat. And tested. And tested again.

"Testing is a really important part of the process," Newbry says. "There's a lot of work to be done at the end of the day to make sure it all goes smoothly."

After the BOT was completed, Newbry oversaw the construction of the Integration Stand, which serves as a surrogate for the telescope itself. In addition to securely supporting all 5.5 by 9.8 feet and 6200 pounds of camera, "The stand needs to make the camera do everything it will do when it's on the telescope," Newbry says. The stand will accompany the camera to Chile so the camera can be tested again at the summit before being installed on the telescope.

All of this testing sounds rather dry, but Newbry disagrees. "It's extremely fun to work on custom equipment. The scale of this project and the global collaboration is much bigger than anything I'm used to—not just objects, but subsystems that have to work together with parts we get from all over the world."

Newbry says he considers the work very satisfying in another sense: "It's good to support an effort like this to answer some of the really important questions of the universe."

Not all of the challenges facing the LSST team are mechanical.

One of the biggest challenges facing researchers who will use data from the Legacy Survey of Space and Time (LSST) is that, as the telescope scans the sky from its perch on a mountain top in the Chilean Andes, it will see a crowded Universe. A number of objects in LSST images will appear to overlap to some extent—galaxies with galaxies, stars with stars, galaxies with stars—creating uncertainties in shapes and redshifts. This is called "blending," and is due to the unprecedented depth of the LSST survey coupled with the blurring of the resultant images due to the Earth's atmosphere. In other words, the more than 50 petabytes of raw image data accumulated by LSST during its 10-year period will show billions of objects reaching back billions of years in the lifetime of the Universe, all crammed into almost 20,000 square degrees of sky, their image further muddled by atmospheric turbulence.

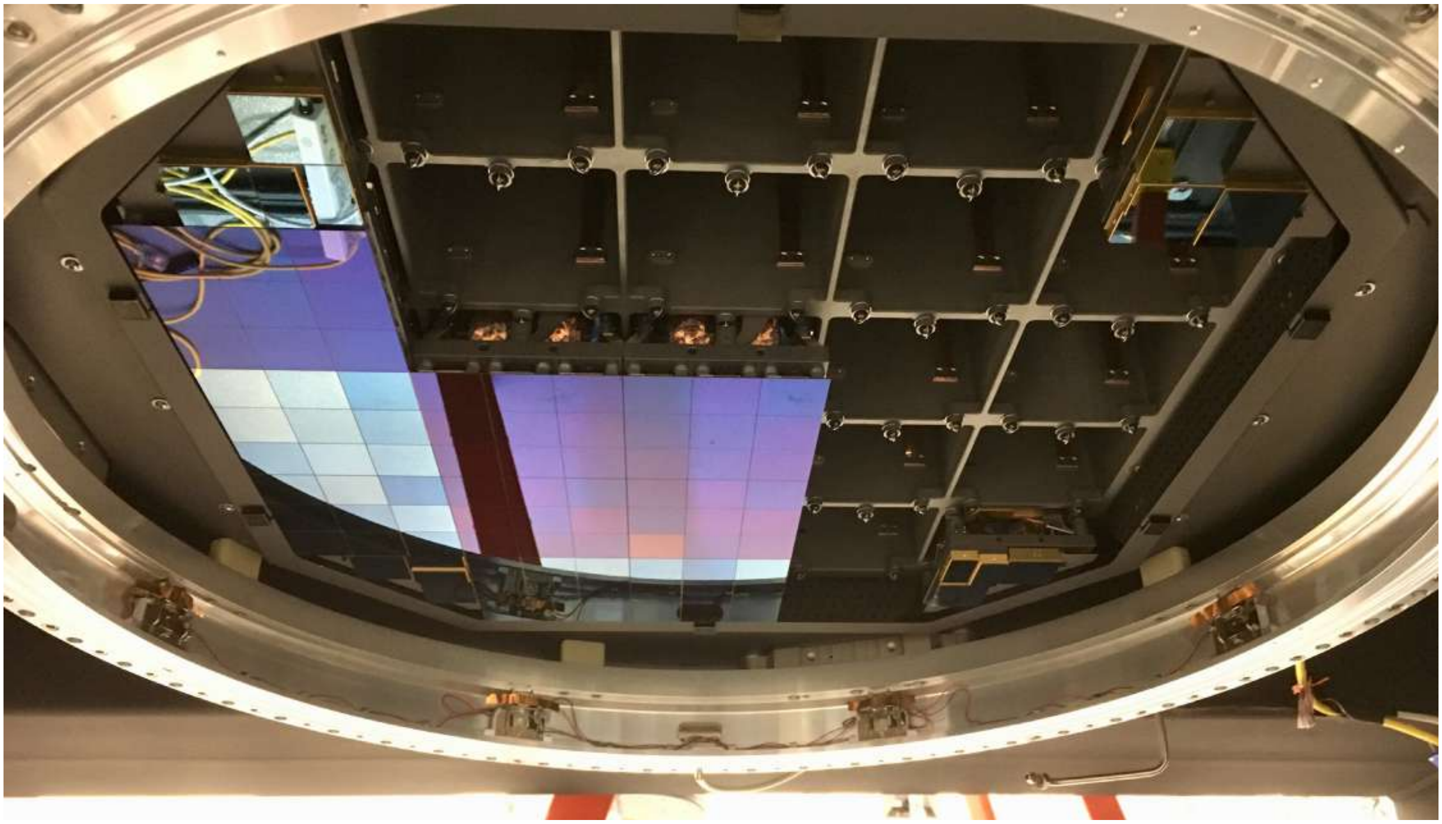
> *"It's extremely fun to work on custom equipment. The scale of this project and the global collaboration is much bigger than anything I'm used to..."*

"When images of objects overlap each other, the techniques we use to measure the properties of single objects, such as their shape or amount of flux, don't work to the accuracy we need with a survey like LSST," says KIPAC professor Patricia Burchat, co-convener of a Blending Task Force for the LSST Dark Energy Science Collaboration.

One way KIPAC researchers are tackling this challenge is with machine learning that trains computers to recognize patterns—in this case, what overlapping galaxies look like.

Machine-learning algorithms have an important advantage over humans, as well as other object-recognition algorithms: machine-learning algorithms can deal with many more color bands than the standard red-green-blue of cameras, and are thus better equipped to analyze images from the LSST camera, which will see light in six different bands.

The most recent manifestations of machine learning have opened up new possibilities in many fields, including image recognition, and KIPAC scientists are embracing it as a powerful tool for many applications in LSST and beyond.



The LSST Camera under construction at SLAC. Photo: Travis Lange, SLAC

Exploring an Exuberance of Exoplanets

The exoplanet group at KIPAC is perhaps best known for their work with the Gemini Planet Imager (GPI); KIPAC faculty member Bruce Macintosh led the construction of GPI before he came to Stanford and now leads the group. He's Principal Investigator of the instrument, which is capable of taking actual images of young, hot, Jupiter-like exoplanets.

The GPI survey is proceeding smoothly; the collaboration finished with initial observations of 600 target stars early in 2019, hoping to capture a few more pictures of exoplanets among them. Then they scheduled time on the Gemini South Telescope, host of GPI and LSST's close neighbor, for any necessary follow-up observations. After that the plan is to remove the instrument from the telescope in preparation for maintenance and upgrades. In the meantime, data from about half of those 600 stars have been analyzed.

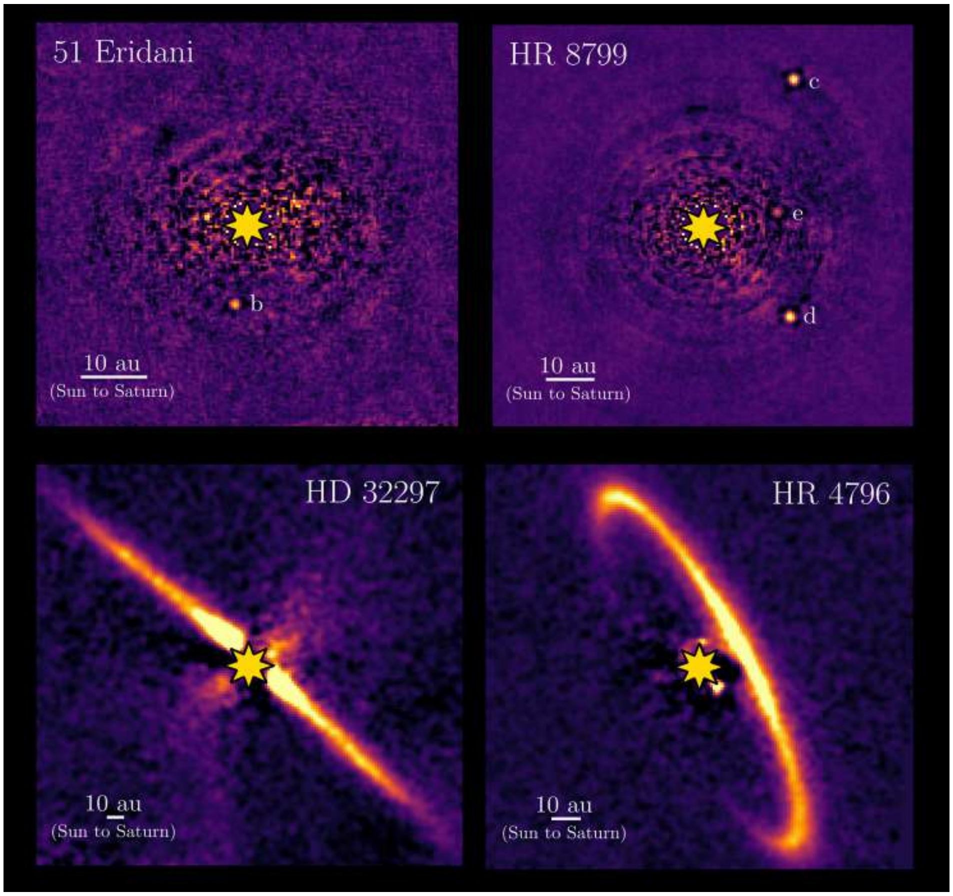
Some interesting trends are already emerging. For example, giant planets (from one to 13 times the mass of Jupiter) at orbits larger than Saturn's are more likely to appear around stars 1.5 times the mass of the sun or greater. But brown dwarf companions don't appear to follow the same rules, suggesting brown dwarfs are truly failed stars that formed by a different process and are not just hyper-planets.

