

KIPAC ANNUAL REPORT 2017

KAVLI INSTITUTE FOR PARTICLE ASTROPHYSICS AND COSMOLOGY

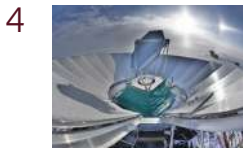
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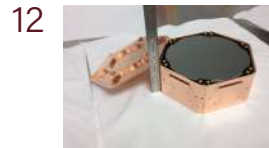
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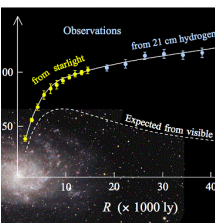


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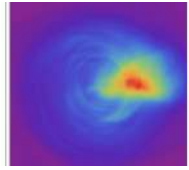
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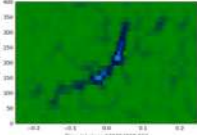
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Pardon our (cosmic) dust



We're in the midst of exciting times here at the Kavli Institute for Particle Astrophysics and Cosmology. We've always managed to stay productive, with contributions big and small to a plethora of projects like the Fermi Gamma-ray Space Telescope, the Dark Energy Survey, the Nuclear Spectroscopic Telescope Array, the Gemini Planet Imager and many, many more—not to mention theory and data analysis, simulations, and research with publicly available data. We have no shortage of scientific topics to keep us occupied.

But we are currently hard at work building a variety of new experimental instruments, and preparing to reap the benefits of some very long-range planning that will keep KIPAC scientists busy studying our universe in almost every wavelength and during almost every major epoch of the evolution of the universe, into the late 2020s and beyond.

Some of the biggest projects include:

The Large Synoptic Survey Telescope (LSST): The survey telescope and facilities are currently under construction in Chile, but the massive CCD camera that will capture photons from the entire southern sky is being assembled and tested at host institution SLAC National Laboratory, a process overseen by KIPAC and KIPAC-affiliated scientists and engineers.

The Super Cryogenic Dark Matter Search – SNOLAB (SuperCDMS-SNOLAB): One of three DOE-supported second-generation (G2) dark matter searches, SuperCDMS-SNOLAB will use detectors of silicon and germanium coupled with state-of-the-art quantum sensors to search for light dark matter. KIPAC scientists are an important part of the collaboration, and the detector wafers and quantum sensors are fabricated at host institution Stanford University.

The LZ dark matter experiment: The second of three DOE-supported G2 dark matter experiments, LZ will use seven tons of the noble gas xenon in its detector. The detector test bed is at SLAC.

In addition to these major experiments, KIPAC scientists are busy at the South Pole with a next-generation CMB experiment (the BICEP Array); studying the very early universe using molecular markers (COMAP); and helping design the next major X-ray telescope (Athena).

Science builds on previous discoveries, and the technology used in scientific experiments builds on the innovations and imaginations of the scientists and engineers involved. KIPAC scientists and engineers are currently developing some ground-breaking tech to help us learn about our universe.

— **Tom Abel**



Building the next generation of physicists

Big experiments are huge investments in time and resources. From defining the science case to designing and building the instruments and writing data analysis software, to actually taking and analyzing data, a major experiment can take years, if not decades, to come to fruition.

But there's one resource—the most important one—that can't be bought or built or simulated or programmed: the people who ask the questions that need answering. Teaching and guiding and inspiring young scientists is KIPAC's primary charge and we take it very seriously.

We start long before budding astrophysicists and cosmologists reach college with our outreach to local elementary, middle grade, and high schools. We love to share what we're doing with everyone in our community, and our open houses include talks and demonstrations suitable for all ages. Parents can share with their children the excitement of learning about black holes and gravity waves, dark matter and dark energy, neutron stars and galaxy clusters—all the fascinating ways physics expresses itself in the way our universe is formed.

Once an interested student reaches college, we can be involved in his or her development more directly. We recently revamped our curriculum to make sure we're teaching the most relevant and up-to-date material. Stanford undergraduates are welcome to get hands-on research experience by working on current experiments. During the summers, we go farther afield, accepting undergraduate students from across the country for research opportunities through a variety of public and private programs, including our two newest: CAMPARE and the Leadership Alliance, both of which give underserved and underrepresented students a chance to participate in cutting-edge research. Summer students work with mentors on current KIPAC research projects and can return to their home institutions knowing they've contributed to the search for answers to some of the most fundamental, challenging problems in science.

Our graduate students are KIPAC's heart: brilliant, enthusiastic, tireless young people who are ready to conquer the world (or at least the find reason why a detector isn't working or some analysis software refuses to cooperate). In the process of learning how to seek the answers to heretofore unanswered questions about the inner workings of our universe, our graduate students learn problem solving skills that stand them in good stead no matter where they go after graduation.

In addition to stepping into their roles as working scientists, our postdoctoral researchers are given the opportunity to mentor younger scientists, preparing them to help keep the cycle of scientific training alive.

Science is often characterized as a towering edifice, with each new generation of scientists adding their own layer of bricks and mortar.

But another way to look at science is as an endless collaboration between the past and the present in preparation for the future. We want all the young scientists whose lives we touch to be prepared to take their places in that future, and make it a future of knowledge and discovery.

— **Patricia Burchat, Greg Madejski, and Risa Weschler**

Preparing for the BICEP Array

The cosmic microwave background (CMB) is a snapshot of the universe at 380,000 years after its birth, when it was a primordial plasma of fundamental particles without stars or galaxies. When combined with other measurements like the Hubble expansion rate, this ancient light, the fading afterglow of the Big Bang, has already told researchers a great deal about the birth and evolution of our universe. We've learned from studying the CMB that we live in a flat universe that's made up of about 5% regular matter, 27% dark matter, and 68% dark energy. The CMB's tiny, one-part-in-100,000 intensity fluctuations represent the lumpiness in the primordial plasma that seeded all the structure we see today.

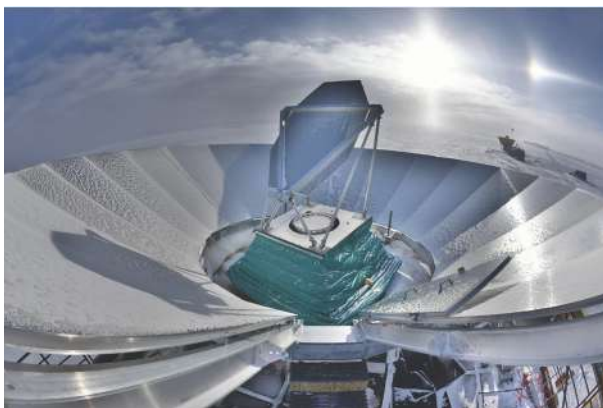
But why stop there? There's more to be learned from the CMB, and several KIPAC scientists are members of the BICEP collaboration, which is intent on deciphering some of the most subtle clues to the birth of our universe held within that ancient light. It's called B-mode polarization, and it's a pattern of wave orientation that can be imprinted on electromagnetic waves by gravity—most notably primordial gravitational waves that are thought to have occurred during inflation, the extreme stretching and reshaping of space itself that cosmologists believe happened in just a tiny fraction of a second after the Big Bang.

Beginning in 2006, the collaboration has used a series of increasingly powerful microwave telescopes located at the South Pole to search for this signal from the beginning of time. The next iteration is the BICEP Array, a collection of four microwave telescopes based on the highly successful BICEP3, built at Stanford under the supervision of BICEP primary investigator and KIPAC professor Chao-Lin Kuo, and then-KIPAC postdoctoral researcher, Zeeshan Ahmed, who now, as a Panofsky Fellow, has his sights set on a slightly more distant target (next page).

But the signal is tiny, and CMB light has to traverse a multitude of different environments before reaching the South Pole. Synchrotron radiation and faintly glowing dust in our galaxy emit their own microwaves, and gravitational lenses can tweak passing light, imprinting their own B-modes. These signals are called foregrounds, and must be separated from the primordial B-modes the BICEP collaboration is searching for.

The telescopes of the BICEP Array will look at five different wavelengths of microwave light, to get a comprehensive view of both the CMB and foreground microwaves, enabling researchers to differentiate between them. A combined total of thirty thousand sensors will collect data in the 30–40 GHz range, 95 GHz, 150 GHz, and 220/270 GHz, providing a balance between clarity and data content (95 GHz is the clearest signal, while the CMB theoretically peaks at 150 GHz), and creating a “Hubble Deep Field” in microwaves of a 400-degree patch of the southern sky.

The telescopes of the BICEP Array will replace Keck Array telescopes (the Keck Array comprises five BICEP2 telescopes), with the first scheduled to be installed for the 2018 South Pole observing season, and by the 2020 season the entire array should be ready to plumb the depths of the universe for signals from the beginning of time.



The mirror for the BICEP3 instrument, upon which the BICEP Array instruments are modeled.

Image courtesy Zeeshan Ahmed.



Credit: Dawn Harmer, SLAC National Accelerator Laboratory.

Zeeshan Ahmed

Many experiments are iterative in nature; researchers use the results to both fine-tune their hypotheses and fine-tune their equipment.

BICEP is no different. Even as plans are being finalized to begin installing the BICEP Array telescopes, the fourth generation of the experiment is taking shape as CMB Stage 4, or CMB-S4.

Panofsky Fellow and KIPAC scientist Zeeshan Ahmed (“Zeesh” for short) has a big role to play in this next experiment. “I’m in charge of the research effort at SLAC to develop a CMB-S4 camera focal plane,” he says, a simple statement that encompasses a considerable amount of cutting edge technology.

The Department of Energy (DOE) has given him a vote of confidence, though, awarding Ahmed an Early Career Research Program grant which “supports the development of individual research programs of outstanding scientists early in their careers and stimulates research careers in the disciplines supported by the DOE Office of Science.”

Ahmed certainly has the right experience and skillset. The BICEP3 instrument, upon which the BICEP Array is based, is very much Ahmed’s baby—he led its design, testing, construction and deployment at the South Pole. His next goal is to expand upon that accomplishment, quite literally, by designing a system that can put hundreds of thousands of sensors on the microwave sky instead of the tens of thousands that the BICEP Array will field. This will enable a survey of about 40 percent of the sky, instead of BICEP’s one percent, but to almost the same depth. Think of it as the LSST survey of CMB experiments, instead of the Hubble Deep Field of CMB experiments.

One of Ahmed’s biggest challenges? Outputting all the data these larger cameras will generate through a limited number of channels without losing any of it using a technique called multiplexing, in which several sensors share a channel.

Ahmed will get a lot of support from his SLAC and Stanford colleagues. “SLAC is an intellectual leader for sensors,” he says. “We’ll have a detector microfabrication facility in the Arrillaga Science Center [currently under construction on the SLAC campus] to mass-produce them. They’re quantum sensors—you could build quantum computers here.”

Instead, the SLAC-Stanford CMB group will build multiwavelength, multiplexing marvels to help us learn about the beginning of our universe.

Hearing the universe's quietest voices

In the vast cosmic chorus, some voices stand out. There are furious, sustained roars from active galactic nuclei, the metronomic blips of pulsars, the sudden shrieks of gamma-ray bursts. These voices tell us thrilling stories about our energetic universe.

But quieter voices have important stories to tell as well, and a small group of KIPAC researchers, led by KIPAC professor Sarah Church, are preparing to listen to a very faint voice indeed: the whisper of a single type of molecule, carbon monoxide, from within the gigantic clouds of gas that fueled an era of prolific star formation about 10 to 11 billion years ago.

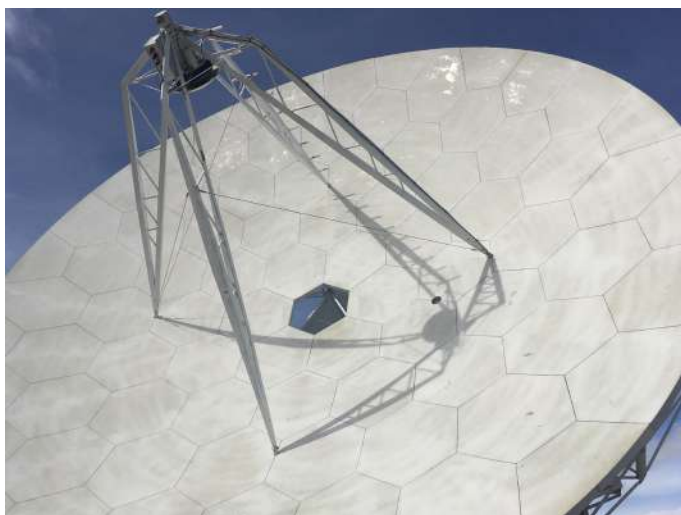
Stars are made of hydrogen, not carbon monoxide (CO), but of the two, CO is a little louder, Church says. "It's difficult to detect hydrogen, so CO makes a very good tracer. It's a good proxy for hydrogen, and there's an empirically derived correlation between them." Tracking the hydrogen at that epoch in cosmic evolution can help researchers build a more complete picture of the early growth of structure in the universe than is possible by trying to map the nascent galaxies alone.

Church and her collaborators will listen to CO by finding its spectral signature using the CO Mapping Array Pathfinder (COMAP), an international collaboration led by Caltech, with collaborators at Stanford, JPL, CITA, University of Oslo, and the University of Manchester. COMAP the instrument is a 19-pixel detector mounted on a 10-meter radio telescope at the Owens Valley Radio Observatory near Bishop, CA. The collaboration has already tested a single pixel, demonstrating that they can isolate the CO signal at 26–30 GHz and 30–34 GHz. This frequency range captures CO emission lines from the peak period of star formation; ultimately, researchers involved in this "intensity mapping" effort, along with complementary projects looking at emissions from other types of molecules, hope to construct a 3D picture of how and where the very first, low-mass galaxies formed.

It's early days in the field of intensity mapping, though. "This is so new that we're figuring out how to do the observations and what we need to worry about," Church says. "If COMAP is successful we'll build a much bigger one," capable of surveying large swaths of sky.

According to Church, success (in other words, detecting and mapping low-mass, early galaxies) can help constrain models of early cosmic evolution. If COMAP doesn't find these gas cloud-cum-galaxies, though, the models, developed using data from high-mass galaxies, will need significant revisions.

Depending on the results of the intensity mapping effort, next steps after COMAP would be looking at even lower frequencies and longer wavelengths, giving researchers a look at the universe when it was less than a billion years old.



One of the Owens Valley radio telescope dishes. The COMAP experiment will be mounted on it or a sibling telescope and used to search for the signals of primordial clouds of carbon monoxide.

Credit: Dongwoo Chung.



Dongwoo Chung tests a pixel prototype.

Dongwoo Chung

KIPAC graduate student Dongwoo Chung is a veteran researcher in the area of low-frequency astrophysics, having worked on cosmic microwave background research at Princeton while an undergraduate. This means he was able to dive right in with COMAP, spending his time investigating other sources of microwave signals, called foregrounds, which can contaminate the data from the carbon monoxide (CO) that's the target of the search. One substance in particular, hydrogen cyanide (HCN), has a spectral signature that can look very much like CO, but in a paper appearing in *The Astrophysical Journal*, Chung shows that HCN emissions should have little effect on COMAP data.

