Happy new year! I am pleased to share this report of KIPAC’s activities from the 2021-22 academic year, which highlights a few of the exciting achievements from KIPAC scientists in the past year.

This was a special year for many of us, returning back to campus and to in-person collaboration in Fall of 2021 after a year and a half working at home. We were also able to reconnect with our community—our public lecture series resumed in person, we organized an eclipse viewing party, and we offered new ways to connect with K-12 students about the universe. We also had a record number of undergraduate summer research students and held a three-day retreat for the KIPAC community.

KIPAC members continued to play key, leadership roles in various scientific discoveries and in large collaborations. The LUX-ZEPLIN experiment has obtained its first scientific data, reaching world-leading sensitivity for dark-matter direct detection. The X-ray Polarimetry Explorer (IXPE) revealed its first image, and will study the most extreme, violent events in the Universe in X-ray wavelengths. The DESI spectroscopic survey took its first data, and now already has taken more galaxy and quasar spectra than all other instruments combined.

Several other ongoing projects – including BICEP/Keck, DES, and COMAP—reported remarkable results, pushing the boundaries of our understanding of the Universe in multiple ways.

We are also thrilled to have new senior members joining the KIPAC community. Rebecca Leane, a theoretical particle astrophysicist, searches for dark matter in unexpected astrophysical environments and Noah Kurinsky, a KIPAC alumnus, returned to develop new technologies for detecting dark matter. Susan Clark, our newest faculty member, now leads the Cosmic Magnetism & Interstellar Physics group to study magnetic fields and the space between the stars using analytic models, observational data, and computer simulations.

We are expecting an exciting 2023. This year marks the 20th anniversary of KIPAC! It’s been an amazing two decades and we are looking forward to celebrating KIPAC’s many achievements as well as looking forward to the next 20 years of discovery. Events to celebrate this milestone include a Community Day on campus in April and a science conference in September. We are also very much looking forward to the future of our largest current project—the LSST camera, built by KIPAC scientists, will be shipped to Chile this summer, This powerful tool will allow us to survey the sky in unprecedented detail and will enable new discoveries based on deeper maps of the universe and new ways of seeing how the universe changes with time. We are also getting started on building the Rubin US data facility, which will host the data from the LSST survey for the entire US community.

Thank you for your continued support and dedication to our mission. We look forward to making more exciting discoveries and growing as a community in the year to come.

Sincerely,

Risa Wechsler
Director, Kavli Institute for Particle Astrophysics and Cosmology
Meet Rebecca Leane, a trailblazing KIPAC member who looks for new ways and new places to search for dark matter as a theoretical particle astrophysicist.

The chance to solve big mysteries initially drew Leane to particle physics. “I’ve always been really attracted to both mysteries and physics, and understanding things that nobody else yet understands,” she says. Then she found a bigger mystery: Dark matter—matter we can’t see, can’t grab onto, but we know it’s there because of how it affects normal matter. “But we haven’t found it yet, or at least we haven’t found a clear signal of its fundamental particle nature.”

As a PhD student at the University of Melbourne, Leane began searching for dark matter at CERN’s Large Hadron Collider, until one facet of the dark matter mystery caught her attention. “All the evidence we have to date about dark matter comes from astrophysics and cosmology,” she says. “This makes it dark matter’s natural habitat, and a very well-motivated search arena.” This is what prompted her to add “astrophysics” to her “particle theorist” title; she now investigates how astrophysical systems and their data can inform theories of dark matter as a fundamental particle.

Astrophysics has another selling point for Leane. She was drawn to the plethora of astrophysical objects available for study: stars, planets, galaxies, black holes, and more. “I really enjoy getting creative with the range of options, thinking, ‘How do I use these systems to find out about dark matter?’”

The elusive nature of dark matter has required a reassessment of what it is and how to find it. But for Leane, that’s a feature, not a bug, because it makes her playground bigger. “I try not to stick to just one particle physics theory for what dark matter could be.” Instead, she focuses on generic signatures dark matter might potentially produce. For example, many theoretical models have dark matter interacting with itself—two particles annihilating to create gamma rays, which are very detectable. This significantly expands the search area, which can seem a mixed blessing—like trying to find a specific gold coin in a dragon’s hoard—but for astrophysics, more options are better because large amounts of high-quality, unambiguous, analyzable data are often hard to come by.

For example, measurements of the center of our own Milky Way show a promising excess of gamma rays, but the center is also a messy, chaotic place that has other possible sources of these high-energy rays. In fact, subsequent analyses of the excess had pointed more towards neutron stars as the primary source.

In a series of papers in 2019 and 2020, Leane and collaborator Tracy Slatyer...
reevaluated the case for neutron stars. They found that the statistical analysis used to determine whether neutron stars were a more probable source of the gamma rays could easily be biased against showing a dark matter contribution. Dark matter was back on the table.

Being able to pin the gamma-ray excess on dark matter is important, as it would constitute the first non-gravitational evidence of the mysterious substance and could provide new insights. For an unambiguous signal researchers need a large concentration of dark matter, which facilitates more annihilations, to isolate it from conflicting background signals.

This has prompted Leane to look in other places where dark matter may be concentrated. A promising prospect is based on another model-based characteristic of dark matter: it may scatter off electrons or atomic nuclei. In doing so, it may lose energy and be captured by the gravity of the object it ran into. In other words, Leane’s calculations show that stars and planets can capture and concentrate dark matter.

And that’s what Leane is researching now—she’s playing with celestial objects, looking for the most likely target. A signal can show up in various ways; dark matter annihilations deep inside an object would result in excess heat, while dark matter annihilating on or close to the surface of an object would result in ionizing radiation that could create detectable chemical byproducts.

A recent project of Leane’s looked for excess gamma rays from Jupiter, which is big enough to capture extra dark matter but cool and close enough to allow detection of lighter dark matter. But for a dark matter heating signal, Jupiter isn’t ideal; it’s still on the small side for Leane’s purposes. Her next creative leap brought her to giant exoplanets and brown dwarfs.

It also helped lead her to KIPAC.

“All the evidence we have to date about dark matter comes from astrophysics and cosmology,” she says. “This makes it dark matter’s natural habitat, and a very well-motivated search arena.”

“Stanford and SLAC have an amazing reputation,” Leane says. “The groups here have some of the best people in the world. They’re just excellent.” Leane has been able to partner with Bruce Macintosh, exoplanet expert and KIPAC’s former deputy director, and dark matter detector expert, Noah Kurinsky, who is a fellow KIPAC staff scientist, to help her expand her research areas further (see pages 8-9).

Where does Leane see herself in five years? Still searching for searches?

“To some degree, you do have to go where the research leads you,” she admits. “If I find that one of my new search ideas returns a significant excess consistent with dark matter, I would pursue that closely. Overall, my overarching goal is to find out what dark matter is, so I want to continue to broaden the search space to maximize our chances of discovery. Another thing that I would like to do is answer the question of this already existing gamma-ray excess at the Galactic center. Is it dark matter or not?”

But it’ll be fun, and Leane will do it at KIPAC.