The point of these investigations is to figure out how planets form, how their orbits change with time, and how their properties are influenced by the properties of their host star, as researchers continue to adjust their models to account for planetary systems that look nothing like our own.

Such an endeavor requires a lot of data. GPI is very different from the famous planet-hunting Kepler satellite, and the type of data GPI collects is still in short supply. Former KIPAC graduate student Jean-Baptiste Ruffio has developed data processing methods capable of wringing even more information from GPI observations, as well as a more general algorithm that could help improve any attempt at direct detection.

One of the systems visited by GPI, called HR 8799, is very familiar to Macintosh—he helped discover it eleven years ago. The HR 8799 system has four super-Jupiters, and ten years' worth of data is invaluable when determining their orbits. The team has used the data to set limits on the masses of the planets, based on how much they perturb each other's orbits gravitationally. "We understand gravity on these scales pretty well, and that lets us test theoretical models of how giant planets cool with time," says KIPAC research associate Eric Nielsen.

In 2022 the GPI instrument will move to its new home at Gemini North in Hawaii, where it will get back to work collecting data on exoplanets and helping researchers discover how they formed.



GPI imaging of two exoplanets and two circumstellar disks. Photo: GPI Collaboration.

IN THE SPOTLIGHT

Lea Hirsch: A different perspective on exoplanents

Kavli Fellow Lea Hirsch brings a different perspective to the crew of KIPAC exoplanet hunters. Instead of direct imaging, Hirsch is an expert at finding planets using a technique called radial velocity, or RV. RV, one of the oldest and most successful methods of detecting exoplanets, works by detecting the motion of a star as it orbits around the center of mass shared by it and any planets circling it; this motion, often called a "wobble," is revealed by Doppler shifts in the spectral lines of the star's light—toward redder (longer) wavelengths as a star moves away, and toward bluer (shorter) wavelengths as the star approaches.

Hirsch, who arrived at KIPAC in September 2018 for her first postdoctoral fellowship, worked with a core group of Bay Area planet hunters at the University of California Berkeley in pursuit of her doctorate. Now on the other side of San Francisco Bay, Hirsch says, "I think there's a complementarity between radial velocities and direct imaging that's going to be more and more important." RV can detect planets that are smaller, cooler, and closer in than what GPI sees, and also planets that are far enough out from their stars to make transits infrequent or at enough of an angle from our line of sight that transits simply don't occur.

RV measurements can also deliver on that raw material of researchers everywhere: data. Researchers been tracking the radial velocities of some stars for three decades. "So at this point we are capable of detecting planets with orbits larger than Saturn's, as long as they're sufficiently massive."

A goal of radial velocity observations is to detect planets farther out from their host stars, even as direct imagers try to identify planets closer to their star's glare, in the hopes that the two techniques—RV and direct imaging—can meet in the middle. Hirsch was involved in one such attempt: studying the star Epsilon Eridani. It's about three parsecs (nearly 10 light-years) away, and a giant planet with an orbital period of about seven years has already been detected using radial velocity measurements. Hirsch's collaborator Dimitri Mawet at Caltech led an effort to image the planet using the Keck Telescope in Hawaii, as the star might barely be young enough that the planet could still be detected. Five hours spent peering at Epsilon Eridani with the powerful scope could not detect the planet; based on this attempt and a few other clues Hirsch puts the mass of the recalcitrant planet at about 1.2 Jupiters' worth.

Hirsch says she's been hooked on planet hunting for almost as long as she's been hooked on astronomy, which happened during her undergraduate studies at Cornell. While studying astronomy, she got the chance to observe her first exoplanet.

"I could detect an exoplanet from the little student observatory at Cornell," she says. "That's when I decided to make exoplanets my career."

Weaving a Trap For Dark Matter

Xenon purification system for the LZ experiment at SLAC. Photo: Jacqueline Orrell, SLAC

There's a reason invisibility is a very popular superpower. Even if you're not a superhero or villain, just think what being invisible could do for you. Think of the chores avoided, the pranks pulled, the knocked-over flower vases blamed on the cat. In fact, that's the only way you could be detected—if you accidentally made a noise or bumped into something. If you were careful, you could glide effortlessly through life, with no one the wiser.

The situation with dark matter is similar. Dark matter is the mysterious stuff that makes up a quarter of the matter/energy budget of the Universe. It doesn't reflect light or glow when it gets hot, and magnets and electrical charges don't interact with it. Its invisibility superpower means scientists still have no real idea what it is. Dark matter does get tugged by gravity, but on human scales gravity is too weak to help in the hunt to directly detect dark matter particles. But, like the Invisible Man bumping into people on the street, invisible particles can bump into regular atoms. Researchers need to create the optimal situation for the particles to bump into something humans can see.

That's why KIPAC researchers in the LUX-ZEPLIN (LZ) collaboration, led by KIPAC professors Dan Akerib and Tom Shutt, have been busy purifying ten tons of liquid xenon and weaving mesh grids out of stainless steel wires about the width of a human hair. The xenon is for dark matter particles to bump into; the grids will ensure that the researchers can literally see the result.

Graduate student Ryan Linehan and postdoctoral researcher Rachel Mannino explain how the apparatus, called a time-projection chamber (TPC), currently installed about a mile underground in a former goldmine in South Dakota, will work. A leading candidate for dark matter is weakly interacting massive particles, or WIMPs, Mannino explains. The hope is that some of these WIMPs, if they exist, will bump into the xenon atoms filling the TPC. "Xenon atoms are well-matched to theoretical WIMP particles in mass to see the most out of possible collisions," she says.

What they hope to see are the visible results of electrons being popped out of xenon atoms when they're struck by WIMPs, and that's where the grids come in, says Linehan. Following an initial flash from the collision itself, an electric field across the TPC caused by voltage differences between the grids captures the errant electrons and pulls them into a volume of xenon gas at the top of the TPC, where the electrons flash again as they give up the extra energy. Light-collecting photomultiplier tubes in the gas detect the flashes; the combination of the two pinpoints the location of a collision and helps determine whether it was caused by terrestrial activity or cosmic rays, or could actually be the signal of a WIMP barging through.

There's more than one way to detect the invisible, though, and KIPAC researchers are hedging their bets when searching for answers about dark matter.

On May 7, 2018, SLAC National Accelerator Laboratory announced that the Department of Energy had approved funds for construction of the Super Cryogenic Dark Matter Search SNOLAB (SuperCDMS SNOLAB), for which SLAC serves as the lead DOE laboratory. Several KIPAC members have long histories with the project and for them—and the collaboration as a whole—the approval came as a welcome milestone in the continuing evolution of CDMS. But as an experiment moves beyond design and prototyping to construction and commissioning, a new set of challenges arises, and SuperCDMS SNOLAB is no exception.

Like LZ, the experiment is looking for dark matter particles, but of a lower mass than what the LZ detector can find. SuperCDMS SNOLAB uses semiconducting disks of silicon and germanium crystals cryogenically cooled to about one one-hundredth of a degree above absolute zero. Any dark matter particle that collides with an atom in such a cold detector can set the semiconductor's crystal lattice vibrating, like a goblet tapped with a spoon. Scientists can measure those vibrations as temperature changes using transition-edge sensors, pioneered by KIPAC professor Kent Irwin, which are balanced on the edge of superconductivity until a tiny influx of heat tips them into a resistive state. Dark matter particles can also pop electrons out of their atomic orbits, and the resultant electron-hole pairs can be detected as well, using a sensor called a HEMT, or high electron mobility transistor.

Constructing and installing 24 crystal detectors into four towers, along with attendant shielding, refrigeration, electronics, and other needed infrastructure, in SNOLAB—a subterranean laboratory more than a mile deep in an Ontario nickel mine—is a challenge researchers will be facing in the near future.

Some KIPAC members with leading roles are Richard Partridge, KIPAC's SuperCDMS-SNOLAB Principal Investigator, Paul Brink, who oversees detector fabrication, Project Director David MacFarlane, Project Manager Ken Fouts, and Operations Manager Rob Cameron.

IN THE SPOTLIGHT

Rachel Mannino

Rachel Mannino, a visiting postdoc at KIPAC, is already an old hand at liquid xenon dark matter detection. During graduate school at Texas A&M, she worked on the grids for LUX, LZ's precursor. She came straight to SLAC National Accelerator Laboratory in May of 2017 to help build and test the equipment for LZ, a project that would tax even the biggest universities. "The scale of LZ is so big that it's really good to be able to draw on the resources of national labs for the hardware projects," Mannino says.

For LZ, Mannino and her colleagues have developed a process for cleaning the grids that doesn't involve several hours of manual labor, and they were shipped on time to SURF (the Sanford Underground Research Facility) in South Dakota, where LZ being installed about a mile below ground.