Chung also spent time at the Owens Valley Observatory, testing the COMAP prototype. "I had to characterize reflections in the system," he says. "The microwaves reflect around the receiver, around the dish. I made sure the receiver behaved the same across the entire bandwidth it's designed to detect." More trips to the observatory await, now that the full 19-pixel array is being installed.

According to Chung, radio and microwave astronomy have other unique challenges; instead of streetlights polluting the night sky, cell phones, drones, and self-driving cars impinge on bandwidths under study. "Finding places to do this where there's no radio interference is getting more difficult," he says.

Chung is also looking at prospects for cross-correlating COMAP results with galaxy surveys such as the Cosmic Evolution Survey (COSMOS). "A cross-correlation with COSMOS would be nice to have so we could tell if we're actually seeing something," he says, "and maybe we could learn something from the cross-correlation itself."

Searches for hydrogen gas clouds have been a part of astrophysics for decades, but the emphasis on other types of molecules is a fairly new field and still growing. "I would hate to give up working in astrophysics and cosmology," Chung says, and with his experience in—and contributions to—a whole new area of investigation, chances are good that he shouldn't have to.

A ground-breaking camera for a sky-covering survey

The webcam at the summit of Cerro Pachón in the Chilean Andes shows a striking edifice taking shape: The building that will house the Large Synoptic Survey Telescope (LSST), an 8.4-meter telescope capable of surveying the entire southern sky once every three nights. The LSST project, led by KIPAC faculty member Steve Kahn, will result in millions of gigabytes of data about our universe, data that will drive discoveries about dark matter, dark energy, cosmic birth and evolution, and, closer to home, discoveries about our own Milky Way and solar system.

Not as visible but no less striking is a large clean room at SLAC National Accelerator Laboratory, where the giant CCD camera that will serve as the interface between photons and data will be assembled under the watchful eyes of KIPAC scientists and engineers led by Professor Aaron Roodman.

The 3.2-gigapixel camera, the largest in the world at its completion, will be the size of a small car and hold 21 “science rafts,” 3x3 arrays of CCD sensors with all the attendant electronics needed to read out the data. The CCD arrays of the assembled rafts comprise the focal plane (as opposed to a focal point) where the light from the telescope comes to a focus. The CCDs of the focal plane will be housed in a cryostat at about -100°C to prevent noise caused by “dark current,” or thermal electrons.

Add in the camera lenses, the filter carousel and five camera filters, the shutter—assembling and testing the LSST camera will be a more modest endeavor in a spatial sense but just as painstaking as putting together the telescope itself.

It’s currently early days in the camera assembly process, but KIPAC scientists and engineers are already busy. A unique, complex camera requires one-of-a-kind tools to build it and test it, and the researchers are hard at work preparing their singular toolkit. They’re building a variety of test units and test environments that mimic different aspects of the camera, from a mini-cryostat for a single science raft up to an SUV-sized Bench for Optical Test (BOT). They’ll use the BOT to test flatness and electro-optical properties of the full focal plane once all of the science rafts are installed into the camera’s full-scale cryostat. That installation process itself requires a custom precision stage assembly to lift the science rafts into the cryostat and position them a mere 250 microns apart from each other. In addition, a car-sized camera requires a truck-sized stand to hold and rotate it during final assembly and testing, so the LSST Camera Clean Room is filling up quickly.

The researchers will get a chance to use their test benches very soon. The first science raft has arrived at SLAC and is settled safely in the clean room.



Work is underway in the LSST camera cleanroom, where Stuart Marshall is running a thermal test on a replica of a science raft inside a scaled-down version of the LSST cryostat.

Credit: Andrew Freeberg, SLAC National Accelerator Laboratory.



Margaux Lopez (L) teaches Arduino skills to Edén Davison.

Margaux Lopez

A physics PhD isn't a prerequisite for the desire—or the ability—to contribute to ground-breaking research, and Margaux Lopez is a prime example of just such a valued contributor. She's a mechanical engineer who is part of the Integration and Test team charged with putting together LSST's giant CCD camera.

"We have a lot of preparation to do," says Lopez. "We're responsible for assembling the camera and making sure it verifies all its top-level requirements via testing." Lopez explains that she is involved in flatness testing of the focal plane and electro-optical testing of the sensors. "We have to make sure all the pixels are good." One of her contributions to the camera-testing toolbox is a mini-cryostat that mimics the -100°C temperature at which the focal plane will be kept.

Her position on the Integration and Test team is the Caltech graduate's first engineering job, and it's proving to be as rigorous an education as the master's degree she's working on at San Jose State University. "I organize cleanroom activities, I design, I get things made, I write procedures, I put things together, and sometimes in the middle of all that I eat lunch," Lopez says. "Going from the design phase to actually building it and using it is really fun and satisfying. I like that I get to wear a lot of hats, and not just on Halloween."

Prior to coming to SLAC National Accelerator Laboratory about two years ago Lopez spent nine months focused on her passion for STEM education, teaching robotics to elementary and middle-school kids during summer camps and after-school programs. She has continued to volunteer for education-related activities at SLAC, such as the Greene Scholars Program and SLAC's own Kids' Night, the annual opportunity for SLAC employees to introduce their kids (and sometimes grandkids) to SLAC science. (See page 16 for more KIPAC involvement in Kids' Night.)

STEM education is so important to Lopez that, she says, "Once the camera ships I want to teach math and physics in high school or elementary robotics."

Until then Lopez is, in a way, realizing one of her own childhood dreams.

"When I was little I really wanted to be an astronaut, so I thought doing anything to study astronomy or space would be really neat—from the relative safety of the ground of course." Now she's working on one of the most important scientific instruments of this century. It's not too far-fetched to think her experience might be the inspiration for her future students to make their way out into the cosmos.

A noble (gas) experiment to look for dark matter

Dark matter makes up most of the matter in the universe—between five and six times more than boring baryons, the normal matter around and within us. Thus far dark matter has only revealed its presence because it can interact gravitationally with regular matter, sculpting the universe on a grand scale through the strength of its attraction. Reacting to (or in physics parlance, coupling with) electromagnetic radiation, our key tool in the exploration of the universe? Not so much.

The prospect of finding something when all your best search tools don't work can either be a recipe for frustration or a spur to greater feats of ingenuity.

KIPAC researchers have chosen the “ingenuity” route. In addition to the Super Cryogenic Dark Matter Search (see page 12), which depends on solid semiconducting detectors, a second group, led by Dan Akerib and Tom Shutt, is deeply involved in the LUX-ZEPLIN, or LZ, collaboration, which will use as its detector a tank filled with seven metric tons of extremely pure liquid xenon. The detector, currently under construction, will be installed in an underground laboratory about a mile down in the Sanford Underground Research Facility in South Dakota, a former gold mine.

A member of the family of noble gases, xenon is known for its unwillingness to react with other elements to form chemical compounds. Looking for an unknown substance that's famously standoffish by setting a trap with a known substance that's also famously standoffish may seem a bit—counterintuitive. But when the substance you're looking for is dark matter, intuition is not the best guide.

Liquid xenon works because it is a scintillator. LZ is looking for a specific mass range of dark matter particle called a WIMP, or weakly interacting massive particle, on the order of $10 \text{ GeV}/c^2$. When a particle of dark matter strikes a xenon atom, it absorbs that energy and gives off a photon—a flash of light. The bump also ionizes the atom, stripping off an electron. A strong electric field through the gas causes the electron to drift to the liquid's surface, where it is extracted into a gaseous layer and gives off another flash of light. Photomultiplier tubes on the top and bottom of the detector pinpoint the horizontal position of the collision, while the time difference between the two pinpoints the vertical, giving the location of the collision in the detector.

The KIPAC group's tasks for the experiment include a broad range of hardware development, detector and background modeling, and xenon purification. They're testing prototype detectors and doing research on the fundamental properties of xenon that will inform LZ and a potential next-generation xenon dark matter experiment. With LZ science projected to start in 2020, students may participate in detector design, fabrication and deployment through initial science operations and analysis.



Rachel Mannino, a visiting postdoc from the University of Wisconsin, is prepping a high-tech loom to weave the first of four stainless steel wire grids that will provide the electrodes necessary to induce the electric field in the xenon tank.

Credit: Steffan Luitz.



Credit: Steffan Luitz.

Maria Elena Monzani

KIPAC staff scientist Maria Elena Monzani is a bit of an anomaly. Many of the long-time members of KIPAC embraced particle astrophysics as SLAC National Accelerator Laboratory, originally a particle physics laboratory, began to expand its portfolio of scientific experiments.

Not Monzani.

“My field was astroparticle physics from the start,” she says. Originally from San Pellegrino, in Italy, she studied solar neutrinos as an undergraduate, then completed her PhD at the University of Milano and the University of Paris, Diderot (also known as Paris 7). After a stint as a post-doctoral researcher at Columbia University, where she first became acquainted with liquid xenon detectors, she came to SLAC, where she spent 10 years working with data from the Fermi Gamma-ray Space Telescope, what she called a welcome respite from the rare event searches she’d been engaged in previously.

“I liked the amount of signals the LAT picked up,” she says with a smile. “I don’t have enough patience to look for something very elusive for thirty years, like some of my colleagues have.” Now, though, Monzani is back on rare event searches with a vengeance, looking for dark matter with the LZ collaboration.

“I’ve been doing essentially the same job on all the experiments since I was an undergrad,” she says. “My interest is high-throughput data processing, machine learning, and simulations.”

She’s LZ’s Level-2 manager for offline computing and software, which means she and her team organize the data storage for the experiment, computing infrastructure, simulation, and analysis software. Monzani does spend some time in the lab, working on high-speed electronics for the LZ test platform. Building hardware and electronics are “what I do for fun.”

She organized the first mock data challenge for LZ over the past summer, during which about 50 people took a batch of mock data from the simulated first month of LZ and practiced analyzing it. She was also the chair of the Liquid Detection in Noble Elements Conference, a KIPAC-hosted conference that brought together experts in liquid noble gas detectors from the neutrino, dark matter, and even medical fields to discuss improving detector performance.

Monzani is “heading back to the mine,” as she says (pre-Fermi she spent seven years working on projects located in Italy’s Gran Sasso underground lab). She found her first trip to SURF very exciting. The LZ group held a collaboration meeting there, including the kickoff for the data challenge, where Monzani was assisted by two KIPAC postdocs, Alden Fan and Tomasz Biesiadzinski. They also took a trip down to the 4850 Level of SURF, to the cavern in which LZ will be housed, the historic Davis Laboratory where Ray Davis first detected solar neutrinos.

In search of wimpier WIMPs

By the time the next iteration of the Super Cryogenic Dark Matter Search, called SuperCDMS-SNOLAB, begins to take data in the early part of the next decade, it—and the many KIPAC members in the collaboration—will be exceptionally well-positioned to contribute to one of the most compelling scientific questions of the 21st century: What is dark matter?

They will be figuratively well-positioned, because SuperCDMS-SNOLAB is one of three flagship Department of Energy (DOE) direct-detection experiments looking for that mysterious substance which cannot be detected using ordinary measures, yet is so ubiquitous it furnishes the scaffolding upon which the entire visible universe is assembled.

They will be literally well-positioned, as SNOLAB refers to the Canadian mine and underground research facility where it's currently being installed about two kilometers below the surface, a location that will protect the experiment from most cosmic rays, which could contaminate the data.

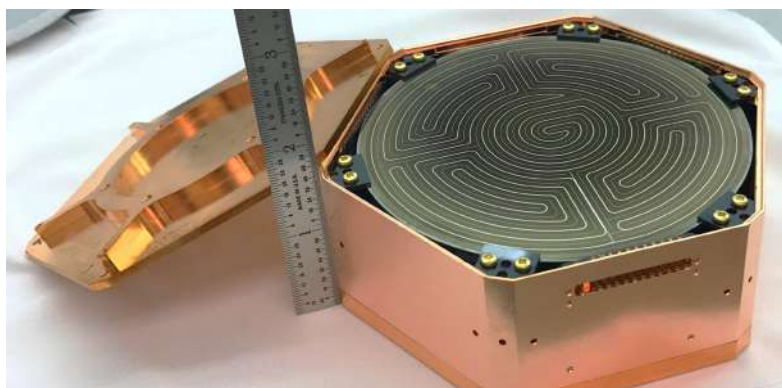
And they will be scientifically well-positioned, since SuperCDMS-SNOLAB is designed to look for dark matter in a mass range that no other semiconductor- or noble gas-based experiment can achieve. Two slightly different types of detectors will share the task; one, dubbed HV, is designed to have better sensitivity to dark matter particles at about $5 \text{ GeV}/c^2$ or less, while the second type, iZIP, is sensitive to particles at higher masses—about $5 \text{ GeV}/c^2$ and higher. The iZIP detectors will also be able to effectively reject background events caused by radiation from decaying substances such as radon or tritium.

The key to their complementarity lies in the type of energy each detector can capture. HV detectors focus on the phonons—discrete, extremely small packets of energy deposited in the semiconductor's crystal lattice structure when a particle of dark matter pings off the nucleus of a silicon or germanium atom. The HV detectors amplify the phonon signals ten-fold, resulting in a corresponding decrease in the mass of the dark matter particles they could detect.

The iZIP detectors detect phonon energy as well, but they also detect ionization energy, or the energy that results when an electron is knocked away from its atom (a likely background event). Ricocheting electrons also result in phonon energy, but much less than nuclear recoils cause, and comparing the ionization energy to the phonon energy can reveal whether an atomic nucleus or an electron was hit, thus ruling out false signals.

Together, the HV and iZIP detectors are capable of searching for a type of dark matter known as low-mass weakly interacting particles, or low-mass WIMPs. In contrast, the liquid xenon-based experiment LZ (see page 10), another of the three DOE-supported direct-detection experiments, will search for WIMPs of about $40 \text{ GeV}/c^2$.

Ultimately, SuperCDMS-SNOLAB will search for dark matter particles comparable in mass to protons. When looking for WIMPs, you can't get much wimpier than that.



One of the initial 24 SuperCDMS-SNOLAB detectors, made from either silicon or germanium disks. SuperCDMS-SNOLAB could expand to as many as 186 detector disks, and be sensitive enough to detect neutrinos.

Credit: Paul Brink.