“It’s one of the best places I could possibly be.”
Little X-ray Telescope Helps Answer BIG QUESTIONS

On December 9, 2021, a SpaceX Falcon 9 rocket launched from Cape Canaveral with a tiny, 730-pound satellite tucked into a payload fairing able to carry 15 tons to orbit. That satellite was the Imaging X-ray Polarimetry Explorer (IXPE), a NASA Small Explorer mission built in collaboration with the Italian Space Agency that looks at high-energy X-rays from some of the most extreme, violent events in the Universe.

Targets of interest for the telescope include supernovae, active galactic nuclei, pulsars and the fast-moving nebulae fanned by pulsar winds, magnetars, blazars and radio galaxies, and accreting black holes.

Since IXPE studies a very specific characteristic of these X-rays—their polarization, or the direction in which their light waves oscillate—it needs a bespoke orbit to protect it from regions of high cosmic-ray flux that can not only cause false positives but can even damage the satellite’s instruments. This required the Falcon 9 rocket to steer not up, not down, but sideways, to drop the little satellite off over the equator.

KIPAC professor Roger Romani is a pulsar expert and co-investigator of the IXPE mission. He’s also the co-chair of the mission’s Science Advisory Board, which means he’s responsible for selecting the objects IXPE looks at. Romani considers the special treatment warranted.

“X-rays are hard to study,” he says, and studying X-ray polarization is especially difficult. Measuring the polarization of light coming from, for example, a supermassive black hole at the center of a distant galaxy needs lots of photons (relatively speaking) to enable researchers to determine the origin of that subtle twist with any confidence.

According to Romani, even though polarimeters are often proposed for observatories, they are often the first to go when cost, mass, or budget constraints raise their ugly heads. However, “It’s a super powerful way to study objects,” Romani says. Polarimetry can provide information about the structure of magnetic fields and gas clouds around objects, and is therefore worth the effort. “So we decided to propose a mission that’s only a polarimeter.”

IXPE is the result: three identical X-ray telescopes and three identical X-ray detectors, all grouped around a central axis and working independently. The
Polarimetry can provide information about the structure of magnetic fields and gas clouds around objects. “It’s a super powerful way to study objects,” Romani says.

Three sets of instruments ensure the maximum number of photons captured while also providing redundancy and the ability to cross-check results.

Several other KIPAC members also contribute to IXPE. In fact, two researchers—staff scientist Nicola Omodei and postdoctoral researcher Niccolò Di Lalla—were members of the Italian team at the National Institute of Nuclear Physics in Pisa that developed the detectors. Called gas pixel detectors, they exploit a phenomenon known as the photoelectric effect that occurs when a photon has enough energy to pop an electron completely out of its shell. In the case of the gas pixel detector, that electron is popped out of an atom of the gas, resulting in a glowing ionized trail in the detector. The polarization of the photon determines the direction the electron travels, and by combining this information with the track’s length and where it starts researchers can tell the direction the photon was traveling, how much energy it had, and how it was polarized.

“We did everything ourselves,” Omodei says. “We kept the detector in our lab where we had an X-ray tube we used to characterize it, we created a simulation to test different gasses, we changed the way the detector read the pixels…. We made it smarter.”

Di Lalla is now a member of IXPE’s pulsar wind nebula and magnetar working groups, where he spends his time on IXPE data analysis and software development. Along with Omodei, he has developed multi-mission maximum likelihood (3ML) software, which can be used to analyze data from the same target, but in different wavelengths and collected by different missions.

Di Lalla appreciates being a part of IXPE. Or, as Omodei puts it, “one of the youngsters.”

“To finally see the data and they are even more beautiful than the simulations, it’s amazing,” Di Lalla says.

KIPAC graduate student Lawrence Peirson also joined Romani’s group as a graduate student in 2021, and now, in addition to contributing to the analysis toolkit, studies pulsars and pulsar wind nebulae. Dinsmore is examining how Peirson’s improved analysis scheme can minimize polarization distortions of these nebulae.

“Polarimetry [the measurement and interpretation of the polarization of transverse waves] can be very useful in figuring out how charged particles are accelerated by magnetic fields,” Wong explains. Wong was able to contribute to an analysis of the Crab pulsar and associated nebula, one of the first IXPE targets.

Dinsmore says he joined the group due to an interest in compact objects like neutron stars and black holes. “I thought it was a really exciting branch of research to explore and one which still has many open questions. I’ve enjoyed my work on IXPE a lot, especially since my project has the potential to directly benefit lots of research, including the other grad students in my group!”

Wong considers herself fortunate to be a member of the collaboration. “The IXPE collaboration is big enough that you get good support if you have a question and there’s already analysis software available,” she says, “but it’s also small enough that you can work on your own project and really make a contribution.”

Or, as Romani says, “Any time you’re discovering things, it’s good.”
Way back in 2017, Noah Kurinsky was a KIPAC graduate student and an integral member of the Super Cryogenic Dark Matter Search at SNOLAB (SuperCDMS-SNOLAB), a direct-detection experiment that uses supercooled disks of germanium and silicon as targets for dark matter particles. During his time as a student, Kurinsky helped improve the detectors in use at the time, which were capable of detecting dark matter particles as small as 5 GeV in mass, about five times the mass of a proton. (Most dark matter searches—then and now—focused on WIMPs, weakly interacting massive particles that could theoretically be anywhere from 2 GeV to 100 TeV in mass.) Kurinsky also redesigned these detectors to enable them to sense energies 100 times smaller.

Another interest of Kurinsky’s during grad school was developing detectors that use quantum sensors, which rely on quantum effects to trigger their capabilities. In tandem with his SuperCDMS duties, Kurinsky worked with KIPAC professor Blas Cabrera on developing future detectors that would use such sensors.

Back then, in an interview for the 2017 KIPAC Annual Report, Kurinsky said, “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.”

A Stanford PhD, a stint as a Lederman Fellow at Fermilab, and a global pandemic later, Kurinsky is back at KIPAC as a SLAC Staff Scientist with a Department of Energy Early Career Award and his own lab, Dark Matter and Quantum Information at SLAC (DMQIS, pronounced “dimkwis”). At DMQIS, Kurinsky designs detectors that use quantum sensors based on superconducting qubits. Some designs incorporate exotic materials such as diamonds and narrow-gap semiconductors to look for meV dark matter. That “m” stands for “milli”—mass measured in thousandths of an electron volt.

According to Kurinsky, returning to Stanford (and KIPAC) was not a difficult choice. Several factors elevated the Stanford offer above others he received. “Kent [KIPAC professor Kent Irwin] has pushed the Fundamental Physics Department at SLAC in an exciting direction, and talking to him while being recruited helped,” Kurinsky says. This direction includes a “big new fabrication facility”—the SLAC Detector Microfabrication Facility, a “quantum foundry” under construction at SLAC. The facility is an integral part of Q-NEXT, a new Department of Energy research program that focuses on next-generation quantum technologies. The SLAC facility will provide superconducting devices such as SQUIDs (superconducting quantum interference device) and TESs (transition-edge sensors), and develop quantum sensing technologies based on qubits. The TES sensors are kept at temperatures of less than a Kelvin, causing them to hover on the edge of superconductivity. Any extra energy deposited in the detector—say, from a dark matter particle that collides with a carbon atom in the diamond—tips the sensor over from a superconductor into a classical conductor, registering as a potential hit. Thus, TES sensors are uniquely suited to dark matter direct detection experiments because of their extreme sensitivity.