Even given the occasional surprise, Mannino says, "I like building detectors. It puts me personally on the frontiers of science." Mannino understands that if the WIMP model LZ is being built to test is incorrect, the detector she's worked so hard on may not be the one to find dark matter, but it doesn't faze her. "It's good to come at this problem of what dark matter is from many different angles. We don't want to miss it," she says. And finding out where dark matter isn't is important, too.

"The more parameter space where we say, 'Dark matter isn't here'," she adds, "The more we can focus our searches. Ultimately we all want to find dark matter even if it isn't our own experiment that finds it."

Revealing the Dark Universe with DES Data

The Dark Energy Survey (DES) has been on a roll: in 2017 and 2018 the collaboration released a series of papers based on data from the Dark Energy Survey Camera (DECam), which has been peering at 5000 square degrees—about one-eighth—of the sky since 2012. DECam collected data on hundreds of millions of galaxies from its mountain-top perch in Chile, and the depth and quality of that data have enabled researchers to contribute to a variety of discoveries: constraints on cosmological parameters, new gravitational lensing results, discovery of tens of dwarf satellite galaxies around the Milky Way, and even the hunt for the hypothesized Planet 9.

Several KIPAC researchers, past and present, have been central to calibrating DES imaging data, running massive computer simulations of the Universe to compare to and help interpret DES data, and to several aspects of the analysis and processing of DES data. The scientific focus at KIPAC includes weak and strong gravitational lensing, clusters of galaxies, galaxy evolution, and substructure within the Milky Way.

Weak gravitational lensing is a particular DES triumph. In contrast to strong lensing, in which the intense gravity of a massive foreground object such as an entire galaxy cluster warps the light from objects behind it enough to

> *"Knowing the actual amount of matter in the Universe and how it is distributed is vital to determining the strength of dark energy, the force that is expanding the Universe at an ever-increasing rate."*

The Blanco Telescope on Cerro Tololo, home of the Dark Energy Camera. Photo: Daniel Gruen reveal them to us, weak lensing is an extremely subtle and difficult-to-detect lensing effect caused by the relatively weaker gravitational fields of less dense foreground matter distributions.

Weak lensing can reveal broad and diffuse foreground collections of dark matter, enabling more precise mapping of that elusive stuff and tighter constraints on the amount of matter our Universe contains. Knowing the actual amount of matter in the Universe and how it is distributed is vital to determining the strength of dark energy, the force that is expanding the Universe at an ever-increasing rate.

A cornerstone of weak lensing analysis is an accurate measurement of the warped shapes of millions of faint galaxies, and DECam served up exquisite images and precise data on the size, distance, and brightness of about 200,000,000 of them. In addition to providing fodder for weak lensing studies, a census of galaxies can be compared to numbers and sizes of galaxies required by different theoretical models for the evolution of the Universe.

The DES results have been combined with and compared to results from other studies, such as the Planck satellite's analysis of the cosmic microwave background, and the results suggest that over the course of the Universe's lifetime, the strength of dark energy has not changed. All in all, DES results support the Lambda-Cold Dark Matter model, the standard model of cosmology which is based on our current understanding of the behavior of cold dark matter and dark energy. These results were the most precise tests at the time they were published. In the coming years, DES researchers at KIPAC and around the world are working with three times as much data to subject these models to even more sensitive tests.

IN THE SPOTLIGHT

Elisabeth Krause

KIPAC alum Elisabeth Krause is now an assistant professor of both astronomy and physics at the University of Arizona in Tucson, but from 2014 to 2017 she was a Kavli Fellow at KIPAC, where she worked on creating a software pipeline for DES that would provide cosmological interpretations for weak lensing and galaxy clustering measurements.

During her tenure at KIPAC, Krause also took leadership roles in DES as co-coordinator of Theory and Combined Probes Working Group; she is now Co-Chair of the DES Science Committee, which oversees the full scope of science in the collaboration.

"While I was a member at KIPAC I really appreciated the friendly atmosphere and how easy it was to talk to experts on all different aspects of DES and LSST. This really helps everyone to do their best science," Krause says.

Krause's work recieved signficant recognition last year; she received the 2019 IUPAP Astrophysics Young Scientist Award and the 2020 American Physical Society Maria Goeppert Mayer Award.

Making Waves With Atoms

In 2015, in a historic first, the Laser Interferometer Gravitational Wave Observatory (LIGO) used light waves to detect gravitational waves generated by colliding black holes. Now KIPAC scientists are working on a way to use matter waves to do the same thing.

LIGO works by splitting a single beam of light in two and sending the new beams along two perpendicular paths. When they reach the ends of these paths, mirrors bounce them back to where they were split. The beams are recombined in such a way that they will destructively interfere; in other words, the light waves will cancel out—but only if neither path has changed in length. If, say, a gravitational wave passed by and stretched one path while shrinking the other, the light waves no longer line up so neatly.

The Mid-band Atomic Gravitational Wave Interferometric Sensor (MAGIS), under development at Stanford University, also uses lasers. But instead of recombining a single split beam, MAGIS sends pulses from two identical lasers through two clouds of strontium atoms that have been cooled to less than a degree above absolute zero.

The strontium atoms serve as atomic clocks to time the passage of the laser pulses between them. This is done by tuning the laser pulses so they "delocalize" the atoms' wave functions, essentially resulting in the atoms being in two places at once. The matter waves recombine with the same sort of interference patterns as LIGO's split laser beam, and comparing the patterns of the strontium clouds reveals any change in path length caused by a passing gravitational wave. Two lasers and two clouds of atoms help reduce laser noise.

The sensitivity of an instrument like MAGIS makes it a good companion to LIGO in the search for gravitational waves. MAGIS will be sensitive to lower frequencies than LIGO (from about 30 mHz to 10 Hz, as opposed to LIGO's 40 Hz to the kHz range) which translates into an ability to detect gravitational waves from less massive objects—for example, colliding white dwarf stars or smaller neutron-star pairs. They'll also spot more massive objects like the black hole pairs that LIGO sees before they spiral in toward each other close enough to become visible to LIGO, thus enabling researchers to learn even more about the process of black hole mergers.

No matter the final fate of MAGIS, its development has already led to technological advances, including the coldest temperature achieved for a cloud of atoms (50-trillionths of a degree K), the widest separation between matter wave packets (54 cm) and the longest amount of time the packets were split (two seconds).

IN THE SPOTLIGHT

Jason Hogan and Peter Graham

Professors Jason Hogan and Peter Graham make a pretty good team. Hogan, an experimentalist, and Graham, a theorist, met in 2006 when both were graduate students at Stanford. Hogan began working on atom interferometry with Mark Kasevich, who continues to use the technique to explore Einstein's Equivalence Principle (EP), while Graham became involved through Kasevich's collaborator (and Graham's advisor) Savas Dimopolous. According to Hogan, EP was the focus during their time as graduate students, but during Graham's many hours hanging out in Hogan's lab, the discussions didn't stop there. "We were already thinking about gravitational waves. That's been a really exciting goal from the start," Hogan says.

To achieve that goal, Hogan, Graham, and their collaborators had to demonstrate that a technology already in use to study some of the most fundamental questions about our universe could handle one more task. "The hardest part is to show atom interferometry can work as a gravitational wave detector," Hogan explains. "We've had to keep improving the EP version of the experiment to make it work for gravitational waves." The group is currently implementing their improvements in a dedicated 10-meter-tall tower.

If there's one thing astrophysicists and cosmologists have learned from as they've turned the entire electromagnetic spectrum into a tool to study the Universe, every new eye they turn outward gives new surprises. As Graham puts it, "We've realized that any time you open a new experimental window you'll find something unexpected."

Summer Research at KIPAC

CAMPARE and Leadership Alliance summer interns. Photo: KIPAC

In other words, a civilization on a planet circling Proxima Centauri could signal us—or we could signal it—using a laser available to the general public.

CAMPARE and Leadership Alliance

The Stanford University Physics Department recently partnered with a summer research program for undergraduates called CAMPARE, which provides California State University and California community college students from underserved backgrounds the opportunity to do hands-on scientific research. The department also expanded access to the Leadership Alliance Summer Research Early Identification Program (SR-EIP), which attracts underrepresented students from across the country. KIPAC has embraced both programs, welcoming several talented young students to Stanford and SLAC to gain valuable experience and help further KIPAC research goals.

Student Highlights

Christina Vides, who is currently at Cal-Poly Pomona, helped inaugurate the CAMPARE program at Stanford as a member of the 2017 cohort. She liked it so much she returned through the Leadership Alliance SR-EIP the following year. Both summers Vides worked with KIPAC Professor Bruce Macintosh and the Gemini Planet Imager (GPI) team.

The work Vides did with Macintosh highlights a specialty of KIPAC researchers: finding unique uses for existing instruments. In fact, her work sounds more like the plot of a science fiction novel. "I'm doing SETI [Search for Extraterrestrial Intelligence] work with Bruce," Vides says.

Vides and Macintosh focused on determining whether GPI could see laser signals from nearby planets. For example, "Tau Ceti is the closest sun-like star at 3.65 parsecs—about 12 lightyears—away and we already know it has planets," Vides explains. "GPI could see a signal from a 24-kilowatt laser on a Tau Ceti planet. Proxima Centauri is the star closest to us at about four lightyears away and it also has planets, though it's a red dwarf. GPI could see a signal from a 336-watt laser on one of those planets."

In other words, a civilization on a planet circling Proxima Centauri could signal us—or we could signal it—using a laser available to the general public.