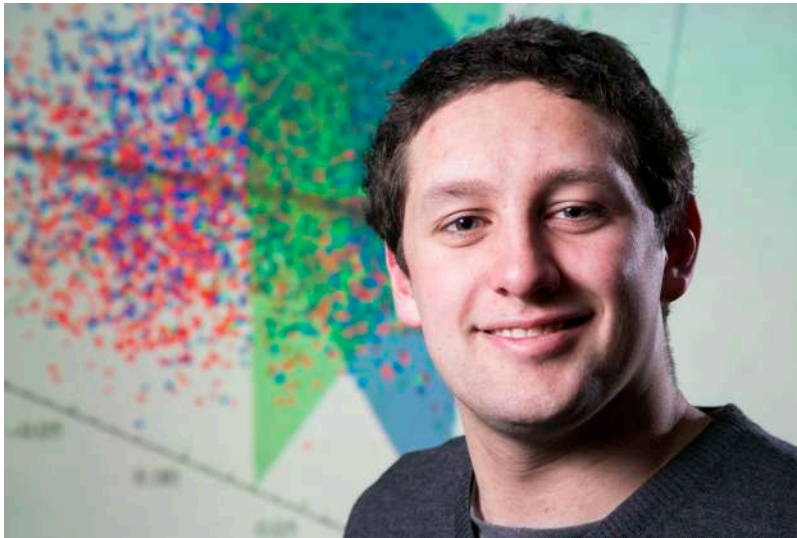


Image courtesy Noah Kurinsky.

Noah Kurinsky

KIPAC graduate student Noah Kurinsky is the detector guy for SuperCDMS-SNOLAB. With a background in both engineering physics and astrophysics and prior research experience on the Planck cosmic microwave background satellite and the ATLAS particle physics experiment at the Large Hadron Collider, Kurinsky is well-suited to creating instruments that capture very faint signals from very small particles.

“I came here because I liked the CDMS detector physics,” he says, and he jumped right into the project, spending his first year designing a new type of detector, called the HV detector, to add to the already-existing iZIP design.

“The older detectors measure charge and phonons in the crystal,” Kurinsky says, “but when you go to low mass you have to optimize to get out the most energy from the phonons. We use a high voltage across a crystal—100 volts across a silicon or germanium disk that’s 100 mm in diameter and 33.3 mm thick.”

The CDMS search for dark matter began during the late 1990s in a tunnel under the Stanford University campus and has undergone several upgrades since, moving to the Soudan Mine in Minnesota and now the Vale Creighton Mine near Sudbury, Ontario, Canada, home of SNOLAB. Kurinsky is the first KIPAC graduate student to focus on the SNOLAB incarnation of the project.

“Basically what I do is design, test, and prove the detectors are going to work,” says Kurinsky. But, on reflection, he points out another part of being a scientist for which he’s receiving invaluable training.

“Blas [Cabrera] and Rich [Partridge] are giving me a good opportunity to network and give talks,” he says. “I’ve given plenary talks.” (Cabrera and Partridge are the Stanford and SLAC CDMS leads, respectively.) “I’m very grateful because they basically just put me in a very central role in the collaboration.”

Meanwhile, Kurinsky’s design-test-prove regimen is bearing fruit. Detector fabrication has begun, with germanium and silicon crystals being fabricated that are destined for installation in the first of four towers. Each tower holds six crystals. From four towers, SuperCDMS-SNOLAB has the room to expand to 31. “We may end up seeing some neutrinos,” Kurinsky says.

All in all, Kurinsky likes where the future of dark matter research is going—at least where the devices are concerned.

“The early 2020s are going to be very interesting for dark matter research. I’ve planned my career around this and I’ll have to wait and see what happens.”

The goddess with the X-ray eyes

Hear the term “hot and energetic universe” and your mind may conjure up images of the vast temperatures at the heart of a star or the incredible energies blasted out by supernovae. These are, indeed, two examples of a hot and energetic universe. But for researchers trying to understand how our universe evolved to look the way it does today, the hot and energetic universe means something very different.

Viewed through a cosmological lens, the phrase refers to the time when most of the stars and galaxies still existing today were formed. This cosmic growth spurt, which peaked billions of years ago, was fueled by massive clouds of (mostly) hydrogen gas that ranged in temperature from tens of thousands to tens of millions of degrees Kelvin. That’s the “hot” part of the phrase. The “energetic” part was supplied by the extreme environments existing at the event horizons of growing supermassive black holes.

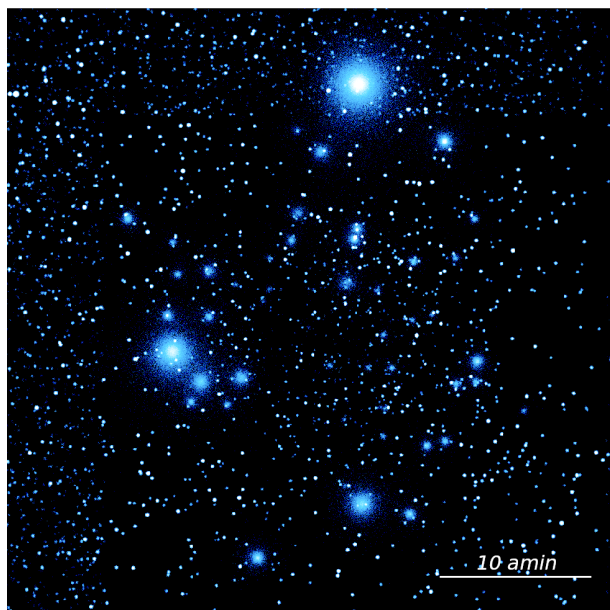
Understanding this relationship between hot and energetic is key to unraveling the processes by which our universe formed its distinctive structure.

Seeing the first galaxies as they formed billions of years ago and billions of light years away is hard enough. Seeing giant clouds of gas—that’s even more difficult. Fortunately, the hot gas glows in X-rays. That’s where KIPAC comes in.

Members are doing double-duty to help build the next big X-ray telescope, a European Space Agency mission called the Advanced Telescope for High ENergy Astrophysics, or Athena. They’re working on the science requirements—in other words, they’re determining the questions that would both reveal the most information about galactic evolution and have the best shot at being answered with available technology. KIPAC members are also helping design some of that technology—electronics that will read out information captured by the Wide Field Imager (WFI), one of the two main instruments on Athena.

Athena isn’t set to launch until 2028 at the earliest, but the scientists working on it will need every day of the coming decade to perfect an X-ray telescope with 20 times the collecting area of XMM-Newton, the next largest. In addition to the WFI, Athena will carry the X-ray Integral Field Unit (X-IFU), an extremely sensitive X-ray spectrometer.

Together, the two instruments will be able to observe the development of supermassive black holes at the centers of early galaxies, watch the formation of large-scale structures of hot gas, and determine the interplay between the two seemingly very different types of cosmic phenomena.



This image is a simulation of what the WFI might see at the center of the galaxy using its full field of view. Researchers building a scientific instrument use simulations to, for example, analyze how well a particular design will perform.

Credit: SIXTE/Athena.



From left: Dan Wilkins and Adam Mantz.

Dan Wilkins and Adam Mantz

KIPAC has the hot and energetic universe covered—at least where the Athena mission is concerned.

Research Associate Adam Mantz was an early KIPAC graduate student and returned after a NASA fellowship and a stint at another Kavli institute. He's the hot gas expert.

Meanwhile, Einstein Fellow Dan Wilkins is an expert in the extreme and energetic environments around supermassive black holes, especially the way X-rays behave under such bizarre circumstances.

The two are part of a concerted effort by hundreds of scientists around the world to establish the science requirements for the Athena X-ray telescope, the European Space Agency mission tentatively scheduled to launch in 2028.

“We’re making the case for the science we want to do with Athena and feeding that to the instrument groups,” Wilkins explains. “We basically tell them, ‘We need this hardware capability to do this science.’ Or they come to us and say, ‘What if we build this, can you use it?’” The process is a years-long negotiation with the goal of optimizing the equipment for the science.

The second feedback loop involved in the process is between their work on the requirements and their own research, including experience with other X-ray telescopes.

Mantz used Chandra data to study the chemical composition of the hot gas in galaxy clusters (hint: even between galaxies in a cluster, the hydrogen gas appears to have been thoroughly mixed with heavier elements formed by novae and supernovae, and it seems to have happened relatively early in the process of cosmic evolution).

Wilkins used data from XMM-Newton to investigate how X-rays bounce off the surface of the material falling into black holes in a phenomenon called X-ray reverberation. This phenomenon can give a closer look at just what’s going on just outside a black hole’s event horizon.

The two researchers have complementary interests but share a common opinion regarding where they do science.

“KIPAC has always been a very supportive environment, with pleasant surroundings and pleasant people,” Mantz says. “I feel like I can be very productive here with so many people with complementary and similar skills.”

Wilkins agrees. “We have world-class scientists in a friendly environment. It’s really helped me expand my research into new areas.”

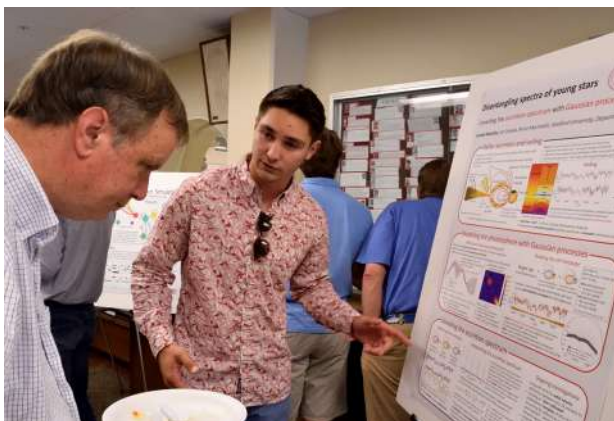
On the care and feeding of young physicists

The faculty and staff of KIPAC have close to two decades of experience helping young people reach their goals and their potential on their paths to becoming working physicists—or successful members of whatever profession they decide to pursue. Below are a just a few of the tried and true principles KIPAC follows as they nurture young scientists through their scholastic career.



Care about their curiosity (above): KIPAC staff scientist Greg Madejski explains cosmic concepts to students during a visit to a local middle school. The students were watching several 3D videos illustrating processes in the growth and evolution of the early universe—videos created by KIPAC scientists.

Undergraduate students



Care about their enthusiasm (above): KIPAC faculty member Peter Michelson listens to undergrad Joseph Murphy explain his summer research project, “Disentangling spectra of young stars.”

Murphy, along with more than a score of undergraduate students from all over the country, spent his summer doing research with KIPAC scientists.

Elementary school through high school

Feed their excitement (below): KIPAC graduate student Devon Powell demonstrates a fiery device called a Rubens’ Tube to spell-bound kids during SLAC National Accelerator Laboratory’s Kids’ Night. A Rubens’ Tube uses flames to visualize sound waves. Budding acoustic physicists could change the configuration of the mini-conflagration using a keyboard for input.



Feed their knowledge (below): Undergraduate student Cameron Park and KIPAC mentor Andrew Norton with the optical system, assembled and integrated by Park, that measured how the changing atmosphere distorted a laser beam originating a few kilometers away.

Park then analyzed the data, which contributed to the development of high-accuracy atomic clocks designed to use free-space laser links.



Photo courtesy Andrew Norton

Graduate students and young postdocs



Care about teaching them vital career skills (left): KIPAC faculty member Risa Wechsler (far right) explains the concepts behind speed collaborating for physicists at a spring retreat in the Sierras. Speed collaborating, in this instance, means finding unlikely collaborators: other KIPAC members who, at first glance, don't seem to have areas of research in common, but with whom unexpected, fascinating, and valuable research can be accomplished.

Feed their need to pay it forward (right): Stanford undergrad Jenny Kim (left) with two of her KIPAC mentors, staff scientist Phil Marshall (center) and graduate student Mike Baumer (right). Kim spent her summer helping develop ways to search the deluge of data that will come from the Large Synoptic Survey Telescope (see page 8 for more information.)

Kim credits the help she's received from all of her KIPAC mentors with enabling her to grow as a data scientist.

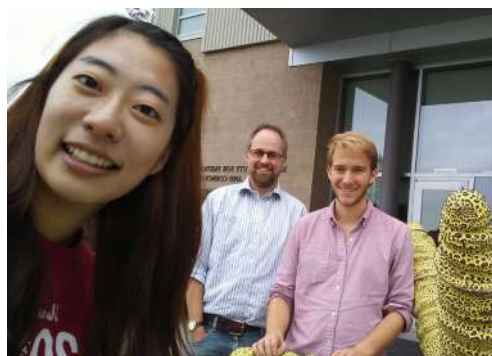


Photo courtesy Jenny Kim

Physics fans of all ages



Care for their enthusiasm and feed their sense of wonder (left): KIPAC postdoc Josh Meyers shares a close-up look at the Sun with SLAC Kids' Night attendees of all ages. Sunspot activity was mild that afternoon, but viewers got to glimpse a side of the familiar star that few see. After it set, Meyer switched to planet- and (other) star-gazing.

In addition to sharing hands-on activities, KIPAC members are available to give talks and tours of their facilities, including a local favorite: the Viz Lab, where visitors can see 3D simulations of the evolving universe created by KIPAC scientists.

Summer researchers for 2017

The people whose names are listed on this page worked on a variety of KIPAC projects during the summer of 2017, contributing to KIPAC research, learning what it's like to do cutting-edge science, and having fun.

In addition to Stanford University's own undergraduate research opportunities, a number of programs exist to help students further their education goals and have the summer of a lifetime:

- The Office of Science Graduate Student Research (SCGSR) Program: Prepares graduate students for science, technology, engineering, or mathematics (STEM) careers critically important to the Department of Energy (DOE) Office of Science mission by providing graduate thesis research opportunities at DOE laboratories.
- The Science Undergraduate Laboratory Internship (SULI) Program: Encourages undergraduate students to pursue science, technology, engineering, and mathematics (STEM) careers by providing research experiences at the DOE laboratories.
- The STEM Teacher and Researcher (STAR) Program: A 9-week summer research internship for aspiring science and mathematics teachers.
- The CAMPARE Program: A network of California State Universities and California community colleges from which students are recruited to participate in cutting edge research in astronomy, planetary and space science, or astrobiology, at one of 15 world-class research institutions.
- The Summer Research–Early Identification (SR-EIP/Leadership Alliance) Program: Provides undergraduates with training and mentoring in the principles underlying the conduct of research and prepares them to pursue competitive applications to PhD or MD-PhD programs.

Stanford University students

Shraddha Anand
Elizabeth Atkin
Paul Draghis
Donny Flynn
Sahil Gupta
Jenny Kim
Joseph Murphy
Cameron Park
Antonio Rodriguez
Roger Romani
Erik Rosenberg
Kaitlyn Shin
George Sivulka
Christian Smith
Kevin Wang

SCGSR student

Alex Malz

STAR teachers

Ramiro Garcia
Melida Paz

SULI students

Jaqueline Blaum
Betty Hu
Madelyn Leembruggen
Aleksandra Safonova
Stephanie Striegel

CAMPARE students

Jonathan Daniel
Jose Esquivel
Denise Lepore
Christina Vides

SR-EIP/Leadership Alliance students

Carrie Fillion
Jasmine Garani

Other student-researchers

Giorgio Dho and Chiara Magliocca, INFN
Lorenz Gärtner, Undergraduate
Visiting Research Intern

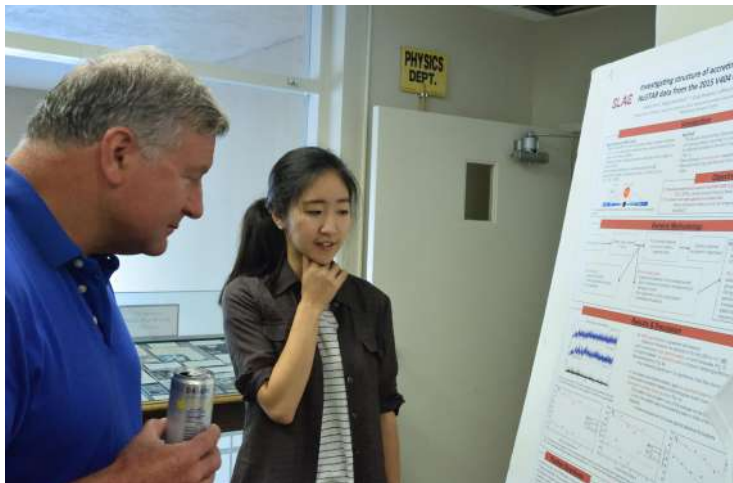


Daniel Akerib greets new CAMPARE students at an ice-cream social to welcome all new summer researchers.