Kurinsky has plans for his new resources. As a Lederman Fellow at
Fermilab, Kurinsky could choose his own avenues of research—which included subjecting small detectors to various “forms of abuse,” as Kurinsky put it, such as a neutron beam at a Duke University facility, in the quest to make them more robust. His time at Fermilab included a year spent studying the effects of radiation on qubits, which are the quantum-computing version of the digital ones and zeroes our own computers use in calculations. This experience taught him how to make detectors that are not only exquisitely sensitive, but dependable enough for complex experimental instruments.

“Career goals weren’t the only reason to come back to the Bay Area. The friends he made while here and the support of his colleagues also called him back to KIPAC. “I got engaged here. I got married here,” Kurinsky says. He pushed through his PhD program in less than four years, and, “Rich [Partridge, KIPAC SuperCDMS principle investigator] was very supportive. When my wife was studying for her boards, Martha [Siegal, long-time KIPAC administrative assistant] got her a desk to work at.”

In addition to his own work building next-generation detectors, Kurinsky is still a member of SuperCDMS-SNOLOB and hopes to include his new detectors in the next generation of the experiment. As dark matter particles of lower and lower mass are proposed, detectors made of atoms with lower and lower mass are necessary, he explains. “We’ve known for a long time that diamond would make an excellent detector, but only recently has industry made them cheap enough.”

Kurinsky is keeping an eye on other tantalizing materials that might work in future detectors. “The vision for CDMS is to have different towers for different weights of dark matter using different technologies,” he says. He hopes the search for dark matter at SNOLOB will continue to expand even beyond SuperCDMS. “Like it’s a dark matter observatory and CDMS is the first telescope.”

In the meantime, Kurinsky is still in the process of setting up his laboratory in a building that has some historic significance for KIPAC: it was the site where the Large Area Telescope—the main detector for KIPAC’s first major project, the Fermi Gamma-ray Space Telescope—was built. In the same building are his SuperCDMS colleagues and the team working on next-generation instruments for detecting the cosmic microwave background. All are dependent on supercooled sensors, and a big focus of the lab is how to integrate cryogenic coolers with the rest of the equipment.

“We’re taking the whole building back for astro cryo,” Kurinsky says, and he and his team are sure to make more KIPAC history.
Weighing WIMPS with LZ

Dark matter, the elusive material that makes up the majority of matter within our Universe, has been hypothesized to be anything from tiny, primordial black holes to an, as yet, undetected new particle. One popular dark matter particle candidate is called a WIMP, or a weakly interacting massive particle, with a range of possible masses from 1/1000th to 1000 times the mass of a proton.

“One reason we look for WIMPs is the ‘WIMP miracle’ or coincidence,” says Maria Elena Monzani, KIPAC senior researcher and the Deputy Operations Manager for LZ’s software and computing. If the particle-like dark matter was produced during the Big Bang, it would need to interact weakly with normal matter (one point for WIMPs) and have a mass around the size of a proton (another point for WIMPs) to explain the distribution of dark matter observed today.

LZ operates out of LUX’s former lab at the Sanford Underground Research Facility (SURF) inside of a massive subterranean cavern within South Dakota’s Homesteak gold mine. Its dark matter detector, a seven-ton vat of liquid xenon, is surrounded by a series of sensitive detectors and a massive tank of liquid water. Like a Russian nesting doll buried deep underground, LZ’s many outer layers serve as tracers for radioactive decay products emitted by the cavern walls and the experiment’s hardware.

“The dark matter signal we’re looking for is a single scatter off the nucleus of

Since 2012, KIPAC researchers have been working in collaboration with scientists from more than 30 institutions around the world to build the state-of-the-art, generation two LUX-ZEPLIN (LZ) dark matter detection experiment. This past July, the LZ collaboration released its first science results to the public. While the team did not find dark matter during the initial 60-day run, the nondetection marked a significant milestone for the lowest limits placed on the hypothesized dark matter particle’s size and area of interaction, motivating the next generation of detectors and astrophysical observations.
a xenon atom,” says Alden Fan, SLAC project scientist and co-lead on the analysis for the LZ collaboration’s first scientific results paper.

The inner detector is designed to directly observe the interaction between dark matter and ordinary matter through a phenomenon called nuclear recoil. Anywhere from millions to billions of dark matter particles pass through the atoms that make up our bodies everyday, but every once in a while, a particle may ‘bump’ into an atom’s nucleus, injecting energy and causing the emission of light, electrons, and heat. By applying a uniform electric field to the liquid xenon, any electrons ejected during a scattering event drift upwards to the second of LZ’s two-phase detection technology, a layer of xenon gas with an even higher electric field that causes the captured electrons to glow, or luminesce.

However, not only dark matter particles cause the emission of light and the release of electrons within the detector. Gamma rays, radioactive decay products, omnipresent radon, and even sparks from the thin wire grid generating the electric field create noisy backgrounds that can obscure the unique nuclear recoil signal of WIMP-like dark matter.

According to KIPAC Postdoctoral Fellow, Ann Wang, by measuring the brightness of the initial flash from the recoiling xenon nucleus and the afterglow from the displaced electrons, scientists can distinguish between background interactions and dark matter. Other factors, such as the time it takes for electrons to drift upwards to the xenon gas layer, provide critical information on where the scattering event took place.

Over 100 million scattering events pinged LZ’s detector during the 60 days of the experiment’s first run. By pruning the overwhelming petabyte of data based on known physical processes, scientists were able to search through a subset of a thousand or so events that could potentially contain the signature of dark matter.

“It’s an extreme needle in a haystack problem,” adds Monzani. “But we can remove nine orders of magnitude of the data by applying all of these cuts that describe background processes within the detector.”

Scientists then used a statistical analysis tool to determine whether dark matter was present within a particular signal or if the signal could be accounted for by other, non-dark matter sources. While all of the analyzed signals were inconsistent with any dark matter scattering events, LZ placed the most stringent limits on WIMP masses above 30 times the mass of a proton and was able to search for masses as low as 10 times that of a proton.

“In this first run, we ran just long enough to achieve the world’s best sensitivity, but it meant that the possibility of detecting new dark matter was pretty small,” says Fan. For the long term, LZ still has over an order of magnitude to go in further sensitivity.

“Right now, as part of the HydroX collaboration, we’re designing this set-up called hydroX to test an idea that if you add hydrogen to the detector medium, we could improve our sensitivity to lower-mass WIMP candidates,” says Wang.

Profs. Dan Akerib and Tom Shutt, together with Monzani, Fan and others are bringing their expertise from LZ to design a next generation experiment, which could contain up to one hundred tons of liquid xenon.