Vides may work on some far-out research, but her own goals are down-to-earth. "Long term, I'd like to work at JPL and teach at Mount San Antonio Community College. I really appreciated the chance I was given. I'd like to pay it forward."

Rene Padilla discovered both CAMPARE and dark matter during his first year at California State University, Stanislaus. "My professor, Wing To, is a member of the LUX [Large Under-ground Xenon] collaboration," Padilla explains.

"I decided to apply after I'd worked with Professor To and learned about LUX and dark matter," Padilla says. "LZ, the experiment I worked on here, is a bigger version of LUX, so the research I did at CSU Stanislaus was a good introduction."

Padilla says he's been hooked on physics since his first class. "Best thing about it—whenever you learn something you realize you know less. Everything expands so quickly. It's fascinating."

Padilla plans to spend the rest of his life learning more and knowing less.

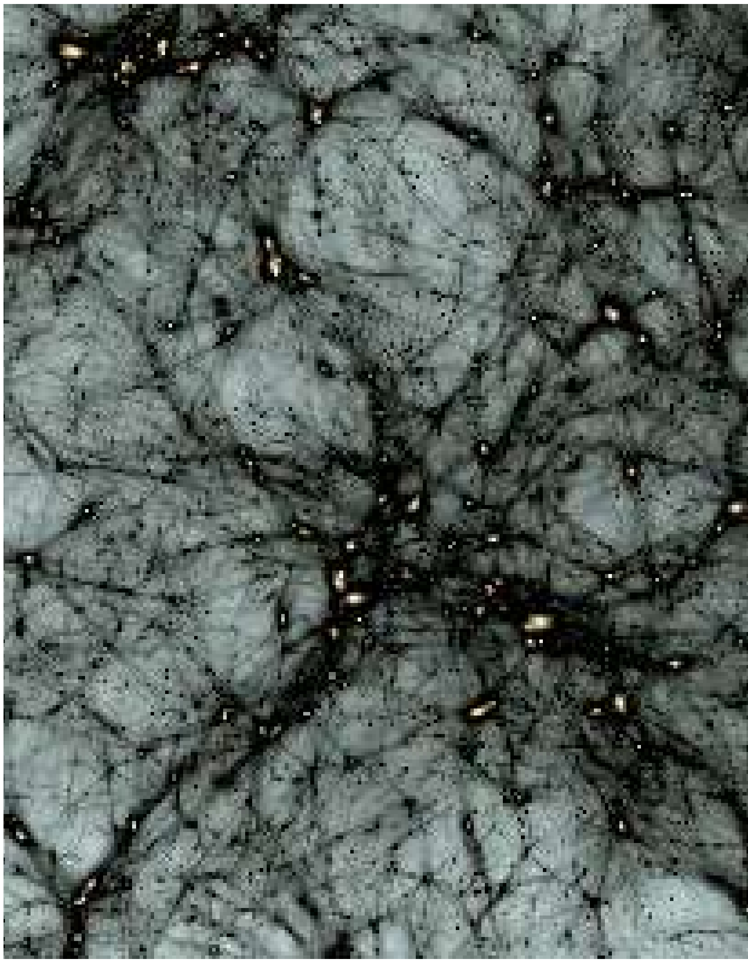
"Grad school is definitely in my future," he says. In fact, he's headed for UC Santa Cruz's graduate program in physics. CAMPARE helped him prepare for the application process. "After CAMPARE I knew what I had to do. Especially after the GRE class and the seminars about requirements for grad students. That part of the program was good because it gave us all the information we needed."

Engaging

If there's a way to reach out to the public to share their amazing discoveries, KIPACers will find it. You'll see them at schools, in pubs, on cruise ships, at museums and science centers, in the blogosphere, on social media. They'll talk about, write about, and demonstrate their research to audiences of all sizes and from all age groups.

This year brought a number of exciting collaborations with artists. Director Risa Wechsler collaborated with visual artist Oxossi Ayofemi on Black Matter, a recent installation at the Contemporary Jewish Museum, that "addressed the notion of being, blackness, and space" (Nan Collymore, C& Magazine). The installation showcased KIPAC visualizations of dark matter and explanations of its role in forming cosmic structures.

Visualization of dark matter forming the cosmic web. Visualization: Ralf Kaehler.



KIPAC Public Lectures

KIPAC Public Lectures are a series of talks given by KIPAC members and noted guests, with subjects as broad as the Universe itself and as down-to-earth (literally) as the giant CCD camera KIPAC members are helping build for the Legacy Survey of Space and Time (LSST). The 32-gigapixel camera, the largest CCD camera ever to be built, will ultimately be shipped to the Vera C. Rubin Observatory to Chile, which is being built to carry out the 10-year survey of the entire southern sky.

Recent guest speakers have included Britain's Astronomer Royal, Sir Martin Rees, whose talk spanned "From Mars to the Multiverse." KIPAC has also hosted Princeton Professor Jo Dunkley, author of "Our Universe: An Astronomer's Guide," cosmologist Wendy Freedman of the University of Chicago, who spoke of the many surprises such as dark matter and dark energy, that our Universe has sprung on us in just the last few decades, and KIPAC visiting Professor Daniel Holz, who spoke about the discovery of electromagnetic radiation from gravitational waves.

Lectures are accessible to the general public and we welcome audience members of all ages who want to learn about our Universe, from its origin almost 14 billion years ago to phenomena such as black holes and neutron stars to the to the discovery of planets outside our solar system.

Roger Blandford and Sir Martin Rees. Photo: KIPAC.

the Public

Risa Wechsler with visual artist and collaborator Oxossi Ayofemi at the opening of Black Matter. Photo: KIPAC

As an artist-in-residence at Stanford, renowned musician-composer Nitin Sawhney was so inspired by visualizations designed by KIPAC's Ralf Kaehler, based on simualtions by Wechsler and former director Tom Abel, that he composed new scores to two of them. The movies and sound were presented at Bing Auditorium as "Music for the Cosmos: An Exploration of Art and Physics."

KIPAC Open House

Aimed at K-12 students but fun for the whole family, KIPAC Open Houses invite members of the public learn about the Universe via a mix of hands-on exhibits that cover the latest astrophysics and cosmology research or demonstrate general physics phenomena, and short, informal talks that present fundamental concepts in ways both accessible to kids and enlightening for their parents. KIPAC members are on hand to help young scientists-in-training launch water rockets detect cosmic rays, and sculpt personal pulsars from modeling clay and LED lights. Other KIPACers introduce audiences to research topics such as dark matter, dark energy, black holes, exoplanets, and much more. Telescopes manned by knowledgeable volunteers provide an opportunity to appreciate the beauty that has brought everyone together.

Visits From Students

KIPAC regularly welcomes student groups to the SLAC campus for more in-depth discussions of astrophysical and cosmological topics. Students spend quality time with KIPAC scientists, learning about dark matter and dark energy, watching 3D visualizations of the early Universe, and asking enthusiastic questions about our planet, our star, our galaxy, and beyond. Add in pizza for lunch, and students leave KIPAC energized about physics and the cosmos.

KIPAC Student Joe DeRose discusses waves. Photo: KIPAC

Ke Fang Searches for High-Energy Bullets from Mini-Black Hole Jets

A microquasar is an active collapsed star, such as a small black hole or a neutron star, which is accreting the material of a more normal companion star. It has jets or particles that shoot out along its poles and an accretion disk of hot material circling it, and is essentially a smaller cousin of Nature's most violent objects, active galactic nuclei (AGN).

Astrophysical jets have been proposed as promising acceleration sites for cosmic rays, energetic charged particles that reach the Earth from galactic and sometimes intergalactic distances. Supporting this view is the discovery that most of the highest-energy photons, daughter particles from cosmic ray interactions, originate from blazars, which are a type of AGN with jets pointing toward us.

Blazars are extragalactic and usually located at a great distance from us. Therefore, they appear as point sources in the eyes of the current generation of gamma-ray telescopes, which typically have sub-degree- to degree-level angular resolutions. As a result, resolving astrophysical jets in the gamma-ray band to find out where the acceleration of cosmic rays happens has been an impossible task.

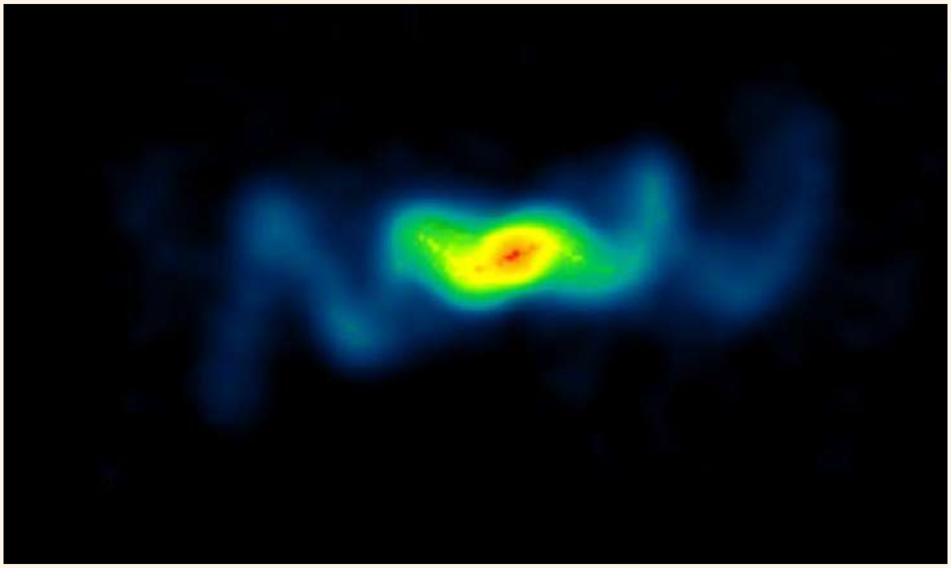
Luckily, with similar disks and jets—albeit thousands of times smaller—galactic microquasars are resolved much more easily. Indeed, the first and one of the most exotic objects in the Milky Way, SS 433 (the first discovered microquasar), has been well-measured from radio to X-ray. Several hot spots have been seen in the hard X-ray map as far back as the 1990s by the RXTE satellite. Spectra of these hotspots suggest that the emission is non-thermal (in other words, not like the emissions from hot glowing gas) and could be synchrotron emissions—radiation given off by extreme-energy particles that are spiraling around magnetic fields. Based on these hard X-ray hotspots, researchers have predicted that several hundred-TeV electrons should exist in the region, and they should emit TeV photons.