Along with Risa Wechsler, Akerib helped bring the two newest programs, CAMPARE and the SR-EIP/Leadership Alliance, to Stanford.

Mentor Aaron Roodman helps SULI student Aleksandra Safonova with some coding questions.

Roodman, who is involved in both the Dark Energy Survey and the LSST camera assembly, kept several students busy over the summer.



KIPAC professor Roger Romani (not to be confused with his son, Stanford student Roger Romani, who worked on his own summer project) listens as Stanford undergrad Kaitlyn Shin explains her project based on analysis of data from the Nuclear Spectroscopic Telescope Array (NuSTAR), a NASA X-ray telescope that launched June 13, 2012.

Several KIPAC scientists are involved in analyzing NuSTAR data.

Closer to home but still cosmic: A total solar eclipse

Several KIPAC members traveled north to view and photograph the Great American Eclipse on August 21, 2017. Below, a few share their impressions, while the next page shows some images.

M. Gill:

...as actual totality began (10:17 am in our location) everything suddenly became much weirder and eerie, even—a twilight fell all around, and everyone was just stunned to see the corona of the Sun streaming outward, with it giving enough light that we could still see one another just as we would some 10 minutes after sunset. Initially, a quietness fell on everyone. But in short order, there was cheering, and whoops all around. It was true—the astronomers did know what they’re doing in predicting this so very rare otherworldly occurrence. ...even if i don’t become a dedicated worldwide “eclipse chaser,” I do plan to make the effort to see upcoming ones that are reasonably accessible (like in Chile in July 2019, or somewhere between Austin and Boston in April 2024).

Pierre Schwob:

Having read and heard from serious eclipse-chasers that one shouldn’t busy oneself taking pix during your first total eclipse I can only share my awe at the sight and my sense of communion with other watchers. I had solar binoculars which helped immensely with the four contacts—and to observe three groups of sunspots. ...the Bailey’s beads and instantaneous emergence and beauty of that corona (and prominences) was truly breathtaking.

Laurence Levasseur:

It was way beyond anything I could have imagined. When I took off the glasses and looked with my bare eyes I actually started crying from the beauty of the phenomena and how just mind-blown I was. “Breathtaking” took a whole new level of meaning for me, as in, literally my breath was taken away. Later my husband Yashar told me that my jaw literally dropped. There are just no words....

Bob Wagoner:

We had ideal viewing conditions, good dorm rooms and food, and little traffic at Oregon State University in Corvallis. The main thing that surprised me during our 1.6 minutes of totality was the structure of the corona: like the petals of a flower.

Junior KIPAC member Amelia Macintosh (via her dad, Bruce):

...Amelia said the eclipse was awesome and pretty, and the best part was seeing the diamond ring flash. She also made a series of pictures as the moon advanced across the sun (see next page).

Devon Powell:

...the crickets began chirping a few minutes before totality, and we saw a deer spring up from its hiding spot and run around frantically as totality occurred. I was amazed at the wispy detail I could see in the Sun’s corona, just with my naked eyes. Our neighboring eclipse-watchers in the cornfield were all transfixed, trying to take last-minute photos. Lots of “Oh my gods” were heard.

Two minutes later, the diamond ring appeared again and totality was over.



A photo by Josh Meyers shows the “diamond ring” effect, just an instant before or after totality. Taken near the Oregon-Idaho border.



A photo by Dan Akerib shows Tom Shutt and family waiting for totality. Tom is wearing the height of eclipse fashion. Taken in Oregon.



A photo by Bruce Macintosh shows junior KIPAC member Amelia Macintosh with a sunspotter provided by KIPAC alum Kate Follette, and Eclipse, the wolf (wearing very stylish sunglasses). Taken in Oregon.



A photo of Carhenge by Devon Powell demonstrates that sometimes the eclipse was not the only attraction. Taken in Nebraska.



A photo by Lori White shows dozens of tiny eclipses through the holes in a common kitchen colander. Taken in eastern Idaho.



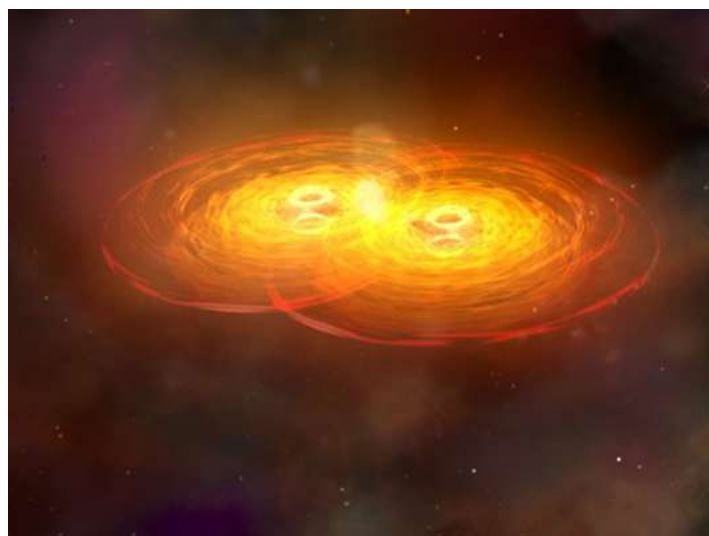
A second photo by Josh Meyers, showing the eerie sight of the sun totally eclipsed by the moon. Taken near the Oregon-Idaho border.

The following excerpts from the KIPAC blog provide just a glimpse of the research being conducted at the institute by its dedicated members, 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.

Nicola Omodei and Giacomo Vianello look for EM counterparts to gravitational waves with Fermi (first published September 25, 2016)

[Check out the original blogpost](#)

...The identification and study of electromagnetic (EM) counterparts to gravitational wave (GW) events is critical as we move into the new area of GW astronomy for several reasons. If an EM signal is also observed it would provide additional information that can give us significantly better constraints on the parameters (such as mass, orbit, spin, etc.) of the binary black hole system. An EM signal would also allow for a cross-check between the distances measured through the GW signal and the redshifts measured through its EM counterpart, providing an independent constraint on cosmological models. Also, the simultaneous detection of a clear EM counterpart can confirm a GW event that hovers at the threshold of significance, effectively increasing the sensitivity of the search and the distance to which GW events can be detected by LIGO.



This illustration shows a stage in the merger of two galaxies that will ultimately form a single galaxy with two centrally located supermassive black holes surrounded by disks of hot gas. The black holes orbit each other for hundreds of millions of years before they merge to form a single supermassive black hole that sends out intense gravitational waves.

Credit: NASA/CXC/
A.Hobart

However, finding an EM counterpart to a GW observation is a challenging proposition. We start with a “probability map” provided by LIGO (which will soon be working in conjunction with its European counterpart, Virgo, which will help narrow down the probability map to a much smaller area), showing the section of the sky in which the gravitational event is most likely to have taken place. The probability map is produced using a complex analysis chain which takes into account various aspects of the detected gravitational waveform signal (frequency in the inspiral, merger,

and ringdown phases, amplitude at peak, length of time it spends in each phase, etc.) as well as the time lag of the signal between the two LIGO detectors. It is usually shaped like a thickened arc (sometimes broken into two pieces) and can cover several hundred square degrees.

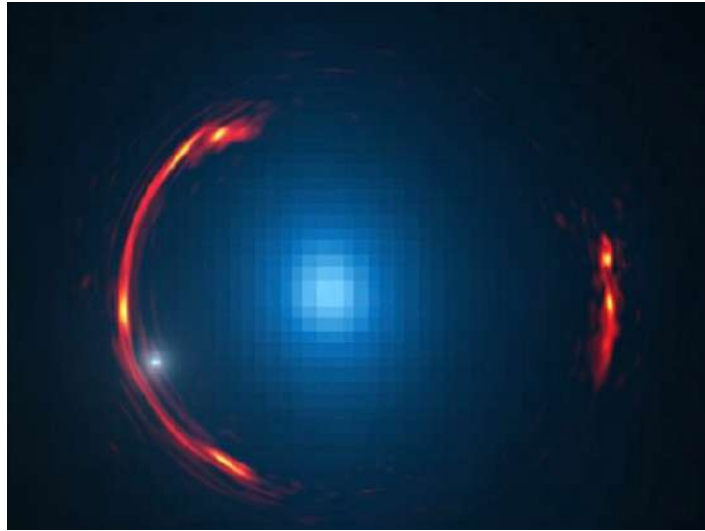
The area covered by the probability map is currently much larger than the field-of-view (FoV) of a typical soft X-ray, optical, or radio telescope, which is at most only a few square degrees for the largest detectors of today. Further, the luminosity of an EM counterpart is also expected to decay rapidly, meaning we need to cover a big patch of sky in a very short time.

On the other hand...gamma-ray detectors such as the Fermi Gamma-Ray Burst Monitor and the Fermi Large Area Telescope have much larger FoVs and can cover the probability map much more quickly. They are therefore expected to play a major role in the discovery of the first EM counterpart to a GW event.

As soon as we received temporal and localization information for the LIGO events, we searched back in the recorded LAT data for an EM counterpart. Searching for a small signal over a large fraction of the sky is like searching for the proverbial needle in a haystack. In contradistinction, the standard LAT analysis process assumes we know the location of a source with some accuracy. Given the size of the localization region of the GW event, the search for a transient counterpart in LAT data is challenging and requires new methods....

Warren Morningstar looks for hidden knots of dark matter (first published October 18, 2016)

...By modeling the warped images of a gravitational lens observed with one of the most powerful telescopes in the world, KIPAC scientists have made the dramatic discovery that there is a clump of dark matter with no currently visible normal-matter counterpart in a far-away galaxy. Such unaccompanied clumps are incredibly difficult to detect and only a small handful of them have ever been discovered, but a concerted effort to find them and determine how and why they form could pay off significantly in the long term by giving us new insights as to the nature of dark matter.



By analyzing distortions in this ALMA/Hubble composite image of the gravitational lens SDP81 (red arcs are the background galaxy; the central blue blob is the nearby lensing galaxy that provided the magnification), astronomers have determined that a dark dwarf galaxy (the white dot at lower left) is lurking nearly 4 billion light-years away. (Credit: Y. Hezaveh, Stanford Univ.; ALMA (NRAO/ESO/NAOJ); NASA/ESA Hubble Space Telescope.)

...simulations find that dark matter naturally forms into large clumps which we call “halos,” because they surround galaxies in much the same way of that ethereal glow that always surrounds angels in artists’ depictions (which is my best guess as to why they’re called halos). Halos are much more massive than the galaxies inhabiting them (about 6 times more, on average), and because dark matter doesn’t condense like normal matter does, they are also significantly larger in size.

[Check out the original blogpost](#)

When we simulate individual halos, we find that because the dark matter is cold, it should further collapse into tens of thousands of even smaller clumps, which we call subhalos. These subhalos are massive enough that, using what we know about conventional galaxies, we might expect that they host small galaxies of their own. These dwarf galaxies should thus be plentiful around galaxies like the Milky Way. When we look for these dwarf galaxies, we find a few dozen of them, but not nearly as many as the theory predicts should be found.

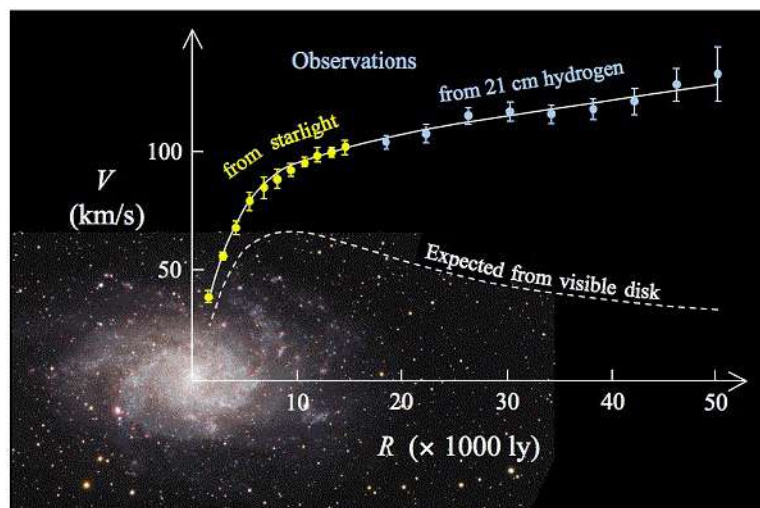
The apparent lack of dwarf galaxies could be explained in a number of ways, but two explanations in particular have gained a lot of ground. The first is that dark matter is not as cold as we once thought, meaning that it had a little bit of random motion in the early universe. This motion would have made the dark matter particles spread out more and clump together less overall, and thus could have provided enough dispersion of the particles to prevent most subhalos from being able to form, leading to an expected number of dwarfs that agrees with observations. Alternatively, dark matter could be cold as we think it is, but low-mass galaxies simply cannot form in the subhalos (and there are multiple unknowns relating to how and why stars form etc. that might explain why this might be the case). Because the second option predicts that most subhalos do not have galaxies, it also says that most subhalos also cannot be seen with telescopes. This implies that what we really need is a means of looking for subhalos that doesn’t require them to host galaxies.

One way to do this is by exploiting a phenomenon called gravitational lensing. Gravitational lensing is caused by light being deflected by a massive object (the lens) located between an observer (us) and a source of light (a distant galaxy). Through the deflection, an image of the source can be stretched, warped, magnified, and multiplied before we observe it, producing stunning images like those seen in the image ...

Harry Desmond takes a closer look at galaxy dynamics (first published December 19, 2016)

[Check out the original blogpost](#)

This image shows the rotation curve of M33, a typical spiral galaxy, plotting the orbital velocity of stars and gas at a given radius from the center of the galaxy. The white dotted line shows the expected orbital behavior of M33's stars, based solely on adding up the gravity of the visible mass using Newton's laws. After reaching a maximum velocity at around 10,000 light years from the galaxy's center, the velocities of orbiting stars should begin to taper off. As shown by the upper line, which is from the actual data, that's not what happens. This ubiquitous behavior of spiral galaxies was one of the earliest motivations for positing the existence of dark matter. (Public domain image.)