Together with their current competitors in the XENON-nT/DARWIN collaborations, they’ve formed the “XLZD” consortium to work toward that goal. “The technology is well demonstrated and consistently world leading,” says Akerib. “We can now envision the definitive experiment that will search for WIMPs down to the irreducible backgrounds imposed by nature.”
CONGRATS TO KIPAC

Congratulations to Ralf Kaehler [left] and Tom Abel for winning the first place prize in the 2021 Art of Science competition, for a beautiful rendition of streams of dark matter.

KIPAC senior scientist Maria Elena Monzani was appointed to the Vatican Observatory as an Adjunct Scholar.

An asteroid discovered in 2001 has been named after KIPAC physicist and former Rubin Observatory Project Director, Steve Kahn.

Congratulations to Risa Wechsler, KIPAC Director, on being named the 2022 Physical and Biological Sciences Distinguished Graduate Student Alumna by UC Santa Cruz.

Former KIPAC Deputy Director, Bruce Macintosh, was recently appointed the director of the University of California Observatories. Bruce also served on the steering committee for the Astro2020 Decadal Survey, which laid out a roadmap for astronomical projects over the next 10 and 20 years.

SLAC scientist and KIPAC member, Noah Kurinsky [left], and KIPAC alumnus, Keith Bechtol (currently an assistant professor at the University of Wisconsin-Madison), have received the Department of Energy Early Career Award. This award provides funding for research to support exceptional researchers during their crucial early-career years.
CMB-S4

CMB-S4 is a joint Department of Energy (DOE)-National Science Foundation (NSF) experiment that aims to image the cosmic microwave background (CMB), the afterglow of the Big Bang, to unprecedented precision. Twenty-one telescopes will be built at the South Pole and in the Atacama Desert in Chile for CMB-S4 to observe the southern sky through the 2030s. Data from these telescopes will be used by KIPAC and CMB-S4 scientists to tackle a variety of cosmological and astrophysical conundrums. We aim to search for gravitational waves generated by cosmic inflation, the rapid expansion of space-time in the early history of the Universe (as opposed to the ones generated by black hole or neutron star mergers that LIGO studies). Scientists can also use CMB-S4 to observe violent explosions and other transient phenomena in the Universe in

Left: The array of small aperture telescopes of the CMB-S4 experiment will observe the sky in nine bands, producing maps of the sky in different “colors.” Frequencies labeled on the bottom left corner of each panel are in Gigahertz. Right: Using different spectral properties of CMB and foreground objects, we can separate out the sought-after signal from the Big Bang. For example, a map of the polarized light originating from thermal dust emission of our Galaxy (middle) and a “cleaned” map of Cosmic Microwave Background B-modes (right). B-modes are a particular polarization pattern caused by primordial gravitational waves, which would lead to biased results in CMB-S4’s cosmic inflation search if contaminated by signals from foreground objects. (Image: Dominic Beck.)
CMB-S4 will search for gravitational waves generated by cosmic inflation; observe violent explosions and other transient phenomena in the Universe; and study the distribution and growth of the large-scale structure.

Millimeter bands. Finally, CMB-S4 will enable detailed studies of the distribution and growth of the large-scale structure, with the ancient CMB as a backlight behind it. Together with the results from optical galaxy survey datasets, such as Vera Rubin Observatory’s Legacy Survey of Space and Time, we will be able to place tighter and more reliable constraints on cosmological parameters.

Conceived in 2014, the CMB-S4 experiment has spent the last few years growing the science collaboration, refining its science case and goals, acquiring community support via Astro2020 and Snowmass 2021, developing a project team and advancing a conceptual design. The experiment is currently preparing for its agency reviews by the NSF and the DOE in 2024.

KIPAC scientists at SLAC have been playing a leadership role for this project. Kimmy Wu, Federico Bianchini, and Dominic Beck are preparing for CMB-S4’s cosmic inflation search. In particular, they have been investigating novel techniques to remove unwanted contamination in CMB images caused by emission from dust and electrons within our own galaxy, which could bias results from a future inflation search with CMB-S4. KIPAC scientists Zeeshan Ahmed and Shawn Henderson, together with SLAC engineers Gunther Haller and Ryan Herbst, have been developing the camera signal amplification and readout system. Last year, they connected the first prototypes of the sensors with their amplifiers in a test vacuum cryostat that operates at 0.1 degrees above absolute zero. The recorded signals demonstrated sufficient sensitivity for CMB-S4’s cameras, validating that the concept works! The KIPAC CMB-S4 team will continue with science simulation and camera sensor development in the following years.

BICEP/Keck

BICEP, a South Pole-based experiment on the CMB, is one of the flagship cosmology projects at KIPAC. In October 2021, the collaboration published the world’s leading measurement on primordial gravitational waves generated during the inflationary period. If the theory of inflation is correct and gravitational waves filled the early Universe, then a distinct signal pattern—called B modes—should be imprinted in the CMB. This latest result improved the previous limit by a factor of several, placing strong constraints on inflationary models. A large portion of the improvements comes from the addition of BICEP3 data, a large-aperture 95GHz telescope primarily designed and developed by KIPAC researchers. “Even though the once-promising inflationary
models have been disfavored [by our result], inflation as a paradigm is still safe and sound,” says Chao-Lin Kuo, the KIPAC professor who leads the BICEP/Keck team at Stanford/SLAC.

The uncertainty on the primordial gravitational wave measurement is currently limited by the contribution from gravitational lensing, which distorts the B-mode signals. Hence, the next big step in the analysis is to incorporate “delensing”—a reverse process to remove the lensing effect. The Stanford/SLAC team is leading one of the pipelines that leverages data from the South Pole Telescope to estimate this lensing component. Astronomical foregrounds, or signals emitted between the observers on Earth and the CMB, is another major source for measurement uncertainty. For example, dust in our own Milky Way galaxy can produce CMB-like radiation in certain wavelengths. For the upcoming year, KIPAC researchers will develop a 220/270 GHz receiver, at a frequency particularly sensitive to dust emission. Of a similar size to the BICEP3 telescope, this receiver will provide the most sensitive measurements on polarized emission from the interstellar dust when deployed to the South Pole Station in Fall 2023.

“Even though the once-promising inflationary models have been disfavored [by our result], inflation as a paradigm is still safe and sound.”
Cosmic Magnetism & Interstellar Physics Group

KIPAC’s newest faculty member Susan Clark leads the Cosmic Magnetism & Interstellar Physics group. Her team is working on a diverse set of problems, broadly focused on understanding the origin and influence of magnetic fields in galaxies, and the rich physics of the interstellar medium. The group’s work addresses the biggest questions in this field: What role do magnetic fields play in the formation of stars and structure in the interstellar medium? How does interstellar gas transition between different phases—from warm, diffuse plasma to the cold, dense birthplaces of stars? How does magnetohydrodynamic turbulence sculpt the interstellar environment?