After almost thirty years, these forecasted VHE (very high energy) gamma rays were eventually found by the High-Altitude Water Cherenkov Gamma-ray Observatory. My colleagues and I studied the origin of these TeV photons. The observed gamma rays and hard X-rays can be explained by the same population of primary or secondary electrons.

In contrast, gamma rays from pion decay of cosmic-ray protons are insufficient due to the low gas density in the lobes. Currently, I am leading a joint analysis using HAWC and Fermi data, aiming to unveil the maximum energy with which particles can be accelerated by the jets.

The fact that sub-relativistic jets can accelerate particles to such high energies is surprising, considering that the jets of SS 433 are not very powerful, and sub-relativistic outflows are only observed close to the central compact object. Based on the detection of high-energy photons in the microquasar, we conclude that astrophysical jets can be very efficient cosmic accelerators. This leads us to believe that the much larger and more powerful jets in AGN could be capable of accelerating the highest-energy cosmic rays in the Universe—bringing us a step closer to resolving this decades-long mystery in astrophysics.

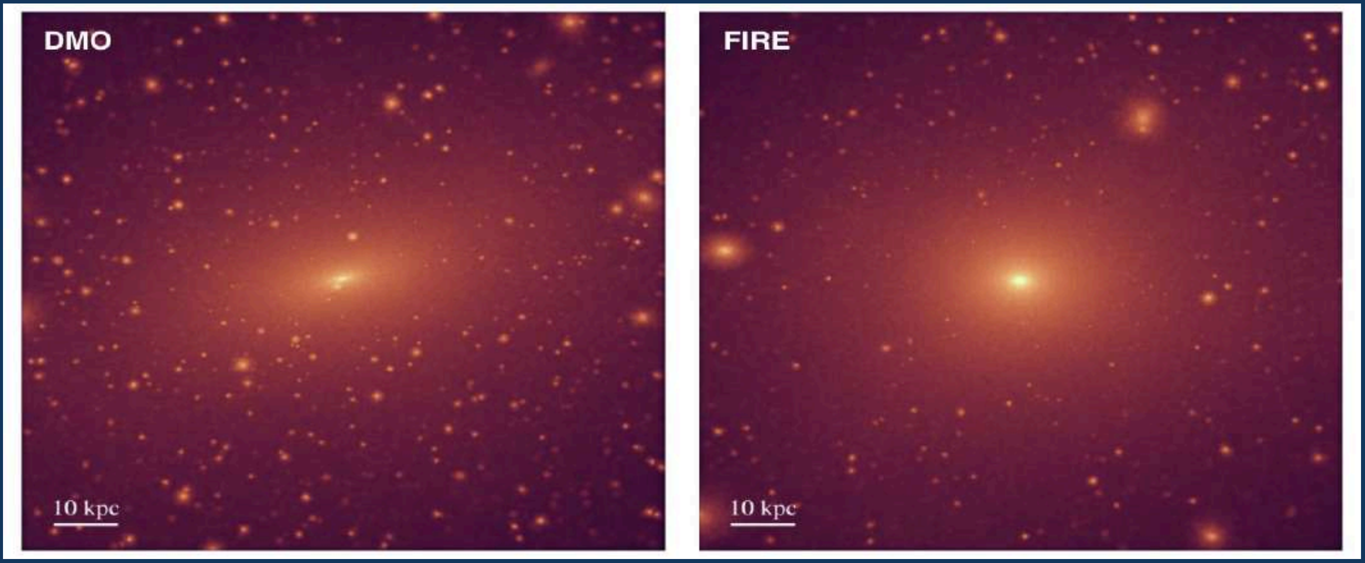
First published: KIPAC blog, April 14, 2019



Left: VLA image of the microquasar SS 433, in the constellation Aquila. This image was made using 10 hours of observing time on the VLA, which was configured to provide the greatest amount of detail in the image. The image shows the corkscrew-like path of subatomic particles that were shot from the core of the microquasar.

Image: NOAO

Ethan Nadler Studies Dark Matter Subhalo Disruption



Near the turn of the century, two seminal papers pointed out a striking discrepancy between the number of dark matter subhalos around Milky Way-like systems in dark-matter-only (DMO) simulations and the number of observed dwarf satellite galaxies around the Milky Way (MW). Historically, this discrepancy (shown graphically in the figure above) led to the notion of the "missing satellites problem" (MSP)—the idea that we observe significantly fewer dwarf satellite galaxies (by a factor of about 10) in the Local Group than predicted by the standard cold dark matter (CDM) cosmological model.

The early papers on the MSP were cautious about interpreting the discrepancy, in large part because subhalo populations in DMO simulations are not perfect indicators of the resulting satellite populations. In particular, while DMO simulations provide a rough estimate of the abundance and properties of satellites in MW-like systems, baryonic physics (the physics of regular matter such as protons, neutrons, electrons, etc.) can dramatically alter these predictions.

For example, cosmic reionization suppresses star formation by limiting gas accretion and slowing cooling rates within subhalos, and these effects can partially or completely inhibit galaxy formation in low-mass systems. Another mechanism that suppresses the abundance of satellite galaxies is the dynamical influence of a central galactic disk. Simulations show that tidal forces exerted on subhalos passing near a disk tend to strip away significant amounts of dark matter.

Perhaps unsurprisingly, modeling subhalo disruption due to an array of complicated baryonic effects is not straightforward. We found that the main factor which determines whether a subhalo will be disrupted is its orbit: subhalos that pass close to the central disk experience strong tidal forces and thus are more prone to disruption.

Rather than explicitly modeling how subhalo disruption depends on a myriad of orbital and internal subhalo features, we use a supervised machine learning model called random forest classification to learn the relationship between subhalo features and disruption likelihood. By training our algorithm on simulations created using the the Feedback In Realistic Environments (FIRE) simulation suite, we taught it to identify subhalos that would be disrupted in FIRE-like hydrodynamic simulations. The trained classifier can then immediately predict surviving subhalo populations from DMO simulations.

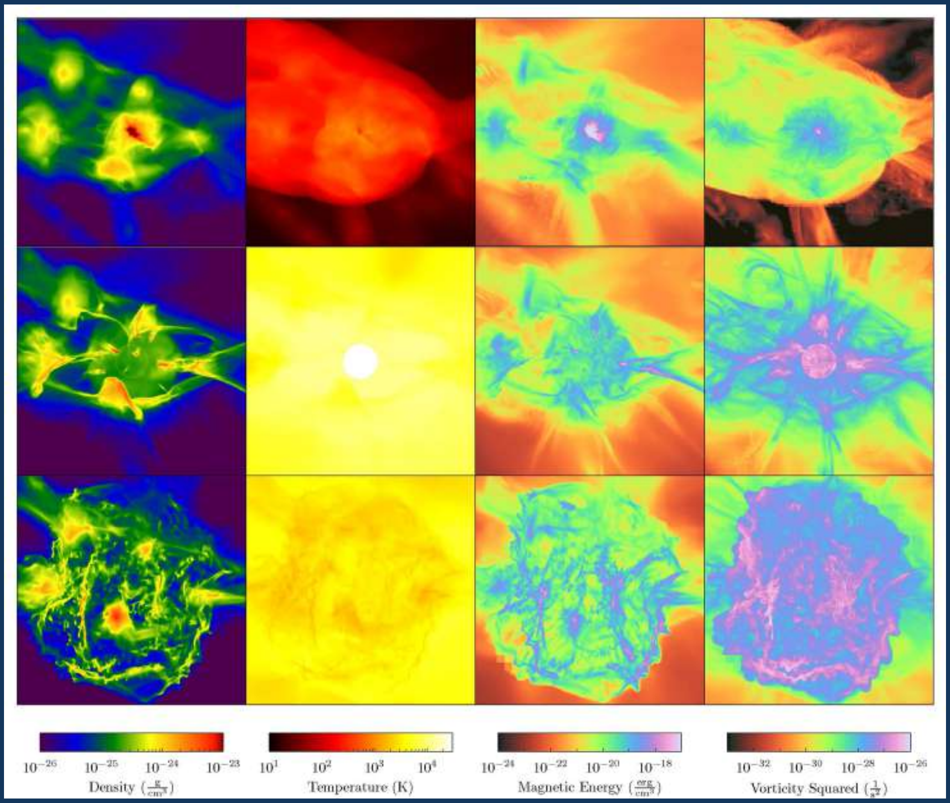
The random forest model gives researchers a flexible, efficient means of accounting for the baryonic physics piece of this puzzle while leveraging the statistical power associated with large numbers of DMO simulations.