...asking a pithy acronym like Λ CDM (Lambda-cold dark matter) to cover all the fine points from the earliest instants of our Universe all the way until now is asking too much. There may be a consensus that concentrations of dark matter, called haloes, guide the growth and development of galaxies, but that's far from the entire picture. How does the ratio of dark matter to normal matter affect a galaxy's evolution? What are the density and dynamics of dark matter in a halo? Do they vary, and if so, how? Is there an actual structure to the dark matter itself? And the most basic, and thus most important, of questions: can dark matter—as we conceive of it—fully explain the Universe we see when we look up into the night sky?

These are not easy questions to answer, but with improvements in observational and analytical techniques

we are beginning to get a detailed enough look at individual galaxies to begin to address them. Partly since we have not directly detected dark matter, we have to compare our models to increasingly detailed observations, revising the description as necessary.

The detailed view we need is provided by observational studies such as the Spitzer Photometry and Accurate Rotation Curves (SPARC) study. SPARC comprises a total of 175 nearby galaxies, including detailed photometric measurements from NASA's Spitzer Space Telescope (which

track stellar mass) and high-quality rotation curves for HI and H α regions (which track hydrogen gas). This gives an unprecedented view of both the total amount of normal matter and how that matter is moving as a function of distance from the center of a galaxy—and hence the distribution of the dark matter largely responsible for determining this motion.

I derived a set of statistics from about 150 SPARC galaxies (resulting in a study published in *Monthly Notices of the Royal Astronomical Society (MNRAS)* in November 2016). These statistics quantified some important features of the mass discrepancy-acceleration relation (MDAR), a surprisingly strong relation between the ratio of total-to-normal matter in a galaxy (the mass discrepancy) and the acceleration of the stars and gas within that galaxy at different radii throughout the disk. I focused on three characteristics of the MDAR:

- The mean shape of the relation
- The scatter, or variance, among the data points (how far from the mean they fall)
- The presence of a “characteristic acceleration,” beyond which the mass discrepancy goes to one and hence dark matter is dynamically insignificant.

Next, I simulated dark matter halos and populated them with galaxies using halo abundance matching techniques pioneered by KIPAC professor Risa Wechsler and her colleagues. Stated simply, this technique relates a galaxy's mass to the mass of the dark matter halo in which it forms (see the references, below, for links to other relevant papers of mine with Risa). After this, I compared the galaxies I had built to the statistics derived from the SPARC data. In essence, I built galaxies based on the rules of Λ CDM and then compared them to the real things.

The H0LiCOW collaboration raises questions about the Hubble constant (first published March 1, 2017)

The H0LiCOW collaboration just released news that they've measured what KIPAC and H0LiCOW collaboration member Phil Marshall calls "a key property of the universe": the Hubble constant, which tells how fast the universe is expanding. According to their measurements, our universe is currently expanding at 71.9 km/s/Mpc, within about 3.8% accuracy, which means that each second, our universe is adding very close to 71.9 kilometers of space per megaparsec (a megaparsec is one million parsecs, and a parsec is about 3.3 light years) in every direction. This expansion is increasing, a phenomenon attributed (for now, at least) to the influence of a new component of the universe, dark energy.

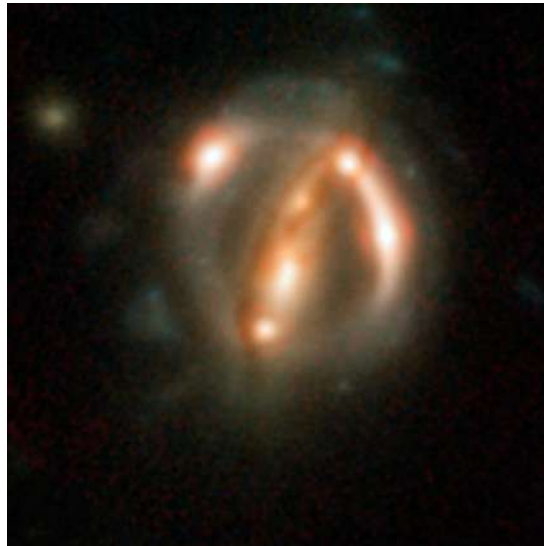
[Check out the original blogpost](#)

What's even wilder? A mismatch between their measurement and another made using a different technique could indicate new physics.

The Hubble constant (i.e. the Hubble parameter as determined at the current time in our universe), known as H_0 (say, "H-not"), is the key to this expansion, says Marshall.

"Our program here is to try to understand what's making the expansion of the universe accelerate—what this dark energy is. So we're interested in making more and more accurate measurements of H_0 ."

To make their most recent measurement, the H0LiCOW collaboration studied images produced by strong gravitational lenses: galaxies which are so massive that light from even more distant objects bends around them. Because strong gravitational lenses are generally not perfect spheres, the light can take four paths of different lengths to reach a telescope, resulting in multiple images (the illustration below does show a perfectly spherical lens, which results in two images).



One of the lensed quasars studied by the H0LiCOW collaboration, is among the five best lensed quasars discovered to date. The foreground galaxy creates four almost evenly distributed images of the distant quasar around it. (Credit: ESA/Hubble, NASA, Suyu et al.)

The H0LiCOW collaboration takes advantage of this fact by studying lensed quasars, which are thought to be very early, far-distant galaxies with central supermassive black holes that power huge outflows of energy. The energy output of a quasar can vary over astoundingly over short time periods—months, days, even hours. And because the light from a lensed quasar takes paths of different lengths to reach us, each separate image of the quasar flickers at a different time. The different path lengths can be determined using basic geometry and knowledge of the speed of light.

"Our first 'Holy cow!' moment came when we realized this technique works!" Marshall says.

The collaboration's accomplishment in measuring the constant is significant for several reasons, says Marshall. "It's the most accurate measurement ever made using this technique, and it's complementary to measurements using Cepheid variables [a type of star known as a kind of cosmic yardstick] and supernovae in nearby galaxies." Having more than one method of measuring H_0 is vital. "Cross-checks are very important to make sure of accuracy."

The H0LiCOW H_0 measurement is also important because it differs to an intriguing degree from another H_0 measurement based on the cosmic microwave background, the relic light from the very beginning of the universe. This discrepancy could point to some fundamental physics we have yet to understand or take into account.

“The CMB research looks at certain cosmic parameters while strong lenses look at others,” Marshall says, “and the combination helps us tell the difference between a few different things that have had an effect on the expansion of the universe. One is dark energy; another is the total mass of neutrinos in the universe.”

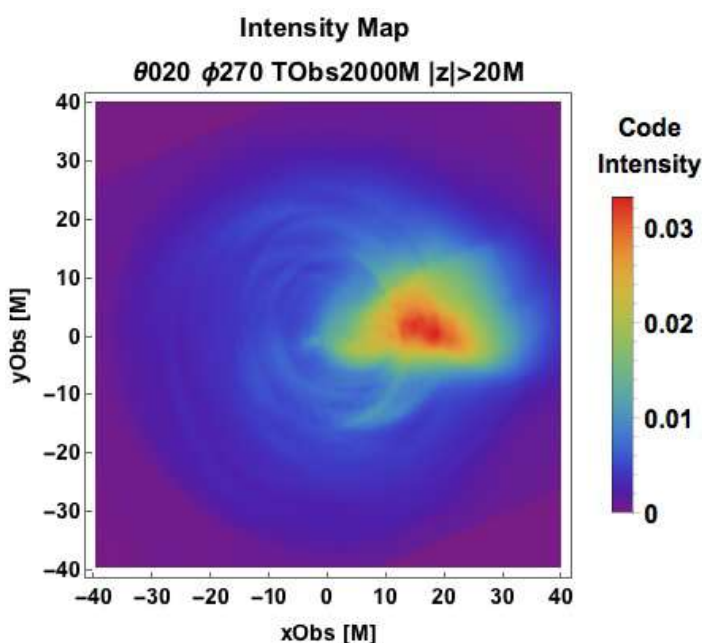
As for why all of these different ways to measure H_0 are necessary, think of the different experiments in cosmology as different colors of paint on a palette. The ability to combine colors results in a painting that’s richer and more accurate than trying to capture a scene with only primary pigments....

Richard Anantua simulates relativistic jets (first published March 8, 2017)

[Check out the original blogpost](#)

The high-energy universe is a fascinating place to observe: giant stars explode into supernovae, briefly outshining their own galaxies; pulsars with more mass than our Sun but only twelve miles across spin hundreds of times each second; and supermassive black holes at the centers of galaxies can suck dust and gas into accretion disks and blast this material in plasma form back out in powerful relativistic jets spewed out at close to the speed of light.

A powerful jet viewed at $\theta=20^\circ$ from the jet axis. This image was generated from an emissivity function in which the gas pressure is constant along the jet. Intensity of a jet not necessarily associated with a known black hole, as above, is measured in code units that can be converted to physical units for a known black hole (see simulation based on M87, below). (Credit: Richard Anantua.)



These jets are some of the largest single objects in the universe, often stretching hundreds and even thousands of light years across the void. Since the jets are emitted roughly along the rotational axis perpendicular to accretion disks around spinning black holes, they’re often visible shooting out into relatively empty space.

Huge and readily visible—we must know a lot about these jets, right?

Unfortunately, it’s not that simple.

These jets may be mind-bogglingly big, but they are still very far away—M87, which is one of the best-known of the jet-hosting galaxies and which I used as a test case for my research—is more than 50 million light years from our galaxy. ...Our ability to observe these objects at such vast

distances and actually unravel what happens near their chaotic central engines still has a lot of room for improvement. ...

In the meantime, theorists are hard at work creating simulations of what’s happening. The best tools for the job combine magnetohydrodynamics (MHD), which is the study of the magnetic properties of electrically conducting fluids, and Einstein’s General Relativity into something called (not surprisingly): general relativistic magnetohydrodynamics (GRMHD). GRMHD simulations give insight into the complicated relationship between density, pressure and magnetic perturbations, and the distortions of spacetime due to the extreme gravity of the nearby black hole—and thus how the two in combination shape the plasma of the accretion disk. Ultimately, the simulations provide insight as to how a jet is actually formed and accelerated.

Observations and simulations may be improving, but the ability to compare the two has not kept pace. In response, I have developed a software pipeline to post-process GRMHD simulations, essentially translating the energy associated with the motion of the fluids implied by a simulation to particle acceleration, accounting for properties such as relativistic velocity, dissipation, opacity and polarization in the radiative transfer (how these particles transfer electromagnetic energy among and between them). The pipeline thus “lights up” the simulations, revealing what the observer actually would see, so that we can compare simulation to reality....

Kyle Story braves the elements for science (first published April 6, 2017)

Last December, I travelled to the southernmost tip of the Earth to install a new camera on the South Pole Telescope. This blogpost brings you along for a bit of that journey!

The South Pole Telescope (SPT) is a radio telescope at the South Pole. My collaborators and I use the SPT to make maps of the oldest light in the universe, the Cosmic Microwave Background (CMB).

[Check out the original blogpost](#)

The CMB was formed about 380,000 years after the Big Bang when the average temperature of the Universe cooled enough for protons and electrons to combine to form hydrogen. This transition occurred relatively rapidly, and the Universe suddenly became transparent to light. Before this time, the Universe was filled with a cloud of hot subatomic particles and a photon could not travel very far before running into a free electron, similar to being in a fog you can't see through. But after the transition, the “fog” cleared and there were very few free electrons left, allowing photons to stream freely through the Universe.

The CMB that we see today is composed of the photons released at this time. So the maps we make of that radiation are effectively “baby pictures,” showing us what the Universe looked like at ~380,000 years after the Big Bang. Scientists have learned a huge amount about the history of the Universe and what it is made of from these baby pictures; for example, they are one of the most reliable sources telling us the age of the Universe—about 13.75 billion years old.



Author Kyle Story at work installing the SPT camera.

Image courtesy Kyle Story.

We want to take even better baby pictures of the Universe, so this year we installed the 3rd-generation (as in third major upgrade) camera on the SPT, called the SPT-3G camera. This camera has 10 times more detectors than the previous camera, a major upgrade! With this improved camera, we'll be able to make much more precise maps of the CMB, especially of the polarization (essentially, the spin the CMB photons have). From these polarization maps, we hope to learn about one of the lightest types of particles—neutrinos—and about the earliest moments after the Big Bang, a hypothesized period called cosmic inflation, during which the Universe expanded incredibly quickly, much faster than the speed of light.

These maps of CMB radiation can teach us about neutrinos in several ways, two of which I'll describe.

First, the neutrino is one of the lightest particles we know, but there are enough of them to make up a noticeable portion of the total mass and energy in the Universe. They even have an effect on the Universe's rate of expansion, which is dictated by how much of the total energy in the Universe comes from radiation (photons), how much comes from matter—which includes neutrinos—considering this matter as energy via Einstein's famous equation, $E=mc^2$, and how much comes from dark energy. Because we measure the rate of expansion of the Universe over time with the CMB, this measurement is sensitive to the amount of energy in neutrinos. [Technically: the more radiative species in the Universe before decoupling, the more the CMB power spectrum is suppressed in the $\ell = 2000\text{--}3000$ range.]

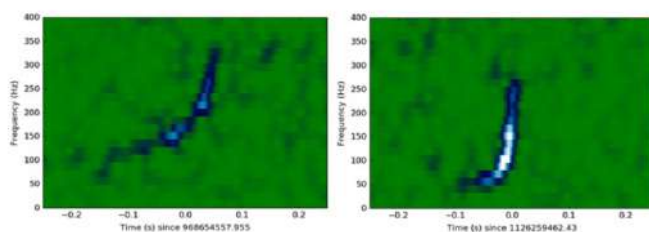
Second, neutrinos are very, very light, but from experiments that study “neutrino oscillation” (neutrinos shifting between three different “flavors,” or types) we know they do have some mass. However, we have not yet measured the exact mass of neutrino particles. Using cosmological measurements—and the CMB in particular—scientists hope to measure the mass of neutrinos with upcoming experiments. We can do this because neutrinos with mass affect the (very large scale) cosmic web of dark matter structure. Information about this dark matter structure is encoded in the CMB by “gravitational lensing,” the bending of the travel paths of CMB photons by the gravitational pull of this dark matter....

KIPAC scientists combat observer bias (first published May 3, 2017)

[Check out the original blogpost](#)

Scientific introspection is necessary because of a known unknown in the world of experimentation called experimenter bias, the name given to all the ways in which simply being human can affect how scientists take data, analyze data, and interpret data. “Experimenter bias” is a known—in other words, it is well-known to exist—but it's also unknown, because the psychology of the human scientist can't be easily quantified. Researchers can't add error bars indicating the strength of a preconceived notion or the weight of an unconscious desire, yet subtle and not-so-subtle influences definitely exist, such as the result of a previous experiment or the conclusion of a popular theory, and these influences can nudge a researcher into accepting a result prematurely or discounting results that don't conform to expectation.