The group tackles these complex questions using a combination of observation, simulation, and analytic theory. For example, graduate student George Halal uses atomic hydrogen emission to better understand the magnetic field structure in the most diffuse regions of the Milky Way galaxy. His work has a specific application to experimental cosmology: By characterizing polarized emission from the interaction of matter with the Galactic magnetic field, cosmologists are able to better measure faint signals in the polarized cosmic microwave background. Graduate student Marta Nowotka is pursuing new ways to combine different probes of interstellar magnetic fields in order to measure the three-dimensional magnetic field structure.

Graduate student Minjie Lei is studying the structure of cold and warm interstellar gas, and how these gas phases may be linked to the interstellar magnetic field. Research scientist Enrique Lopez Rodriguez leads a collaboration that is analyzing the magnetic field structure of nearby galaxies. Finally, a number of undergraduate students are working on a variety of topics, from theoretical work on turbulence in interstellar gas to new techniques for quantifying magnetic field morphology in data. With these frontier studies, members of the Cosmic Magnetism & Interstellar Physics group are leading innovative work on a broad range of questions in Galactic astrophysics.
DESI Year 1

The Dark Energy Spectroscopic Instrument (DESI) is an ambitious 5-year project to map the visible Universe in 3D, going much bigger and farther than its predecessors. This is accomplished using a 4-meter telescope to scan one-third of the entire night sky and measure the spectra of up to 5000 galaxies and quasars at a time. Within the first year of observations, DESI has already measured the spectroscopy for more than 15 million galaxies and quasars, 10 times more than all previous observations combined. Each spectrum tells us about the distance to the galaxy as well as many of its basic physical properties. The map made by DESI will be used to measure the expansion history of the Universe and the rate at which structure grows in exquisite detail. Together these measurements will revolutionize our understanding of the fundamental properties of the Universe, including dark energy, neutrinos, dark matter, and inflation. The large number of spectra will also inform our understanding of the complex physics of galaxy evolution, and will dramatically expand our understanding of the structure of the Milky Way.

KIPAC scientists are contributing to this project in a number of key ways and we are already learning exciting new aspects of our Universe. KIPAC Postdoctoral Fellow Sihan Yuan is co-leading the analysis of early DESI galaxy clustering data and developing model pipelines for the eventual full data analysis using state-of-the-art cosmological simulations. Sihan is also co-chairing the simulation working group within DESI and leading the galaxy-halo connection task force.

KIPAC graduate student Elise Darragh-Ford and KIPAC Director Risa Wechsler are also leading a special mini survey, the DESI LOW-Z Survey, focusing on the smallest and most nearby galaxies. These dwarf galaxies are exciting natural laboratories for understanding the process of galaxy formation at the smallest scales. Having accurate positions of these galaxies can also help us quickly pinpoint targets in the optical bands when gravitational waves or transient events are detected in other wavelengths or by other means. This program makes use of spare optical fibers—not needed for the main DESI observations—to target nearby low-mass dwarf galaxies using a combination of color- and brightness-based selection criteria and modern machine-learning methods.

A selection of the lowest-mass galaxies in the LOW-Z survey. These are dwarf galaxies in the nearby Universe, which have stellar masses that are roughly 0.01 to 0.1% the mass of the Milky Way. (Image: Darragh-Ford, Wechsler, and the DESI Collaboration).
1. BICEP / Keck XIII: Improved Constraints on Primordial Gravitational Waves Using Planck, WMAP, and BICEP/Keck Observations Through the 2018 Observing Season

BICEP/Keck collaboration, Physical Review Letters, 2021

Presents world-leading constraints on primordial gravitational waves as measured through the polarization of the cosmic microwave background (CMB) by the BICEP/Keck telescope series.

2. Current Status of the Ali CMB Polarization Telescope Focal Plane Camera

Salatino et al., IEEE Transactions on Applied Superconductivity, 2021

Presents the design of the Focal Plane Unit of the AliCPT telescope, a CMB telescope with one of the biggest focal planes to date that is currently under integration and testing at KIPAC.

3. The Origin of Parity Violation in Polarized Dust Emission and Implications for Cosmic Birefringence

Clark et al., Astrophysical Journal, 2021

Finds that the magnetic geometry of the filamentary ISM drives the observed correlation between the total intensity and polarization mode of Galactic dust emission, and predicts a not-yet measured Galactic dust polarization signature that could complicate searches for new physics with cosmic microwave background data.

4. Search for Lensing Signatures in the Gravitational-wave Observations From the First Half of LIGO-Virgo’s Third Observing Run


Finds no compelling evidence for gravitational-lensing signatures in the gravitational-wave signals from compact binary mergers.

5. Evolution of a Mode of Oscillation within Turbulent Accretion Disks

Wagoner & Tandon, Astrophysical Journal, 2021

Investigates the effects of subsonic turbulence and finds that turbulence does not weaken the oscillation modes, providing an explanation of why high-frequency quasi-periodic oscillations have not been produced by any computer simulations yet.

6. Integral Field Spectroscopy With the Solar Gravitational Lens

Madurowicz & Macintosh, Astrophysical Journal, 2022

Demonstrates that it may be possible to resolve the surfaces and atmospheres of extrasolar planets in detail by creating a Solar System-scale telescope with the Sun being a gravitational lens.

7. Investigating the Accretion Nature of Binary Supermassive Black Hole Candidate SDSS J025214.67-002813.7

Foord et al., Astrophysical Journal, 2022

Finds that a previously thought binary active galactic nucleus (AGN) is better explained by a reddened, single AGN model based on multi-wavelength data from radio to X-ray.

8. First Dark Matter Search Results From the LUX-ZEPLIN (LZ) Experiment

The LUX-ZEPLIN collaboration. e-Print: 2207.03764

Finds that the magnetic geometry of the filamentary ISM drives the observed correlation between the total intensity and polarization mode of Galactic dust emission, and predicts a not-yet measured Galactic dust polarization signature that could complicate searches for new physics with cosmic microwave background data.
First science results from the LZ Dark Matter experiment, establishing world-record sensitivity to weakly interacting massive particles (WIMPs)–a proposed candidate for dark matter.

9. Detection of Spatial Clustering in the 1000 Richest SDSS DR8 RedMaPPer Clusters With Nearest Neighbor Distributions


First successful detection of gravitational clustering–where galaxy clusters become more concentrated under the effect of gravity–using a novel statistical method (K-Nearest-Neighbor summary statistics) on real-universe massive clusters.

10. Single Classical Field Description of Interacting Scalar Fields

**Eberhardt, Zamora, Kopp & Abel, Physical Review D, 2022**

Simulates quantum systems to better understand how quantum mechanics affects the predictions of strongly interacting systems traditionally simulated with classical mechanical methods.

11. Resonant Nonlinear Pairs in the Axiverse and Their Late-time Direct and Astrophysical Signatures

**Cyncynates, Giurgica-Tiron, Simon, Thompson, Physical Review D, 2022**

Demonstrates that axions with similar masses can experience a novel form of nonlinear resonance (where the resonance frequency depends on the amplitude of the oscillation), which can significantly enhance their direct detection prospects and seed dark-matter substructure at scales of dwarf galaxies or smaller.