First published: KIPAC blog, April 19, 2018

Top: Visualizations of dark matter in a DMO simulation of a Milky Way-mass host halo (left) and in a hydrodynamic simulation of the same system from the FIRE project (right). The galactic disk in the baryonic simulation disrupts nearly all of the subhalos that pass close to the center of the host and reduces the overall number of subhalos by a factor of two.

Image: Garrison-Kimmel et al., 2017

Daegene Koh Looks for Pop III Stars



Left: 2-D projections of the instant before the star is formed (top panels), the instant after the supernova sets off (middle), and the aftermath as the supernova shock expands outwards (bottom). Notice the growing magnetic energy hroughout the process.

Image: Daegene Koh

Often in the world of astronomy and astrophysics, unexpected observations lead to new ideas and understanding. However, there are occasionally some models that are built up more traditionally from theories to observational predictions. This is a story of one such model—that of the very first stars in the universe, called, somewhat counterintuitively, Population III (Pop III) stars. We haven't seen Pop III stars yet because of how long ago they first formed—and then rapidly died.

We know from models of Big Bang nucleosynthesis (which explain how the first atomic nuclei beyond hydrogen were formed and in what percentages), that for the first few hundred million years of its life, the Universe contained only hydrogen, helium, and a scant fraction of lithium. This means the abundance of metals (what astronomers call all elements heavier than helium) found in stars decreases as one looks farther back in time and examines objects that formed earlier in the Universe's life. Since there were virtually no metals in the early Universe, the very first stars must have also been formed without them at all. These are the hard-to-find Pop III stars.

By using the high-resolution computer simulation code Enzo, I studied the growth of magnetic fields through the lifetime of a Pop III star, from birth, through its explosive death, and then during its aftermath.

These simulations show phenomenal growth of magnetic fields that can be associated with two distinct periods. The first period is during the gravitational collapse of the gas prior to the formation of the star. As the gas piles upon itself due to its own gravitational pull, the magnetic field lines also tightly wound up, thus becoming greatly amplified. The second phase occurs shortly after the star explodes in a supernova, as the resulting shockwave expands outwards and begins to cool.

The temperature difference between the cooling shock front and the heated shockwave results in the formation of turbulent motion which begins to twist the magnetic fields and amplify them.

After millions of years, the gas collapses back on itself with the heavier elements formed and released during the supernova mixed in. The previously non-magnetized gas has become highly magnetized in the vicinity of the affected region.

First published: KIPAC blog, March 8, 2018

Krysta Lynne Smith Uses Exoplanet Hunting Satellites to Study Supermassive Black Holes

Although quasars are among the most luminous objects in the Universe, we still do not understand the detailed physics of how the matter they gobble up behaves. This is now changing thanks to new insights and advances from an unexpected source: the highly sensitive timing satellites used to search for planets around other stars by continuously monitoring their brightness over time and searching for periodic dips caused by transiting planets.

The big problem facing the study of accretion disks is that they cannot be directly imaged. Fortunately, there is one ubiquitous property we can exploit to facilitate our studies: optical variability.

The Kepler exoplanet hunting satellite (and its subsequent version, K2) is a timing satellite that searches for exoplanets by staring, unblinking, at a large patch of the sky containing many stars for months to years at a time, waiting for the periodic dip in a star's brightness that occurs when a planet moves in front of it. In order to see this tiny signal, it requires even sampling at very high photometric precision, making it the best optical timing instrument ever built. All of the things that make this satellite ideal for exoplanet hunting also make it ideal for accretion disk physics.

In order to find quasars in the Kepler field, my colleagues and I conducted an X-ray survey of that region using the Swift satellite, since quasars are well known to be bright X-ray emitters. We also did this for several of the K2 fields of view. In order to confirm whether or not the X-ray sources are actually quasars, my colleagues and I traveled to many observatories to collect spectra, from which we could measure the masses of the black holes and their accretion rates. Once we had this information, we could ask Kepler/ K2 to monitor our galaxies.

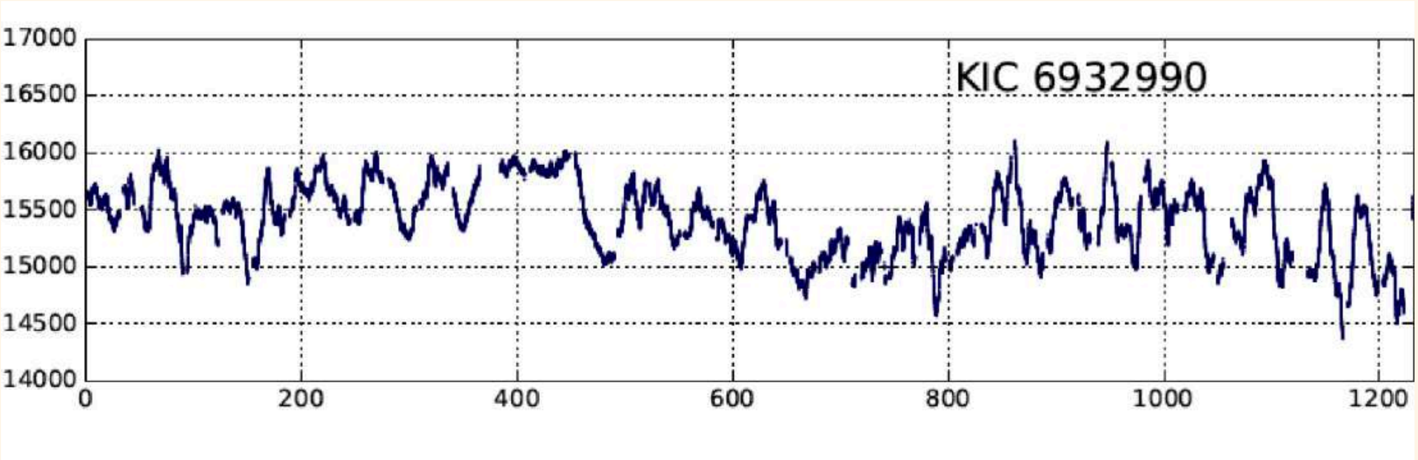
Since the Kepler data were never intended to be used for the type of analysis that we needed, a very large effort was required to reduce and repair the data. Much of my work involved the creation of a software pipeline to facilitate the use of Kepler products for accretion disk physics.

Although this was quite challenging, the results have been worthwhile: the best-sampled, highest-precision optical light curves of quasars ever collected. Such fantastic data have enabled the discovery of characteristic variability timescales in some objects, usually around several days to weeks, that may tell us about important physical processes occurring near the black holes. Comparing these timing results with X-ray variability studies also tells us about the geometry of the gas near the black hole, and how the very hot, energetic X-ray emitting regions are related to the larger optical light-emitting disk.

First published: KIPAC blog, August 3, 2018

Below: Variable light curve for quasar KIC 6932990 based on Kepler data (higher is brighter on the y-axis). Gaps in the curve can be caused by a variety of technical issues, such as cosmic rays or when Kepler needed to point away from its target to download data.

Image: K.L. Smith



Publication Highlights

Search for annual and diurnal rate modulations in the LUX experiment
Akerib, D. S. and the LUX Collaboration

Gas Perturbations in the Cool Cores of Galaxy Clusters: Effective Equation of State, Velocity Power Spectra, and Turbulent Heating
Zhuravleva, Irina; Allen, Steven W.; Mantz, Adam; Werner, Norbert

Multi-Messenger Observations of Black Holes: an Overview
Blandford, Roger

Dark Energy Survey Year 1 Results: A Precise H0 Estimate from DES Y1, BAO, and D/H Data The Dark Energy Survey Collaboration

Low-mass dark matter search with CDMSlite Agnese, R. and the CDMS Collaaboration

First Results from the Dense Extragalactic GBT+ARGUS Survey (DEGAS): A Direct, Quantitative Test of the Role of Gas Density in Star Formation Kepley, Amanda; Bigiel, Frank; Bolatto, Alberto; Church, Sarah; et al

The cosmic axion spin precession experiment (CASPEr): a dark-matter search with nuclear magnetic resonance Garcon, Antoine; Aybas, Deniz; Blanchard, John W.; Centers, Gary; Figueroa, Nataniel L.; Graham, Peter W. et. al

A Spread-Spectrum SQUID Multiplexer Irwin, K. D.; Chaudhuri, S.; Cho, H.; Dawson, C.; Kuenstner, S.; Li, D.; Titus, C. J.; Young, B. A.

Searching for Subsecond Stellar Variability with Wide-field Star Trails and Deep Learning
Thomas, David and Kahn, Steven M.

The Connection Between Galaxies and Their Dark Matter Halos
Wechsler, R. H.; Tinker, J. L.

Constraints on Primordial Gravitational Waves Using Planck, WMAP, and New BICEP2/Keck Observations through the 2015 Season BICEP2 Collaboration; Keck Array Collaboration; Ade, P. A. R.; Ahmed, Z. et al.

A Bayesian Framework for Exoplanet Direct Detection and Non-detection
Ruffio, J.; Mawet, D.; Czekala, I.; Macintosh, B.; De Rosa, R. J.; Ruane, G.; Bottom, M.; Pueyo, L.; Wang, J. J.; Hirsch, L.; and Nielsen, E. L.