The image on the left is a fake gravitational wave signal, added to LIGO data in 2010. The image on the right is an actual gravitational wave signal from 2015. (Credit: The LIGO Team and the LIGO Scientific Collaboration.)



This is where “blind analysis” comes in—which means scientists implementing some method to remove all-too-human foibles and frailties from their data analysis. In a blind analysis, scientists cannot be tempted, even subconsciously, to influence the results of an experiment because they hide something about the experiment from themselves. There are multiple approaches to doing this: they

can lock some of the data away in a “black box” while they use the rest to determine the best way to analyze it. They can “salt” the data, which means adding extra data that looks real but actually isn't, and then just pull it back out when they do the final analysis. They can fudge with the numbers in the data by adding an unknown factor or constant (or both) to them, thus obscuring what will be the final results (and again, remove that factor at the very end).

These techniques have been used in particle physics experiments for decades, but are still rare in the realms of astrophysics and cosmology, chiefly because we've only recently entered the era of precision astrophysics and cosmology. In other words, these two disciplines have only recently begun to achieve observational results that are precise enough to make experimenter bias worrisome.

Yet it didn't take long for the scientific stakes to get high enough to make reducing experimenter bias a crucial part of several current and upcoming experiments.

As KIPAC professor Aaron Roodman explained in his introductory talk, the stakes are rising because of the type of data researchers need, the amount of data they need, and the mounting expenses of getting the data they need. After a few hundred years of pointing telescopes at individual targets, they need to broaden their scope (no pun intended) to get the big picture of the universe as a whole, so they can measure the parameters that affect how the Universe as a whole behaves.

To do this, astrophysicists and cosmologists need surveys, and surveys need different—and very expensive—instruments, both space- and Earth-based, that can collect light from all across the electromagnetic spectrum. Many of these instruments, such as the Large Synoptic Survey Telescope (currently under construction in Chile), or the Dark Energy Spectroscopic Instrument (planned to be installed on the Mayall Telescope on Kitt Peak in Arizona in 2018) are or will be one-of-a-kind instruments, and the data they collect is ultimately shared publicly.

The sharing of a single data set has big implications for making sure a result is reproducible—the cross-checks and verifications so necessary to science—and the members of the Blind Analysis workshop had a keen awareness that when several different scientific groups are all looking at the same data, one of the big differences in their results could be the scientists themselves....

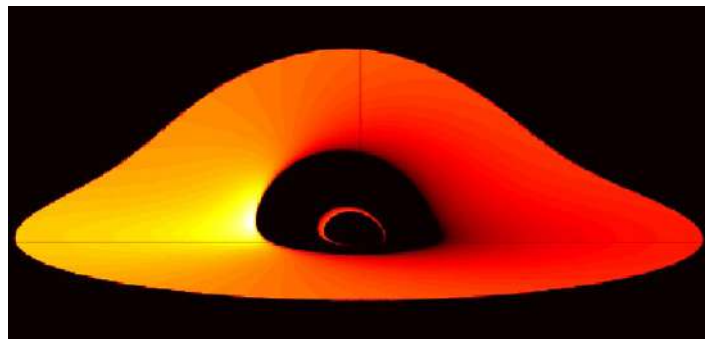
Dan Wilkins uses X-rays to get a closer look at supermassive black holes (First published June 16, 2017)

Supermassive black holes power some of the most luminous objects we see in the Universe. When material spirals into a supermassive black hole in the center of a galaxy that is in excess of a million Solar masses it gives rise to an active galactic nucleus, or AGN.

[Check out the original blogpost](#)

In addition to spewing electromagnetic radiation running from visible light through ultraviolet all the way to X-rays and gamma rays, many AGN can launch jets of particles at close to the speed of light.

These jets are detected through the radio waves they emit by synchrotron radiation and can extend between 50 and 100 kpc (about 150,000 to 300,000 light years) from the central black hole. All this activity occurs in and around the accretion disc: the flattened disc of gas that is spiralling into the black hole, just moments before it plunges through the surface of no return, the “event horizon” of the central massive black hole.



X-rays that are reflected off of the disc of inflowing material pass through the curved spacetime in the extreme environment around the black hole. (Image credit Dan Wilkins.)

The vast energy spewing forth from the accretion disc region indicates that AGN are a critical component in understanding the formation of structure in the Universe.

However, a great deal of mystery still surrounds these impressive systems. We still don't understand exactly how energy is extracted from the material as it falls into the the black hole. We do know that a crucial piece of the puzzle is a structure outside the black hole known as the corona, a super-heated region producing intense X-ray light. It's likely that the corona plays an important role in launching the jets at close to the speed of light which astrophysicists at KIPAC are starting to learn about for the first time.

The corona is formed from energetic particles in the extreme environment right outside the black hole's event horizon. There are two possibilities for its structure; either it sits covering the innermost parts of the inspiralling accretion disc or it is located at the launching point of the jet where—in addition to being heated by the gravitational energy released as the disc material falls in—it can tap energy from the spinning of the black hole itself.

Our latest research suggests that the corona is, in fact, a combination of both of these structures. Although we know the corona is responsible for a significant fraction of the energy output, the mechanism that energizes these particles remains a mystery. The intertwining of magnetic field lines that are generated in the accretion disc, and their eventual breaking and reconnecting, is widely believed to be responsible for this.... The X-rays that are emitted by the material falling into the supermassive black hole provide us with a unique probe of what is happening in that extreme environment, right down close to the black hole's event horizon. These emissions are incredibly variable. The corona is typically millions of kilometers (i.e., tens of light minutes) across, yet incredibly active, with the intensity of the emissions we detect varying by factors of two, three, or more on timescales of just hours. On some occasions the x-ray intensity will even suddenly flare very intensely.

Some of the X-rays that are emitted from the corona shine back down onto the disc of inflowing material and are reflected. Astrophysicists at KIPAC are able to use these reflected X-rays to probe, in detail, how the corona behaves and evolves over the course of some of these impressive X-ray flares. Different atoms in the inflowing disc, when illuminated by X-rays from the corona, reflect these X-rays at specific energies. The X-rays that reflect off the accretion disc must pass through space and time that has been severely curved by the extreme gravity of the black hole. This path through curved space-time bends the paths of the X-rays and shifts their energies (the energy of an X-ray can be thought of as analogous to the color of a specific wavelength of visible light). By measuring the shift in the X-ray energy by the time it reaches our telescope, as well as keeping track of the time delays between reflections from different parts of the disc (i.e., how long it takes the X-rays from the corona to reach different parts of the disc), we can see the echoes as the X-rays reflect off different parts of the disc, allowing us to build up a picture of the inflowing material and of the corona.

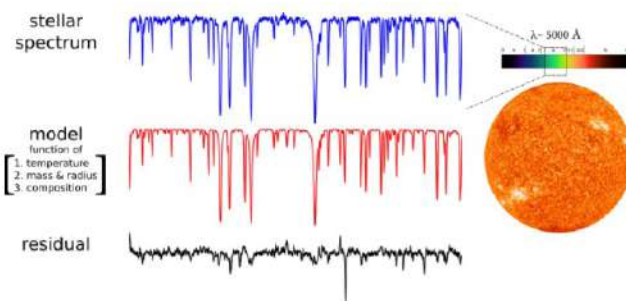
Observing the behavior of the corona during flares is giving important insight into exactly how it is energized and is even starting to give clues about the process that launches jets....

Ian Czekala examines the environments where planets form (first published September 21, 2017)

[Check out the original blogpost](#)

As an astronomer, I think I live in a spectacularly exciting time to be studying the process of planet formation. Little needs to be said about how dramatically the Kepler satellite telescope and other exoplanet

A demonstration of how fitting stellar spectra is often not straightforward (a stellar spectrum is the intensity of light from a star as a function of wavelength). The top spectrum is the data and the second row is one of the best-fit synthetic models. The bottom spectrum shows the residuals (data minus the model), which have a red-noise structure to them. Obtaining proper estimates of stellar properties like temperature, mass, and radius requires accounting for this covariant structure. (Credit: Ian Czekala.)



surveys have revolutionized our understanding of the exoplanet population, as these kinds of discoveries pop up in the news on a seemingly daily basis. We now know that the planet formation process produces a diverse set of final products, many of which (such as hot Jupiters and super Earths) look very different from the planets in our own solar system.

What may be less appreciated, however, is that we are also making great strides in understanding exoplanet formation by studying their birthplaces in ever

greater detail. High-resolution observations of protoplanetary disks, from the optical to sub-millimeter wavelengths, probe exoplanetary systems during their formation epochs and provide new evidence to help us understand the processes at work. What is exciting is that these two approaches of understanding planet formation—extrapolating backward in time from the exoplanet population and conjecturing forward in time from the initial conditions—are beginning to meet in the middle.

I have focused my attention on circumbinary disks because the presence of an additional star in the system creates an active dynamical environment and permits a more detailed characterization of the system architecture.

To understand these systems better requires a multi-wavelength approach, and so we turn to high resolution optical and infrared spectroscopy from a variety of echelle instruments (“echelle” refers to the instruments’ specialized diffraction gratings), such as the TRES spectrograph on Mt. Hopkins, to study the stellar photospheres. Because we have also obtained radial velocity measurements (in other words, figuring out how rapidly the star is moving towards and away from us, as it orbits the other) to precisely constrain the dynamics of the stellar orbit, we can check whether or not our disk-based measurements agree, and in the process search for interesting things like misalignment between the disk and the stellar orbital plane. The stringent dynamical constraints in such a multiple system also allow us to test pre-Main Sequence evolutionary models—which predict fundamental stellar properties like effective temperature, radius, and composition as a function of stellar mass and age—by comparing with our measurements.

With binary stars, however, there is an added complication. As the stars move in their orbits, we only ever see the “tangled” spectra. I recently developed a new technique that uses Gaussian processes to disentangle binary star spectra and simultaneously infer the orbital parameters, which opens new avenues for spectral analysis of multiple star systems, including precise stellar mass measurements. Improvements in our understanding of stellar properties help us refine our theories of how stars form and protoplanetary disks evolve, because these constrain the timescale (stellar age) and gravitational environment (stellar mass) for planet formation.

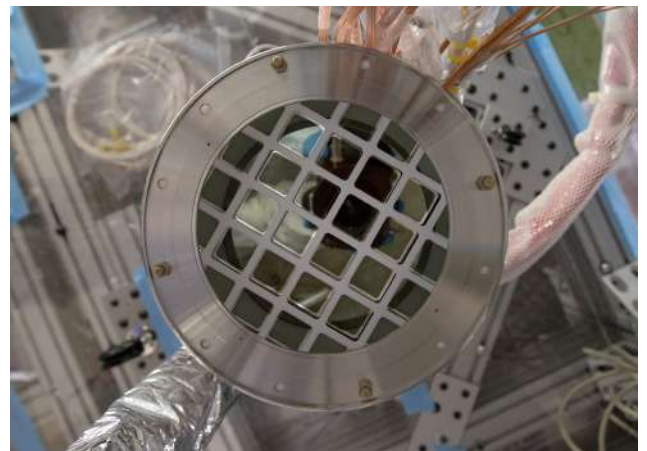
You can read more about KIPAC’s science at <http://kipac.stanford.edu/kipac/researchlist>, and follow us on Facebook at <https://facebook.com/KIPAC> and Twitter at <https://twitter.com/KIPAC1>



A portion of a special refrigerator called a dilution refrigerator that’s used by the SuperCDMS team to test detector crystals and their associated electronics.

Credit: Paul Brink.

It’s not too far-fetched to think that the equipment shown here, destined for dark matter experiments SuperCDMS-SNOLAB (left) and LZ (below), may provide fodder for upcoming blog posts....



This array of 32 photomultipliers, a type of light sensor, was put together by a team led by KIPAC postdoc Alden Fan and installed in a small-scale prototype of LZ, which will use nearly 500 of them when constructed.

Credit: SLAC National Accelerator Laboratory.



Top photo: KIPAC members on a retreat in the Sierra Mountains. Bottom photo: A gathering in the Fred Kavli Building on the SLAC National Accelerator campus.





From left: staff scientist Melissa Tallis and graduate students Sean McLaughlin and Adam Snyder bond over beer and bosons on a sunny afternoon.

LZ leads Dan Akerib and Tom Shutt having a seriously good time talking to Roger Blandford during a break from hiking.



A group of KIPACers discuss cosmic wonders while surrounded by earthly ones during a retreat in the Sierra Mountains.

A rapt group of KIPACers, past and present, listen to Aaron Roodman explain what goes on in the LSST cleanroom. (See page 8 to find out more.)



The latest crop of postdocs get their first taste of KIPAC hospitality. From left: Arka Banerjee, Susmita Adhikari, Jeff Chilcote, Shawn Henderson, Ioannis Liodakis, and Krista Lynne Smith.