12. New Identifications and Multi-wavelength Properties of Extragalactic Fermi Gamma-ray Sources in the SPT-SZ Survey Field

**Zhang, Vieira, Ajello et al. (incl. Madejski), Astrophysical Journal, 2022**

Presents a novel technique to identify optical or radio counterparts of gamma-ray sources using data from the South Pole Telescope.

13. PSR J0952-0607: The Fastest and Heaviest Known Galactic Neutron Star


Presents a robust mass measurement of pulsar PSR J0952–0607, the fastest known spinning neutron star in the disk of the Milky Way, making it the heaviest pulsar found to date.
14. Priors on Red Galaxy Stochasticity From Hybrid Effective Field Theory
Kokron, DeRose, Chen, White, & Wechsler, MNRAS 2022
Develops an efficient and precise method to investigate the stochastic (or non-deterministic) properties of typical red galaxy samples.

Proposed a model to interpret the observations of the supermassive black hole in M87 made by the Event Horizon Telescope.

16. Cosmological Constraints From Gas Mass Fractions of Massive, Relaxed Galaxy Clusters
Mantz, Morris, Allen et al., MNRAS, 2022
Uses observations of the hot gas and dark matter in massive galaxy clusters to measure the expansion of the Universe over time, placing constraints on the cosmic density of dark matter and dark energy.

17. BASS. XXI. The Data Release 2 Overview
Koss, Trakhtenbrot, Ricci et al. (incl. Powell), Astrophysical Journal Supplement Series, 2022
Provides the census of accreting supermassive black holes in the local universe by providing the masses, accretion rates, and host galaxy properties of a highly complete sample of AGN.

18. Astrometric Gravitational-wave Detection via Stellar Interferometry
Fedderke, Graham, Macintosh & Rajendran, Physical Review D, 2022
Discusses the potential for gravitational-wave detection using extremely high-precision astrometry of a small number of non-magnetic, hot white dwarfs.

19. Illustrating Galaxy-halo Connection in the DESI Era With ILLUSTRIS-TNG
Investigates the connection between dark-matter halos and mock samples of Luminous Red Galaxies and Emission Line Galaxies using hydrodynamical simulations.

20. ADDGALS: Simulated Sky Catalogs for Wide Field Galaxy Surveys
Presents a methodology for creating large volumes of realistic sky surveys, which is being widely used by major survey collaborations including the Dark Energy Survey, the Dark Energy

Smoothed X-ray images of dynamically relaxed galaxy clusters at distances corresponding to looking 0.3 (left), 3.6, 5.7 and 8.3 (right; top to bottom) billion years into the past. Precise measurements of the gas and dark matter content of such clusters over a wide range of cosmic time provide powerful constraints on the cosmic expansion history. New observations of the Perseus Cluster have provided a precise anchor in the recent past, significantly improving constraints on dark energy.
KIPAC scientists used the NuSTAR and XMM-Newton X-ray telescopes to study bright flares emitted from material falling into a supermassive black hole.

21. COMAP Early Science. I. Overview

*The COMAP Collaboration (with Chung, Church, Wechsler), Astrophysical Journal, 2022*

First results from the CO Mapping Array Project (COMAP), which uses line intensity mapping of carbon monoxide (CO) to trace the distribution and global properties of galaxies over cosmic time.

22. Dark Energy Survey Year 3 Results: Cosmological Constraints From Galaxy Clustering and Weak Lensing


Key results from the Dark Energy Survey Year 3 data, which provide the strongest current constraints on matter clustering in the Universe.

23. Acceleration and Cooling of the Corona During X-ray Flares From the Seyfert Galaxy I Zw 1

*Wilkins et al., MNRAS, 2022*

First evidence that the corona of energetic particles surrounding a supermassive black hole cools down as it is launched away from the accreditation disk during X-ray flares.

24. Mapping the Magnetic Field in the Taurus/B211 Filamentary Cloud With SOFIA HAWC+ and Comparing With Simulation

*Li, Lopez-Rodriguez, Ajeddig et al. MNRAS, 2022*

Discovers that magnetic fields impede star formation in the filamentary dark cloud in Taurus by comparing observations with simulations.

25. Evidence for PeV Proton Acceleration from Fermi-LAT Observations of SNR G 106.3 +2.7

*Fang, Kerr, Blandford, Fleischhack & Charles, Physical Review Letters, 2022*

Provides strong evidence for proton acceleration in a nearby supernova remnant using 12 years of Fermi-LAT gamma-ray data, demonstrating that very high energy gamma-rays may have a distinct, hadronic origin.


*Leane, Shin, Yang et al., 2022*

Discusses avenues to resolve intriguing signals with excesses that could point to a dark matter origin, as well as actions the field can take over the next several years.

27. SNOWMASS2021 Cosmic Frontier: Cosmic Microwave Background (CMB) Measurements White Paper

*Chang, Huffenberger, Benson, Bianchini et al., 2022*

Outlines the broad and unique impact of CMB science in the upcoming decade and calls for the development of key capabilities and facilities needed to achieve transformative CMB measurements.

28. SNOWMASS2021 Cosmic Frontier Dark Matter Direct Detection to the Neutrino Fog

*Akerib et al., 2022*

Presents a summary of future prospects for direct detection of dark matter within the GeV to TeV mass range, and discusses plans for next-generation experiments and novel R&D concepts that will help us push past the “neutrino fog,” where dark matter signals become hidden underneath a remarkably similar-looking background from neutrinos.
Wren Suess, Stanford-Santa Cruz Cosmology Fellow

My research is focused on understanding how galaxies grow and evolve over cosmic time. Over the past year, I’ve worked with data from the Hubble Space Telescope, the ALMA radio array, and the new James Webb Space Telescope (JWST). I’m particularly interested in understanding how and why galaxies shut down their star formation as well as how galaxy sizes change over time and across wavelengths.

As a member of the JWST/NIRCam team, I’m excited for the coming year as we continue to collect more and more data with this amazing instrument! Lately, most of my days have been spent analyzing and understanding this rich new data. My first JWST project showed that massive galaxies are much smaller than they appeared in previous Hubble imaging, hinting at the many exciting revelations to come with JWST’s first look at the infrared universe.

Examples of two massive galaxies, which JWST reveals to be smaller than they appeared with HST. Left: infrared color images of two galaxies observed with JWST, and single-band black-and-white images at 4.4 microns (μm). This is the first time we have been able to study the sizes and structures of distant galaxies at these long wavelengths. Right: Data at 4.4μm, showing the difference between the data and two models. The best-fit 4.4μm model fits the data well (though you can see complex structures like spiral arms!) However, the 1.5μm model underestimates how bright the center of the galaxy is, indicating that the galaxy is more compact at longer wavelengths. This hints at complex structure and a variation in the stellar ages or dust properties across the galaxy. Image adapted from Suess et al. (2022c).
Taweewat Somboonpanyakul, Kavli Fellow

My research focuses on studying the properties and evolutions of clusters of galaxies and their massive central galaxies in order to understand different mechanisms that are responsible for the diverse groups of clusters we have observed so far. Together with other people from KIPAC, we have been working on discovering and characterizing new galaxy clusters in order to obtain more samples that we can use to study their evolution across the cosmic time.