A gamma-ray determination of the Universe's star formation history
Abdollahi, S. and the Fermi-LAT Collaboration

Implications of a Loop-top Origin for Microwave, Hard X-Ray, and Low-energy Gamma-Ray Emission from Behind-the-limb Flares Petrosian, Vahé

Linking high-energy cosmic particles by black-hole jets embedded in large-scale structures Fang, Ke and Murase, Kohta

Cross-correlation redshift calibration without spectroscopic calibration samples in DES Science Verification Data Davis, C.; Rozo, E.; Roodman, A.; and the DES Collaboration

On-Orbit Performance of the Helioseismic and Magnetic Imager Instrument onboard the Solar Dynamics Observatory Hoeksema, J. T.; Baldner, C. S.; Bush, R. I.; Schou, J.; Scherrer, P. H.

Dark Energy Survey year 1 results: Cosmological constraints from galaxy clustering and weak lensing
The Dark Energy Survey Collaboration

Unresolved Gamma-Ray Sky through its Angular Power Spectrum Ackermann, M.; Ajello, M.; Baldini, L.; Ballet, J.; Barbiellini, G.; Bastieri, D.; Bellazzini, R.; Bissaldi, E.; Blandford, R. D. et al

WordCloud based on titles of KIPAC's 2018 publications

Liquid xenon scintillation measurements and pulse shape discrimination in the LUX dark matter detector
Akerib, D. S. and the LUX collaboration

SLAC Microresonator Radio Frequency (SMuRF) Electronics for Read Out of Frequency-Division-Multiplexed Cryogenic Sensors Kernasovskiy, S. A.; Kuenstner, S. E.; Karpel, E.; Ahmed, Z.; Van Winkle, D. D.; Smith, S.; Dusatko, J.; Frisch, J. C.; Chaudhuri, S.; Cho, H. M.; and 13 coauthors

The STRong lensing Insights into the Dark Energy Survey (STRIDES) 2016 follow-up campaign - I. Overview and classification of candidates selected by two techniques Treu, T.; Agnello, A.; Baumer, M. A.; Birrer, S.; Buckley-Geer, E. J.; Courbin, F.; Kim, Y. J.; Lin, H.; Marshall, P. J.; et al

EFT of large scale structures in redshift space Lewandowski, Matthew; Senatore, Leonardo; Prada, Francisco; Zhao, Cheng; Chuang, Chia-Hsun

DES Y1 Results: validating cosmological parameter estimation using simulated Dark Energy Surveys MacCrann, N.; DeRose, J.; Wechsler, R. H.; Blazek, J.; Gaztanaga, E.; Crocce, M.; Rykoff, E. S.; Becker, M. R.; Jain, B.; Krause, E.; and the DES Collaboration

Splashback in galaxy clusters as a probe of cosmic expansion and gravity Adhikari, Susmita; Sakstein, Jeremy; Jain, Bhuvnesh; Dalal, Neal; Li, Baojiu

Observational signatures of massive black hole formation in the early Universe Barrow, Kirk S. S.; Aykutalp, Aycin; Wise, John H.

Digging for red nuggets: discovery of hot haloes surrounding massive, compact, relic galaxies Werner, N.; Lakhchaura, K.; Canning, R. E. A.; Gaspari, M.; Simionescu, A.

Reducing noise in cosmological N-body simulations with neutrinos Banerjee, Arka Powell, Devon, Abel, Tom, and Villaescusa-Navarro, Francisco

Multiwavelength cross-correlations and flaring activity in bright blazars Liodakis, I.; Romani, R. W.; Filippenko, A. V.; Kiehlmann, S.; Max-Moerbeck, W.; Readhead, A. C. S.; Zheng, W.

Extending semi-numeric reionization models to the first stars and galaxies Koh, Daegene and Wise, John

Centre-excised X-ray luminosity as an efficient mass proxy for future galaxy cluster surveys Mantz, Adam B.; Allen, Steven W.; Morris, R. Glenn; von der Linden, Anja

chroma: Chromatic effects for LSST weak lensing Meyers, Joshua E. and Burchat, Patricia R.

Properties of the Binary Neutron Star Merger GW170817 Abbott, B. and the LIGO Collaboration

Revealing the structure of black hole coronae, jets and accretion discs through X-ray reverberation Wilkins, Dan

The Polarization Behavior of Relativistic Synchrotron Jets Peirson, A. L. and Romani, Roger W.

Galactic reddening in 3D from stellar photometry - an improved map Green, Gregory M. et al

Discovery of a White Dwarf Companion to HD 159062 Hirsch, Lea, et al

Overview of the DESI Legacy Imaging Surveys Dey, Arjun and the DESI Collaboration

Low-mass dark matter search with CDMSLight Agnese, R. and the CDMS Collaboration

The Gemini Planet Imager Exoplanet Survey; Giant Planet and Brown Dwarf Demographics from 10 to 100 AU Nielsen, Eric, De Rosa, Robert, Macintosh, Bruce and the GPi Collaboration

A Decade of Gama-Ray Bursts Observed by Fermi-LAT: The Second GRB Catalogue Ajello, M and the Fermi-LAT Collaboration

LiteBIRD: A Satellite for the Studies of B-Mode Polarization and Inflation from Cosmic Background Radiation Detectione Hazumi, M. and the LiteBIRD Collaboration

The Kepler Light Curves of AGN: A Detailed Analysis Smith, Krista Lynn et al

Constraints on Dark Matter Microphysics from the Milky Way Satellite Population Nadler, Ethan O.; Gluscevic, Vera; Boddy, Kimberly K.; and Wechsler, Risa H.

KIPAC Members

KIPAC members at a retreat in Fall 2018, Falling Leaf Lake Photo: KIPAC

Faculty
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Diogo Braganca
Saptarshi Chaudhuri
Dongwoo Chung
Joe DeRose
Andrew Eberhardt
Stanislav Fort
Claire-Alice Hebert
Ares Hernandez
Wei Ji
Sowmya Kamath
Dinesh Kandel
Jae Hwan Kang
Nickolas Kokron
Steven Kuenstner
Ryan Linehan
Alex Madurowicz
Jamie McCullough
Sean McLaughlin
Warren Morningstar

Justin Myles
Ethan Nadler
Emil Noordeh
Anna Ogorzalek
Ji Won Park
Abel Lawrence Peirson
Jean-Baptiste Ruffio
Noah Shutty
Adam Snyder
Kelly Stifter
David Thomas
Charles Titus
Chun-Hao To
Sebastian Wagner-Carena
Randy White
Thomas Whitis
Adam Wright
Hung-I "Eric" Yang
To Chin Yu
Cyndia Yu
Alvaro Zamora

Scientific and Technical Staff

Zeeshan Ahmed - CMB
Tomasz Biesiadzinski - LZ
Perry Anthony - LSST
Joanne Bogart - LSST
Tim Bond - LSST
Anders Borgland - LSST
Gordon Bowden - LSST/TID
Boyd Bowdish - LSST
Craig Brackett - LSST
Paul Brink - SuperCDMS
Robert Cameron - SuperCDMS
Concetta Cartaro - SuperCDMS
Eric Charles - Fermi / LSST
James Chiang - LSST
Sherry Cho - Dark Matter / TID
Derek Chow - LSST / Mech. Eng.
Wesley Craddock - LSST
Seth Digel - Fermi / LSST
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John Hodgson - LSST / Mech. Eng.
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Fritz Mueller - LSST
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Marco Oriunno - LSST
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Nathan Pease - LSST Data Mgt
James Pigula - LSST
Troy Porter - Fermi
Yongqiang Qiu - LSST
Andrew Rasmussen - LSST
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Maria Salatino - CMB
Lupe Salgado - LSST / SuperCDMS
Owen Saxton - LSST
Michael Silva - LSST
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Stephen Tether - LSST
Gregg Thayer - LSST
Jana Thayer - LSST
Keith Thompson - CMB
Vaikunth Thukral - LSST
Jeffrey Tice - LSST
Mark Tindall - LSST
Thanhson To - LSST
Massimiliano Turri - LSST
Jaroslav Va'vra - LZ
Giacomo Vianello - HEPL Affiliate
Dennis Wright - SuperCDMS
Ki Won Yoon - CMB

Administrative Staff

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Kelly Carson - KIPAC
Mandeep Gill - KIPAC Outreach
Chris Hall - KIPAC
Donna Hernandez - LSST
Ziba Mahdavi - KIPAC
Regina Matter - LSST
Sara McCardle-Blunk - KIPAC
Carol Reynolds - LSST
Dorrene Ross - HEPL
Heather Shaughnessy - LSST
Christine Sohldahl - SLAC FPD
Martha Siegel - KIPAC
John Skinner - KIPAC
David Stricker - KIPAC
Dee Taumalolo - HEPL
Jeff Wade - KIPAC Computing
Lori Ann White - KIPAC Outreach

KIPAC Leadership 2018-19

Risa Wechsler, Director
Bruce Macintosh, Deputy Director
Ziba Mahdavi, Managing Director
Daniel Akerib, Advisory Committee
Steve Allen, Advisory Committee
Pat Burchat, Advisory Committee

Fellowships

Kavli Fellows
Alexandra Amon
Alden Fan
Lea Hirsch
Arran Phipps
Ed Young

Porat Fellows
Kirk Barrow
Ian Czekala
Gregory Green
Jessica Muir

Panofsky Fellow
Zeeshan Ahmed

Einstein Fellows
Daniel Gruen
Ke Fang
Ashley King
Krista Lynne Smith
Daniel Wilkins

Hubble Fellows
Yashar Hezaveh
Georgiana Ogrean

Humboldt Fellow
Manuel Meyer

Giddings Fellows
Ji Won Park
Ares Hernandez

Chabolla Fellows
Saptarshi Chaudhuri
Sebastian Wagner-Carena

ARCS Fellow
Warren Morningstar

NSF Graduate Fellows
Ethan Nadler
Kelly Stifter
Sebastian Wagner-Carena
Cyndia Yu

Lieberman Fellow
Michael Baumer

2018-19 Porat Fellows Greg Green, Jessie Muir, Kirk Barrow. Credit: KIPAC.