Characterizing 51 Eri b from 1 to 5 μm : A Partly Cloudy Exoplanet, *The Astronomical Journal*. Extreme variability quasars from the Sloan Digital Sky Survey and the Dark Energy Survey, arXiv. Improving and Assessing Planet Sensitivity of the GPI Exoplanet Survey with a Forward Model Matched Filter, *The Astrophysical Journal*. Evidence That the Directly Imaged Planet HD 131399 Ab Is a Background Star, *The Astronomical Journal*. Measurements of resonant scattering in the Perseus cluster core with Hitomi SXS, arXiv. Individual, Model-independent Masses of the Closest Known Brown Dwarf Binary to the Sun, *The Astrophysical Journal*. Utilizing X-ray gas velocity measurements as a new probe of AGN feedback in giant elliptical galaxies, *American Astronomical Society*. Resonant scattering as a sensitive diagnostic of current collisional plasma models, *American Astronomical Society*. Core or Cusps: The Central Dark Matter Profile of a Strong Lensing Cluster with a Bright Central Image at Redshift 1, *The Astrophysical Journal*. CMB-S4 Technology Book, First Edition, arXiv. Broadband parametric amplifiers based on nonlinear kinetic inductance artificial transmission lines, *Applied Physics Letters*. Discovery and Physical Characterization of a Large Scattered Disk Object at 92 au, *The Astrophysical Journal Letters*. 1-2.4 μm Near-IR Spectrum of the Giant Planet β Pictoris b Obtained with the Gemini Planet Imager, *The Astronomical Journal*. Hard X-Ray Emission from Partially Occulted Solar Flares: RHESSI Observations in Two Solar Cycles, *The Astrophysical Journal*. Fermi Large Area Telescope Observations of High-Energy Gamma-ray Emission From Behind-the-limb Solar Flares, *APS April Meeting 2017*. Electromagnetic counterparts to Gravitational Wave events with the Fermi Large Area Telescope, *American Astronomical Society*. In-flight performance of the Soft Gamma-ray Detector (SGD) onboard Hitomi, 7 years of MAXI: monitoring X-ray Transients. Glimpse of the highly obscured HMXB IGR J16318-4848 with Hitomi, arXiv. Hitomi Observation of Radio Galaxy NGC 1275: The First X-ray Microcalorimeter Spectroscopy of Fe-K(α) Line Emission from an Active Galactic Nucleus, arXiv. Deriving the contribution of blazars to the Fermi-LAT Extragalactic γ -ray background at $E \sim 10^8$ GeV with efficiency corrections and photon statistics, arXiv. Atmospheric gas dynamics in the Perseus cluster observed with Hitomi, arXiv. Probing the EBL Evolution at High Redshift Using GRBs Detected with the Fermi-LAT, *The Astrophysical Journal*. Data-driven Simulations of Magnetic Connectivity in Behind-the-Limb Gamma-ray Flares and Associated Coronal Mass Ejections, *American Astronomical Society*. Is Flat fielding Safe for Precision CCD Astronomy? Publications of the Astronomical Society of Pacific. Searches for Angular Extension in High Latitude Fermi-LAT Sources, *American Astronomical Society*. Unveiling the cosmic history of light, *American Astronomical Society*. Fermipy: An open-source Python package for analysis of Fermi-LAT Data, arXiv. Hitomi X-ray studies of Giant Radio Pulses from the Crab pulsar, arXiv. US Cosmic Visions: New Ideas in Dark Matter 2017: Community Report, arXiv. Sloan Digital Sky Survey IV: Mapping the Milky Way, Nearby Galaxies, and the Distant Universe, *The Astronomical Journal*. The Atacama Cosmology Telescope: two-season ACTPol spectra and parameters, *Journal of Cosmology and Astroparticle Physics*. Search for Thermal X-ray Features from the Crab nebula with Hitomi Soft X-ray Spectrometer, arXiv. Complex Spiral Structure in the HD 100546 Transitional Disk as Revealed by GPI and MagAO, *The Astronomical Journal*. An Optical/Near-infrared Investigation of HD 100546 b with the Gemini Planet Imager and MagAO, *The Astronomical Journal*. Doppler effect on indirect detection of dark matter using dark matter only simulations, *Physical Review D*. VDES J2325-5229 $z = 2.7$ gravitationally lensed quasar discovered using morphology-independent supervised machine learning, *Monthly Notices of the Royal Astronomical Society*. Searches for Angular Extension in High Latitude Fermi-LAT Sources, *APS April Meeting 2017*. See Change: the Supernova Sample from the Supernova Cosmology Project High Redshift Cluster Supernova Survey, *American Astronomical Society*. A Blind Search Pipeline for Dark Satellites of the Milky Way in Gamma Rays, *American Astronomical Society*. Orbits for the Impatient: A Bayesian Rejection Sampling Method for Quickly Fitting the Orbits of Long-Period Exoplanets, *American Astronomical Society*. BLAST-TNG: A Next Generation Balloon-borne Large Aperture Submillimeter Polarimeter, *American Astronomical Society*. Accurate halo-galaxy mocks from automatic bias estimation and particle mesh gravity solvers, *Monthly Notices of the Royal Astronomical Society*. Inversion Domain Boundary Induced Stacking and Bandstructure Diversity in Bilayer MoSe₂, *Nano Letters*. Distributed Imaging for Liquid Scintillation Detectors, arXiv. Cosmic-ray propagation with DRAGON2: II. Nuclear interactions with the interstellar gas, arXiv. Comparing Fully General Relativistic and Newtonian Calculations of Structure Formation, arXiv. Millisecond pulsar origin of the Galactic center excess and extended gamma-ray emission from Andromeda - a closer look, arXiv. Advanced ACTPol Low Frequency Array: Readout and Characterization of Prototype 27 and 39 GHz Transition Edge Sensors, arXiv. Uncertainties in Parameters Estimated with Neural Networks: Application to Strong Gravitational Lensing, *The Astrophysical Journal Letters*. Full-sky Gravitational Lensing Simulation for Large-area Galaxy Surveys and Cosmic Microwave Background Experiments, *The Astrophysical Journal*. A Hitch-hiker's Guide to Stochastic Differential Equations, *Solution Methods for Energetic Particle Transport in Space Physics and Astrophysics*, *Space Science Reviews*. Sensitivity of the Cherenkov Telescope Array to the detection of a dark matter signal in comparison to direct detection and collider experiments, *Physical Review D*. On the galaxy-halo connection in the EAGLE simulation, *Monthly Notices of the Royal Astronomical Society*. The clustering of galaxies in the completed SDSS-III Baryon Oscillation Spectroscopic Survey: single-probe measurements from DR12 galaxy clustering - towards an accurate model, *Monthly Notices of the Royal Astronomical Society*. Productive interactions: heavy particles and non-Gaussianity, *Journal of Cosmology and Astroparticle Physics*. Constraints on Patchy Reionization from Planck CMB Temperature Trispectrum, arXiv. On the Bispectra of Very Massive Tracers in the Effective Field Theory of Large-Scale Structure, arXiv. ProtoDES: First On-Sky Technology Demonstration for the Dark Energy Spectroscopic Instrument, arXiv. Scientific Synergy Between LSST and Euclid, arXiv. Radiation Hardness of Fiber Bragg Grating Thermometers, arXiv. Learning Deep Context-aware Features over Body and Latent Parts for Person Re-identification, arXiv. Subaru Hyper Suprime-Cam Survey for An Optical Counterpart of GW170817, arXiv. Kilonova from post-merger ejecta as an optical and near-infrared counterpart of GW170817, arXiv. J-GEM observations of an electromagnetic counterpart to the neutron star merger GW170817, arXiv. Single-beam Dielectric Microsphere Trapping with Optical Heterodyne Detection, arXiv. The Architecture of the GW Ori Young Triple Star System and Its Disk: Dynamical Masses, Mutual Inclinations, and Recurrent Eclipses, arXiv. Probing Primordial Gravitational Waves: Ali CMB Polarization Telescope, arXiv. MC²S: Subaru and Hubble Space Telescope Weak-Lensing Analysis of the Double Radio Relic Galaxy Cluster PLCK G287.0+32.9, arXiv. On the IR-Resummation in the EFTofLSS, arXiv. Towards Replacing Resistance Thermometry with Photonic Thermometry, arXiv. Assessments of Ali, Dome A, and Summit Camp for mm-wave Observations Using MERRA-2 Reanalysis, *The Astrophysical Journal*. Realistic estimation for the detectability of dark matter subhalos using Fermi-LAT catalogs, *Physical Review D*. Dynamical dark energy in light of the latest observations, *Nature Astronomy*. No Ly α emitters detected around a QSO at $z = 6.4$: Suppressed by the QSO? $\langle \text{SUP} \rangle$, *Monthly Notices of the Royal Astronomical Society*. The clustering of galaxies in the completed SDSS-III Baryon Oscillation Spectroscopic Survey: cosmological analysis of the DR12 galaxy sample, *Monthly Notices of the Royal Astronomical Society*. On the level of cluster assembly bias in SDSS, *Monthly Notices of the Royal Astronomical Society*. An effective formalism for testing extensions to General Relativity with gravitational waves, *Journal of High Energy Physics*. A Challenge to Identify an Optical Counterpart of the Gravitational Wave Event GW151226 with Hyper Suprime-Cam, arXiv. DESCQA: An Automated Validation Framework for Synthetic Sky Catalogs, arXiv. Line-Intensity Mapping: 2017 Status Report, arXiv. Preliminary Results of the Fermi High-Latitude Extended Source Catalog, arXiv. The clustering of galaxies in the completed SDSS-III Baryon Oscillation Spectroscopic Survey: a tomographic analysis of structure growth and expansion rate from anisotropic galaxy clustering, arXiv. Studying cosmological γ -ray propagation with the Cherenkov Telescope Array, arXiv. Optical polarization variations in the blazar PKS 1749+096, arXiv. The Importance of Preventive Feedback: Inference from Observations of the Stellar Masses and Metallicities of Milky Way Dwarf Galaxies, *The Astrophysical Journal*. Observing and modelling the poloidal and toroidal magnetic fields of the global dynamo, *American Astronomical Society*. Quantitative modeling of multiwavelength observations of the behind the limb solar flares observed by Fermi and other instruments, *American Astronomical Society*. High-density array of ferroelectric nanodots with robust and reversibly switchable topological domain states, *Science Advances*. Prescriptions on antiproton cross section data for precise theoretical antiproton flux predictions, *Physical Review D*. Fast automated analysis of strong gravitational lenses with convolutional neural networks, *Nature*. The clustering of galaxies in the completed SDSS-III Baryon Oscillation Spectroscopic Survey: tomographic BAO analysis of DR12 combined sample in configuration space, *Monthly Notices of the Royal Astronomical Society*. Detection of baryon acoustic oscillation features in the large-scale three-point correlation function of SDSS BOSS DR12 CMASS galaxies, *Monthly Notices of the Royal Astronomical Society*. The clustering of galaxies in the completed SDSS-III Baryon Oscillation Spectroscopic Survey: on the measurement of growth rate using galaxy correlation functions, *Monthly Notices of the Royal Astronomical Society*. IR-safe and UV-safe integrands in the EFTofLSS with exact time dependence, *Journal of Cosmology and Astroparticle Physics*. HST Grism observations of the highest- z massive galaxy cluster, *HST Proposal id.15267. Cycle 25*. Resolving the Extragalactic Gamma-ray Background, *American Astronomical Society*. Exploring the particle nature of dark matter with the All-sky Medium Energy Gamma-ray Observatory (AMEGO), *American Astronomical Society*. Nanolayer and nano-convection based enhanced thermal conductivity of Copper-CO₂ nanofluid: A molecular dynamics approach, arXiv. DES Science Portal: II- Creating Science-Ready Catalogs, arXiv. Gaussian Prototypical Networks for Few-Shot Learning on Omniglot, arXiv. The imprint of neutrinos on clustering in redshift-space, arXiv. Theoretical Interpretation of Pass 8 Fermi-LAT e^+e^- Data, *The Astrophysical Journal*. A Simple Depth-of-Search Metric for Exoplanet Imaging Surveys, *The Astronomical Journal*. Magnetoluminescence, *Space Science Reviews*. Geometry and growth contributions to cosmic shear observables, *Physical Review D*. The clustering of galaxies in the completed SDSS-III Baryon Oscillation Spectroscopic Survey: towards a computationally efficient analysis without informative priors, *Monthly Notices of the Royal Astronomical Society*. Discovery of a $z = 0.65$ post-starburst BAL quasar in the DES supernova fields, *Monthly Notices of the Royal Astronomical Society*. The clustering of galaxies in the completed SDSS-III Baryon Oscillation Spectroscopic Survey: angular clustering tomography and its cosmological implications, *Monthly Notices of the Royal Astronomical Society*. Few-layer Tellurium: one-dimensional layered elementary semiconductor with striking physical properties, arXiv. The Fourteenth Data Release of the Sloan Digital Sky Survey: First Spectroscopic Data from the extended Baryon Oscillation Sky Survey and from the second phase of the Apache Point Observatory Galactic Evolution Experiment, arXiv. Opening the black box of energy modelling: strategies and lessons learned, arXiv. The Effective Field Theory of Large-Scale Structure in the presence of Massive Neutrinos, arXiv. Ab Initio Simulations of a Supernova-driven Galactic Dynamo in an Isolated Disk Galaxy, *The Astrophysical Journal*. Understanding Solar Cycle Variability, *The Astrophysical Journal*. Massively parallel