I have used a wide range of ground- and space-based observatories from various wavelengths of light, including Hubble Space Telescope (optical), Chandra X-ray Observatory (X-ray), the South Pole Telescope (sub-millimeter), and the Magellan telescopes (optical). Each telescope allows us to study galaxy clusters from different perspectives, and a combination of these data will help us capture a full picture of what is going on in these systems.
Ann Miao Wang, KIPAC Fellow

I split my time between processing and analyzing data for the LUX-ZEPLIN (LZ) experiment and developing future liquid noble detectors. My first year at KIPAC coincided with an exciting time for LZ, which is an experiment designed to directly detect dark matter particles with a liquid xenon detector. We have recently released our first physics result with world-leading sensitivity, which I and several other KIPAC members contributed to.

On the detector research and development side, I am working on a small experiment (as part of the HydroX collaboration) to test the use of hydrogen in xenon for dark matter experiments, which could vastly improve LZ’s ability to detect dark matter particles with lower mass. A test stand will be hosted at SLAC’s Liquid Noble Test Facility (LNTF), which is home to an array of liquid noble detector R&D projects. I am also helping build a liquid xenon storage system to support the projects at LNTF.

An image of the clean tent at the SLAC Liquid Noble Test Facility (LNTF). The cylinder on the right (hanging from the top) is a detector formerly used in a system test for LZ, which will be repurposed for HydroX.
My research focuses on learning about the fundamental properties of the Universe and unlocking the secrets of galaxy evolution, using available information encoded in the distribution of the observed galaxies. In my first year at KIPAC, I am heavily involved in the Dark Energy Spectroscopic Instrument (DESI), which is the current flagship spectroscopic survey that observes the spectra of millions of galaxies to obtain their 3D positions and properties. Within its first year of operation, DESI has already observed more than 15 million spectra, more than all previous spectroscopic surveys combined!

My job is to develop models and analysis pipelines using huge computer simulations to analyze this monstrous amount of data. The level of precision (the bigger the sample, the more precise the measurement) we expect out of the DESI survey makes my job very challenging, because the smallest errors in the model can lead to a huge deviation in the science results. However, the exciting news is that we are already discovering new astrophysics with DESI’s early data and we can’t wait to find out more. Stay tuned!

The AbacusSummit simulations, which we use to build highly accurate models for DESI data. These simulations were run with the Summit supercomputers, the largest supercomputer in the world, and contain more than 60 billion particles—more particles than all previous cosmological simulations combined.
In a recent study led by KIPAC researchers, the authors placed the most stringent constraints to date on the mass of warm dark matter particles by combining two powerful probes of dark matter on small scales—strong gravitational lensing and ultra-faint dwarf galaxies.

Cold dark matter (CDM) cosmology makes a crucial, but unverified prediction: a large number of self-gravitating dark matter clumps, called “halos,” that are too small to form galaxies. Fainter galaxies live in smaller dark matter halos, and these dark, tiny halos are an important testing ground for dark matter models. In particular, the number of these small halos that formed in the early Universe and survive until today is sensitive to the microscopic properties of the dark matter particle, based on which there are theories about warm dark matter, sterile neutrinos, and axions. While the most straightforward way to hunt for small halos is simply to search for these tiny galaxies, detecting such ultra-faint dwarf galaxies is extremely challenging.

Our census of the faintest galaxies has dramatically improved in recent years thanks to the Dark Energy Survey (DES). By comparing the abundance of dwarf galaxies detected by DES to detailed simulations, KIPAC members and those in the DES collaboration have set precise constraints on the minimum halo mass for galaxy formation, along with a variety of dark matter properties.

“Strong gravitational lensing,” where the path of the light from a distant object is perturbed by the presence of matter along the line of sight, is another powerful tool for detecting tiny halos of dark matter. The strength and occurrence rates of such perturbations of light paths help us determine the presence and abundance of dark matter halos in our Universe.
How to Tease out the Tiniest Distortions of Galaxy Shapes to Probe the Secrets of the Universe
Adapted from the original version published on January 5, 2022

By Jamie McCullough

Measuring galaxy shapes in large quantities can lead us to a deeper understanding of how matter clumps together across space and time, telling us more about what our universe is made out of and the forces that shape it. However, shapes are only part of the picture. We need to know how galaxy shapes and colors respond to an artificial stretching, or shear, to probe the underlying matter distribution that distorts the light from those galaxies (this is called “weak gravitational lensing”).

In the year three (Y3) analysis of the Dark Energy Survey (DES), more than 100 million galaxies were observed with shape measurements. We need to understand the responsiveness of a galaxy to an applied shear due to gravitational lensing, so that we can use our shapes to measure the lensing shear itself. This is known as “shear calibration”, and it involves a very good set of image simulations that look as close to the real pictures as possible. The figure below shows a side-by-side comparison of the DES image simulations with real data.

The left image shows real data, while the right image shows the equivalent simulated tile. Note that large foreground objects like stars in our own galaxy are not simulated. In fact, these bright objects get masked out of our data analysis since they don’t tell us much about structure. (Image: DES Collaboration, MacCrann et al., 2021.)
A key part of measuring the cosmic structure is to determine the distances to the many galaxies we observe with our telescopes. As the Universe is expanding, distant galaxies are all moving away from us, and they appear redder than they really are because their motion effectively stretches the waves of light they emit. We use “redshift” to describe the reddening of a galaxy due to its recession, and getting a precise measurement of redshift is time consuming. We overcome this problem by taking a picture of each galaxy more than once, each time covering the camera with one of several filters which only let light of a certain range of colors through. The resulting redshifts we measure with images from these filters are called “photometric redshifts.”

In our latest work, we take advantage of a new way of combining color information from multiple telescope surveys of the sky using a type of machine learning algorithm called a self-organizing map. By combining colors from different telescopes, we reduce the uncertainty in our knowledge of the relationship between observed color and redshift. We used this algorithm to figure out distances to over 100 million galaxies observed by the Dark Energy Survey (DES). This new method improves our estimate of the average redshift of galaxies in our sample by approximately 50%, helping make the DES survey data the most powerful dataset of its kind.

Relative likelihood of a galaxy in our dataset to be at a given redshift, separated into four bins with a different range of redshifts. Each symbol represents how likely a galaxy from our sample is to be at a particular redshift. The symbol also represents the uncertainty we obtained on that likelihood: wider parts of the oval are of higher probabilities than narrower parts. (Figure: Myles and the Dark Energy Survey Collaboration, 2021.)
New research led by KIPAC PhD student Alex Madurowicz describes a novel technique to image Earth-like exoplanets in detail by using the Sun as a telescope. The gravity of the Sun lenses and magnifies light from a distant planet, but also distorts the image into what is now known as an Einstein ring. By tracing the path of light as it bends around the Sun, the Einstein ring can be deconstructed to recover an image of a distant planet. Using both the information encoded in the structure of the Einstein ring while scanning the telescope across the projected image of a distant exoplanet could improve the reconstruction even further. A number of instrumental engineering challenges still need to be overcome to make this vision a reality, including pinpointing a target planet in the sky, aligning the telescope with the sun and target planet, and removing contaminating light from the sun and surrounding objects.