KIPAC PhD Graduates

Saptarshi Chaudhuri completed his PhD working with Kent Irwin. His work focused on developing a new search for QCD axion dark matter. He has accepted a Dicke Fellowship at Princeton.

Joe DeRose completed his PhD working with Risa Wechsler, with a focus on large simulations for cosmological galaxy surveys. He is now a oostdoctoral fellow jointly at UCSC and UC Berkeley.

Wei Ji, who did her PhD on the LUX/LZ dark matter experiments with Dan Akerib and Tom Shutt, is now working for Intuitive, makers of the Da Vinci surgical robot.

Jae Hwan Kang completed his PhD working with Chao-Lin Kuo on the observation and data analysis of the BICEP3 experiment, which is measuring polarization of the cosmic microwave background from the South Pole. Jae Hwan will stay at Stanford as a postdoctoral researcher.

Warren Morningstar completed his PhD working with Roger Blandford and Yashar Hezaveh. He applied modern machine leanring approaches to observations made with the ALMA telescope to study small-scale structure within gravitationally lensed galaxies He has since started a fellowship with Google.

Anna Ogorzalek completed her PhD working with Steve Allen on the use of high spectral resolution X-ray observations to probe the physics of AGN feedback. Next, she will take up a postdoctoral position at Goddard Space Flight Center.

Jean-Baptiste "JB" Ruffio completed his PhD working with Bruce Macintosh on advanced signal processing and Bayseian methods for studying exoplanets with integral field spectroscopy. He is now a Caltech Instrumentation Postdoctoral Fellow with Dimitri Mawet.

Adam Wright completed his PhD working with Steve Allen on the use of weak lensing measurements for galaxy cluster cosmology. He has since accepted a faculty position at the Milwaukee School of Engineering.

2019 KIPAC graduates with their PhD advisors. Credit: Mandeep Gill.

Alumni Highlights

Vanessa Bailey took a staff position at JPL, where she continues her research on exoplanets.

Keith Bechtol and **Kim Palladino** are assistant professors at the University of Wisconsin, Madison, where Bechtol will continue studying dark matter and dark energy in a cosmological context and Palladino will continue with the direct search for dark matter particles using cryogenic liquids.

Peter Behroozi is now an assistant professor at the University of Arizona, where he is continuing to work on modeling galaxy formation.

Jeff Chilcote is now an assistant professor of astrophysics at the University of Notre Dame.

Ian Czekala is now a Hubble Fellow at UC Berkeley.

Chris Davis and **Kyle Story** joined former KIPAC postdocs **Sam Skillman** and **Ryan Keisler** at Descartes Lab, where they work on image processing, machine learning, and climate change mitigation.

Mattia DiMauro joined the Fermi team at the Astroparticle Physics Laboratory at NASA / Goddard.

Kate Follette is an assistant professor at Amherst College in Massachusetts. She will continue working on searches for planets around nearby stars.

Greg Green started a new Postdoctoral Fellowship at the Max Planck Institute for Astrophysics in Heidelberg.

Daniel Gruen has accepted the Panofsky Fellowship at SLAC, so we will be lucky to keep him at KIPAC in this new capacity.

Yashar Hezaveh and **Laurence Perreault Levasseur** left the Center for Computational Astrophysics in New York to start faculty positions at the University of Montreal.

Noah Kaminsky is a Lederman Postdoctoral Fellow at Fermi National Accelerator Laboratory.

Ji-hoon Kim, who was a graduate student at KIPAC and later returned in the final year of his NASA Einstein fellowship, is now a faculty member at Seoul National University.

Ashley King is working for the startup company Carbon Lighthouse as a data scientist.

Elisabeth Krause is now an assistant professor at the University of Arizona, and is continuing her collaborations with KIPAC on DES and LSST. She was recently awarded the APS Maria Goeppert Mayer Award for her contributions to theoretical cosmology and astrophysics.

Pierre-Francois Leget is continuing to work with the LSST Dark Energy Science Collaboration with the group at the Laboratoire de Physique Nucléaire et de Hautes Energies (LPNHE) in Paris.

Manuel Meyer is a Marie Curie Fellowship in Erlangen to work on blazars, B-fields, and axions with the Cherenkov Telescope Array.

Josh Meyers moved to Lawrence Livermore National Laboratory while continuing to work on LSST Data Management.

Hiro Odaka took a position at the RIKEN institute in Tokyo, Japan. He will continue his analysis of Hitomi data, and will be working on modelling of X-ray emission from astrophysical sources.

Devon Powell is a postdoctoral researcher at the Max Planck Institute for Astrophysics.

Krista Lynne Smith has accepted a faculty position at the Southern Methodist University, which she take up following another year at KIPAC.

After two years with the exoplanet group, research associate **Melisa Tallis** has enrolled in a Master's program in Argentina on climate change mitigation.

Samuel Totorica is a postdoctoral researcher at Princeton University.

Ondrej Urban is working for a software startup HAL24K Data Intelligence Labs.

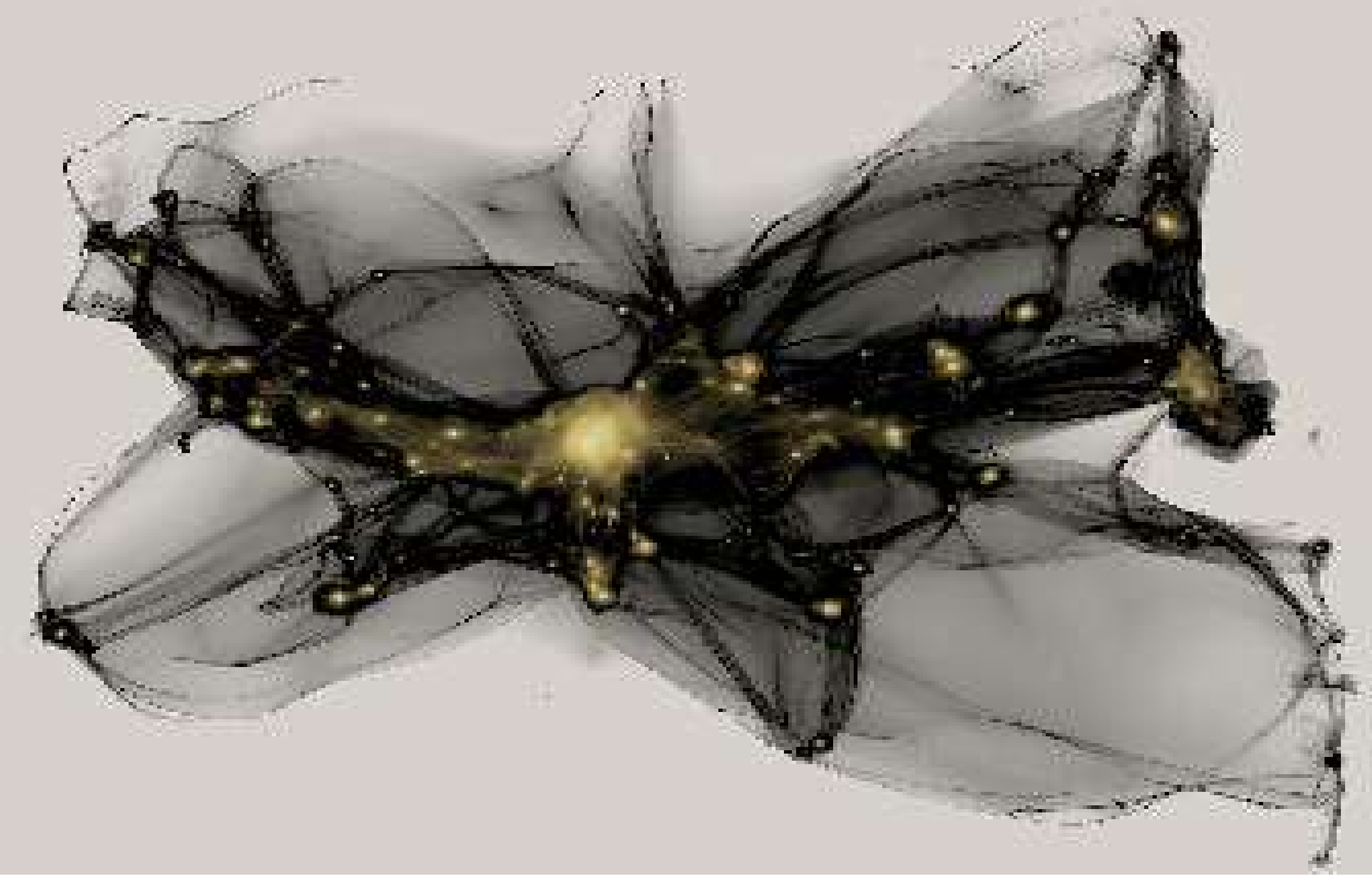
Giacomo Vianello is a senior data scientist at Cape Analytics.

Marco Viero started a new position as data scientist at Wahoo Fitness.

Radek Wojtak has returned to the Dark Cosmology Center in Copenhagen, where he still works on numerical cosmology.

Matthew Wood is a data scientist at Orbital Insights.

Irina Zhuravleva is Clare Boothe Luce Assistant Professor, Department of Astronomy and Astrophysics, University of Chicago.



A simulated dark matter halo. Visualization: Ralf Kaehler

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