computation of accurate densities for N-body dark matter simulations using the phase-space-element method, *Astronomy and Computing*. Revisiting the extremely fast disc wind in a gravitationally lensed quasar APM 08279+5255, *Monthly Notices of the Royal Astronomical Society*. The large-scale three-point correlation function of the SDSS BOSS DR12 CMASS galaxies, *Monthly Notices of the Royal Astronomical Society*. The clustering of galaxies in the completed SDSS-III Baryon Oscillation Spectroscopic Survey: cosmic flows and cosmic web from luminous red galaxies, *Monthly Notices of the Royal Astronomical Society*. Clustering of Extremely Red Objects in the Subaru GTO 2deg Field, *Journal of the Korean Astronomical Society*. Isophote Shapes Of Early-Type Galaxies In Massive Clusters At $Z \approx 1$ and 0, *The Astrophysical Journal*. Galaxy Evolution Across Time. Layer- and doping-tunable long range ferromagnetic order-ing in two-dimensional CrS₂, arXiv. L-Edge Spectroscopy of Dilute, Radiation-Sensitive Systems Using a Transition-Edge-Sensor Array, arXiv. Geometry and growth contributions to cosmic shear observables, arXiv. Data Reduction Pipeline for the CHARIS Integral-Field Spectrograph I: Detector Readout Calibration and Data Cube Extraction, arXiv. Adversarial-Playground: A Visualization Suite for Adversarial Sample Generation, arXiv. Deep Optical Imaging of the COSMOS Field with Hyper Suprime-Cam Using Data from the Subaru Strategic Program and the University of Hawaii, arXiv. A Parameter Study for Modeling Mg ii h and k Emission during Solar Flares, *The Astrophysical Journal*. Radio continuum JVA observations of the dwarf galaxy Sextans A, *American Astronomical Society*. CMB internal delensing with general optimal estimator for higher-order correlations, *Physical Review D*. Magnetic bubble chambers and sub-GeV dark matter direct detection, *Physical Review D*. The effect of X-ray dust scattering on a bright burst from the magnetar 1E 1547.0-5408, *Monthly Notices of the Royal Astronomical Society*. The clustering of galaxies in the completed SDSS-III Baryon Oscillation Spectroscopic Survey: Cosmological implications of the Fourier space wedges of the final sample, *Monthly Notices of the Royal Astronomical Society*. Anisotropies in the flux of cosmic ray electrons and positrons, *Journal of Physics: Conference Series*. The Future of Black Hole Astrophysics in the LIGO-VIRGO-LPF Era, *Journal of Physics: Conference Series*. An effective description of dark matter and dark energy in the mildly non-linear regime, *Journal of Cosmology and Astroparticle Physics*. PSOAP: Precision Spectroscopic Orbits A-Parametrically, *Astrophysics Source Code Library*. Multiwavelength study of X-ray Luminous Clusters in the Hyper Suprime-Cam Subaru Strategic Program S16A field, arXiv. Two- and three-dimensional wide-field weak lensing mass maps from the Hyper Suprime-Cam Subaru Strategic Program S16A data, arXiv. The first-year shear catalog of the Subaru Hyper Suprime-Cam SSP Survey, arXiv. Distribution of the number of particles in the final state of hadron-nucleus collisions, arXiv. The Halo Boundary of Galaxy Clusters in the SDSS, *The Astrophysical Journal*. Disentangling Time-series Spectra with Gaussian Processes: Applications to Radial Velocity Analysis, *The Astrophysical Journal*. Disk-Jet Connection in Active Supermassive Black Holes in the Standard Accretion Disk Regime, *The Astrophysical Journal*. Orbits for the Impatient: A Bayesian Rejection-sampling Method for Quickly Fitting the Orbits of Long-period Exoplanets, *The Astronomical Journal*. The clustering of galaxies in the completed SDSS-III Baryon Oscillation Spectroscopic Survey: anisotropic galaxy clustering in Fourier space, *Monthly Notices of the Royal Astronomical Society*. GRACKLE: a chemistry and cooling library for astrophysics, *Monthly Notices of the Royal Astronomical Society*. The clustering of galaxies in the completed SDSS-III Baryon Oscillation Spectroscopic Survey: tomographic BAO analysis of DR12 combined sample in Fourier space, *Monthly Notices of the Royal Astronomical Society*. An automated system to measure the quantum efficiency of CCDs for astronomy, *Journal of Instrumentation*. Efficient exploration of cosmology dependence in the EFT of LSS, *Journal of Cosmology and Astroparticle Physics*. Subaru High-z Exploration of Low-Luminosity Quasars (SHELLQs). II. Discovery of 32 Quasars and Luminous Galaxies at $5.7 < z < 6.8$, arXiv. A Very Large ($\theta < \text{SUB-E} < \text{SUB} > 40^\circ$) Strong Gravitational Lens Selected with the Sunyaev-Zeldovich Effect: PLCK G287.0+32.9 ($z = 0.38$), *The Astrophysical Journal Letters*. Integral Field Spectroscopy of the Low-mass Companion HD 984 B with the Gemini Planet Imager, *The Astronomical Journal*. Hyper Suprime-Camera Survey of the Akari NEP Wide Field, *Publications of The Korean Astronomical Society*. Linear redshift space distortions for cosmic voids based on galaxies in redshift space, *Physical Review D*. Resolved Stellar Populations of the interacting galaxies of the M81 group, *Formation and Evolution of Galaxy Outskirts*. The Grism Lens-Amplified Survey from Space (GLASS). VIII. The Influence of the Cluster Properties on H α Emitter Galaxies at $0.3 < z < 0.7$, *The Astrophysical Journal*. Cosmic-Ray Transport in Heliospheric Magnetic Structures. II. Modeling Particle Transport through Corotating Interaction Regions, *The Astrophysical Journal*. Testing parity-violating physics from cosmic rotation power reconstruction, *Physical Review D*. J-GEM follow-up observations of the gravitational wave source GW151226*, *Publications of the Astronomical Society of Japan*. The clustering of galaxies in the SDSS-III Baryon Oscillation Spectroscopic Survey: RSD measurement from the power spectrum and bispectrum of the DR12 BOSS galaxies, *Monthly Notices of the Royal Astronomical Society*. Boost breaking in the EFT of inflation, *Journal of Cosmology and Astroparticle Physics*. Cosmic-ray propagation with DRAGON2: I. numerical solver and astrophysical ingredients, *Journal of Cosmology and Astroparticle Physics*. Testing redMaPPer Centering Probabilities using Galaxy Clustering and Galaxy-Galaxy Lensing, arXiv. First Data Release of the Hyper Suprime-Cam Subaru Strategic Program, arXiv. Placing the Spotted T Tauri Star LkCa 4 on an HR Diagram, *The Astrophysical Journal*. Exploring the Evolution of Star Formation and Dwarf Galaxy Properties with JWST/MIRI Serendipitous Spectroscopic Surveys, *The Astrophysical Journal*. Evidence against Star-forming Galaxies as the Dominant Source of Icecube Neutrinos, *The Astrophysical Journal*. The clustering of galaxies in the completed SDSS-III Baryon Oscillation Spectroscopic Survey: baryon acoustic oscillations in the Fourier space, *Monthly Notices of the Royal Astronomical Society*. The clustering of galaxies in the completed SDSS-III Baryon Oscillation Spectroscopic Survey: Cosmological implications of the configuration-space clustering wedges, *Monthly Notices of the Royal Astronomical Society*. The clustering of galaxies in the completed SDSS-III Baryon Oscillation Spectroscopic Survey: combining correlated Gaussian posterior distributions, *Monthly Notices of the Royal Astronomical Society*. The clustering of galaxies in the completed SDSS-III Baryon Oscillation Spectroscopic Survey: observational systematics and baryon acoustic oscillations in the correlation function, *Monthly Notices of the Royal Astronomical Society*. Hitomi X-ray Astronomy Satellite: Power of High-Resolution Spectroscopy, *The Multi-Messenger Astrophysics of the Galactic Centre*. Precision measurement for particle physics and cosmology, *APS April Meeting 2017*. Magnetizing the Universe during the Epoch of Reionization, *APS April Meeting 2017*. Searches for Axionlike Particles with the Fermi Large Area Telescope, *APS April Meeting 2017*. Resolving the Extragalactic Gamma-ray Background, *APS April Meeting 2017*. First NuSTAR observations of the BL Lac - type blazar PKS 2155-304: constraints on the jet content and distribution of radiating particles, *APS April Meeting 2017*. Searches for point sources in the Galactic Center region, *APS April Meeting 2017*. The GeV Galactic Center Excess-Uncertainties in the Measured Spectrum and Morphology and Dark Matter Implications, *APS April Meeting 2017*. Progress in Astrophysics of Cosmic Rays, *APS April Meeting 2017*. Nuclear recoil measurements with the ARIS experiment, *APS April Meeting 2017*. ALMA Measurements of Circumstellar Material in the GQ Lup System, *The Astrophysical Journal*. Isophote Shapes of Early-type Galaxies in Massive Clusters at $z \sim 1$ and 0, *The Astrophysical Journal*. First minute-scale variability in Fermi-LAT blazar observations during the giant outburst of 3C279 in 2015 June, *AIP Conference Proceedings*. PyXel: A Python Package for Astronomical X-ray Data Modeling, *American Astronomical Society*. Searching for short-duration transients in the Chandra archive, *American Astronomical Society*. The Primordial Inflation Polarization Explorer (PIPER), *American Astronomical Society*. The dark matter distribution of merging galaxy cluster PLCKG287.0+32.9 by weak lensing, *American Astronomical Society*. Probing the EBL evolution at high redshifts using 22 GRBs detected with the Fermi-LAT, *American Astronomical Society*. 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The Gemini Planet Imager Exoplanet Survey, *American Astronomical Society*. The Hard X-ray Imager onboard Hitomi (ASTRO-H), 7 years of MAXI: monitoring X-ray Transients. Hitomi observation of the Perseus cluster - gas motions and resonant scattering, 7 years of MAXI: monitoring X-ray Transients. An X-ray spectral variability of fast disk winds in AGN, 7 years of MAXI: monitoring X-ray Transients. Cosmology with the Square Kilometre Array by SKA-Japan, *Publications of the Astronomical Society of Japan*. Grackle: Chemistry and radiative cooling library for astrophysical simulations, *Astrophysics Source Code Library*. Tests of Neutrino and Dark Radiation Models from Galaxy and CMB surveys, arXiv. The Atacama Cosmology Telescope: The Polarization-sensitive ACTPol Instrument, *The Astrophysical Journal Supplement Series*. The AGORA High-resolution Galaxy Simulations Comparison Project, II. Isolated Disk Test, *The Astrophysical Journal*. A Weak Lensing View of the Downsizing of Star-forming Galaxies, *The Astrophysical Journal*. Galaxy-scale Gravitational Lens Candidates from the Hyper Suprime-Cam Imaging Survey and the Galaxy And Mass Assembly Spectroscopic Survey, *The Astrophysical Journal*. The Coupled Physical Structure of Gas and Dust in the IM Lup Protoplanetary Disk, *The Astrophysical Journal*. Dynamical Mass Measurement of the Young Spectroscopic Binary V343 Normae AaAb Resolved With the Gemini Planet Imager, *The Astronomical Journal*. Host Galaxy Identification for Supernova Surveys, *The Astronomical Journal*.

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Risa Wechsler for “innovation, insight, and attention to detail in understanding galaxy formation and evolution through combining large simulations and surveys; for leadership in large survey projects; and for mentorship of younger scientists.”

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Zeeshan Ahmed as one of a cohort of young scientists receiving funding to “support the development of individual research programs of outstanding scientists early in their careers and stimulate research careers in the disciplines supported by the DOE Office of Science.”

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

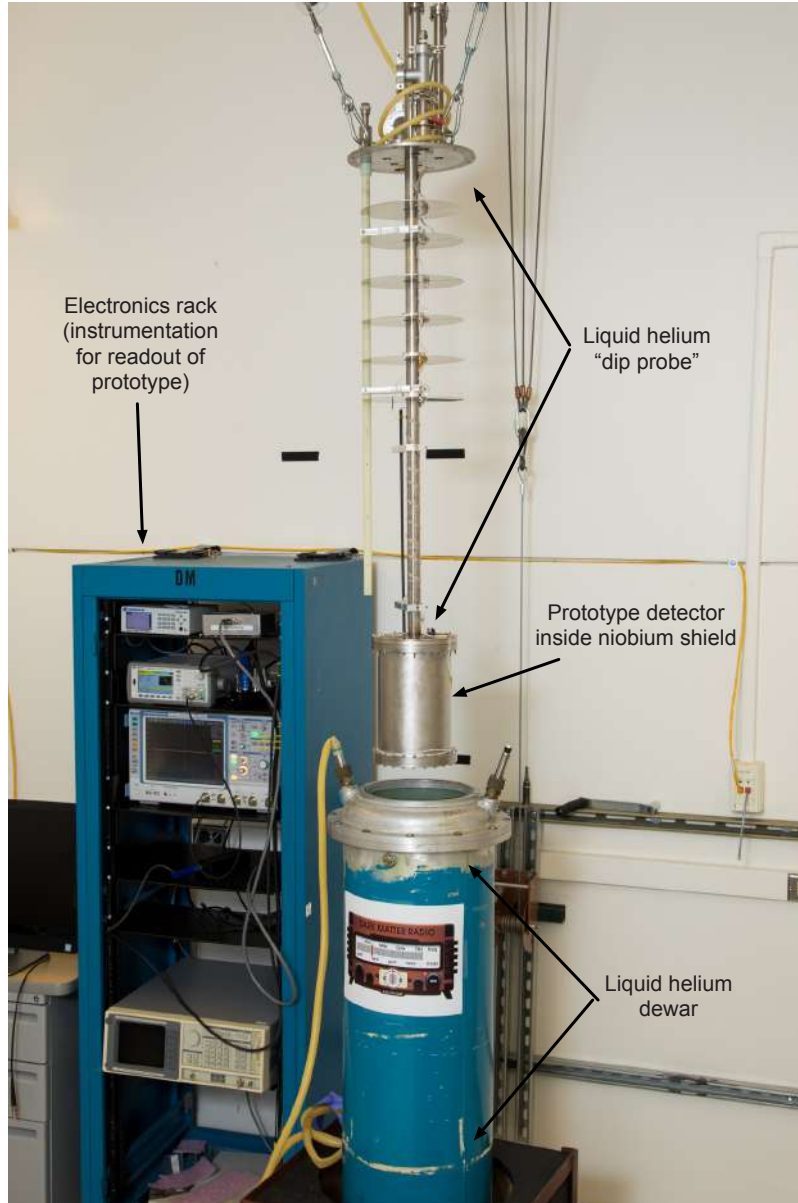
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Research update: DM Radio



Above: The Dark Matter (DM) Radio project has come a long way from where it stood when it was covered in last year's annual report. The detector, which will look for dark matter that is so light it's more wave-like than particle-like, has progressed from schematics and design document to a small-scale prototype instrument now scanning a relatively narrow frequency band for the faint signals of dark matter waves.

Ultimately, two full-scale DM Radios will scan frequencies in the kilohertz-to-gigahertz range, listening for the true music of the night.

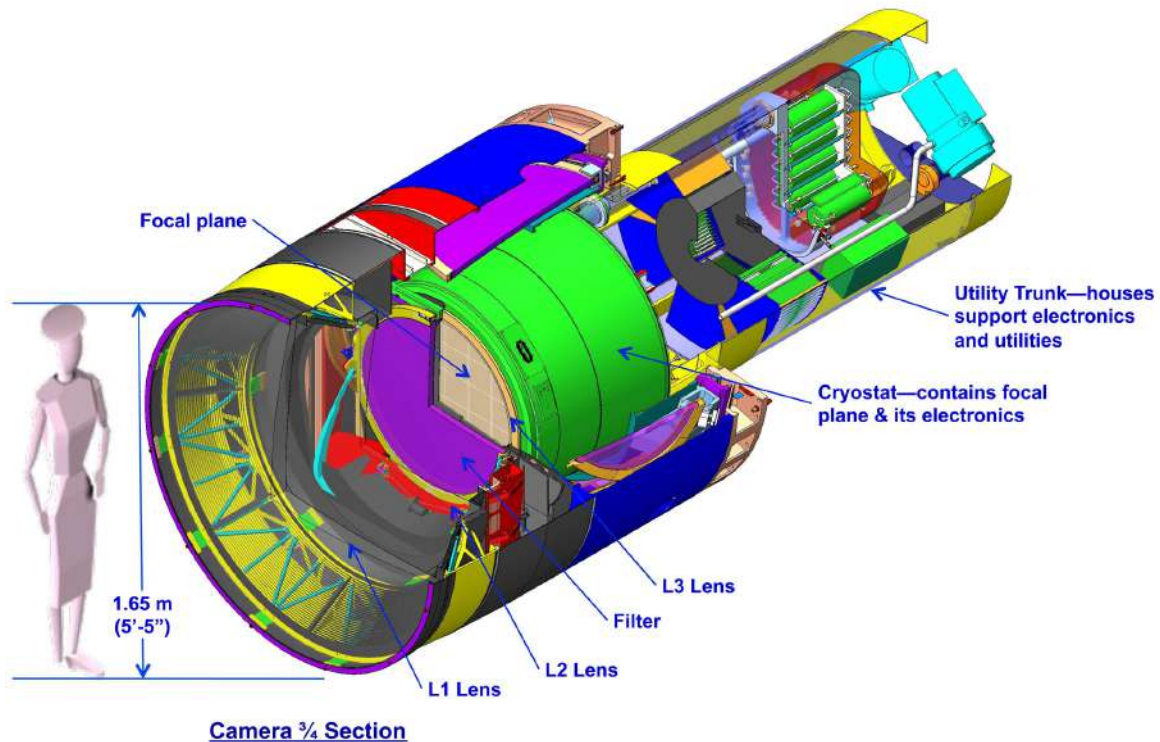
Photo courtesy Arran Phipps.

On the cover

A simulated night sky provides a background for the LSST facilities building on Cerro Pachón. 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.

KIPAC scientists are intimately involved in major aspects of the LSST project, including building the camera (see below and page 8) and preparing to analyze the data.

Credit: Todd Mason, Mason Productions Inc. / LSST Corporation.



Above: The LSST camera is designed to provide a wide field of view with better than 0.2 arcsecond sampling and spectral sampling in five or more bands from 400nm to 1060nm. The image surface is flat with a diameter of approximately 64 cm. The detector format will be a circular mosaic providing more than three gigapixels per image. The camera includes a filter mechanism and, if necessary, shuttering capability.

The camera is being assembled at SLAC National Accelerator Laboratory with extensive KIPAC involvement. See page 8 for more information.

Credit: LSST Project/NSF/AURA.



SLAC



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