Deploying a Hubble-sized telescope to the solar gravitational lens could enable observations that sound more like science fiction than science fact. By spatially and spectrally resolving the surfaces of extrasolar planets, one could investigate atmospheric composition and dynamics, and resolve details like oceans, continents, forests, and perhaps even extraterrestrial cities on other worlds. Who knows what fascinating and futuristic observations the twenty-second century will hold?
NASA’s Fermi hunts for long gravitational waves using pulsars

Adapted from the original version published on July 27, 2022

By Niccolò Di Lalla

Our Universe is believed to be filled with a chaotic sea of low-frequency gravitational waves, perturbations in space-time caused by orbiting pairs of supermassive black holes at the centers of merging galaxies. A long gravitational wave, passing between us and a pulsar (a rapidly spinning neutron star), will stretch or squeeze the very fabric of space, causing the light to arrive either early or late by just billionths of a second. For decades, scientists have been hunting for gravitational waves using large radio telescopes around the globe. Now a powerful new tool has been developed and the hunt has moved to space using gamma rays, the highest-energy form of light.

Using data from the Fermi Gamma-ray Space Telescope, the Fermi/LAT collaboration searched for the gravitational wave background (GWB) using (1) the common variation observed in gamma-ray pulse arrival times from pulsars; and (2) analytical models to infer the most likely set of parameters that describe the potential contribution from the GWB. The two methods give consistent results and, although no potential GW signal was detected, the authors were able to set an upper limit on the GWB amplitude. While the technique is not yet sensitive enough to make an actual detection, researchers think gravitational signals from supermassive black hole binaries could be within Fermi’s reach over the next five years.

Constraints on the gravitational wave background (GWB) from various means of measurements. The dashed red line shows the expected scaling of the Fermi-LAT limit as a function of time. Fermi will reach a sensitivity comparable to radio measurements in five to 10 years. (Figure: The Fermi-LAT Collaboration, 2021.)
1. **Saarik Kalia** completed his PhD with Professor Peter Graham. He explored novel methods for detecting dark matter and new models of a period of the early universe known as cosmic inflation. He is currently a postdoctoral researcher in the William I. Fine Theoretical Physics Institute at the University of Minnesota.

2. **Dinesh Kandel** worked with Professor Roger Romani on pulsar physics, focusing on the short-period binary stars known as black widows. His modeling of the optical and X-ray signals from these binaries helped identify the most massive neutron star known, with important implications for physics in extremely dense environments. Dinesh has taken a position as a Data and Applied Scientist at Microsoft.

3. **Ryan Linehan** worked with Professors Tom Shutt and Daniel Akerib to design, build, and analyze data from LUX-ZEPLIN, an experiment designed to make a direct detection of dark matter interacting with ordinary matter on Earth. Most of his effort focused on building and characterizing signals from the high-voltage electrode grids, which create necessary electric fields in the detector. Ryan is moving on to a postdoctoral research position with the Quantum Science Center group at Fermilab to develop new technologies for dark matter detection.

4. **Ji Won Park** worked with Dr. Phil Marshall and Professor Aaron Roodman to develop cosmological analysis tools for the Vera C. Rubin Observatory Legacy Survey of Space and Time (LSST). She applied machine learning algorithms to study the properties of strong gravitational lensing systems and supermassive black holes. Ji Won is now a Machine Learning Scientist at a biotechnology company, Genentech/Roche. She continues to collaborate with Phil, Aaron, and others at KIPAC as a citizen scientist.
Astrophysics Is for Everyone

This past academic year was a very exciting time for KIPAC outreach and engagement. With the Stanford campus reopening and two new staff members—Xinnan Du and Bryné Hadnott—hired, KIPAC is not only revitalizing its educational offerings, but also expanding our goals to share cutting-edge astrophysical research and the beauty of the cosmos with the public.

KIPAC Public Lectures

After a short hiatus, we restarted the Discover Our Universe public lecture series in February 2022, kicking it off with a presentation by the newest KIPAC faculty member, Susan Clark. Offered on a monthly basis and in a hybrid format, these lectures are typically given by KIPAC faculty, postdoctoral researchers, graduate students, and alumni. A special lecture series was planned with female astrophysicists who are also popular science book writers: Emma Chapman (April 2022), Chanda Prescod-Weinstein (May 2022), and Katie Mack (September 2022). KIPAC members that are subject matter experts on the topic of each lecture were recruited as moderators to answer live questions from the online audience, and the hybrid format enabled audiences from the Bay Area and all over the world to actively participate in the event at the same time. We are excited to offer an upcoming mini-lecture series on the James Webb Space Telescope (JWST) early science, and to present future lecture topics based on audience preferences and KIPAC specialties.

Telescopes Viewings & K-12 Sessions

To better engage younger learners and stargazing enthusiasts, we rolled out a few new outreach programs to offer various channels for these audiences to explore astronomy. These included telescope viewing nights, K-12 camp sessions, and bilingual (English/Spanish) outreach efforts. We hosted a “Blood Moon” lunar eclipse viewing party on the Stanford campus in May 2022, celebrating the celestial event with a few hundred people from the local community by watching the moon with telescopes (including two newly acquired Unistellar eVscopes) and binoculars. The “Virtual Astronomy Night” sessions, a quarterly joint event in collaboration with Stanford’s Camp Cardinal, introduced various astronomy concepts and phenomena to students in grades K-10 through hands-on activities. The sessions were so popular...

Left: Stanford-Santa Cruz Fellow, Johannes Lange, giving a public lecture on “Simulating the Universe” on July 5, 2022.

Below: The local community gathered on the Stanford campus to observe the “Blood Moon” lunar eclipse with KIPAC scientists.
that they reached the maximum capacity two weeks before the event. Finally, we established partnerships with several local high schools that have a large Spanish-speaking student population. Bilingual (English/Spanish speaking) KIPAC members will visit classrooms with presentations, hands-on activities, and their own career stories, to engage Latinx students in learning astronomy in a culturally relevant way.

**Summer Program & PUWMAS Scholars**

In Summer 2022, KIPAC welcomed a record number of more than 50 undergraduate students to conduct astrophysical research with KIPAC members. Similar to previous years, these students were recruited from Stanford, California community colleges, and universities nationwide through Cal-Bridge Summer, the Leadership Alliance Summer Research Early Identification Program (SR-EIP), the Science Undergraduate Laboratory Internships (SULI) at SLAC, and the Undergraduate Research Program in the Department of Physics at Stanford. Various professional development opportunities and social events were organized for the summer interns throughout the 8 to 10 weeks they spent on the Stanford campus. We invited a subgroup of 17 summer students, who are gender or ethnic minorities or first-time research interns, to become Physics Undergraduate Women and Gender Minorities at Stanford (PUWMAS) Summer Scholars. To help this group better navigate the academic environment, build community, and strengthen their Physics identity, we provided additional non-research advising and group activities through one-on-one chats, group meetings, and dinner gatherings. Ninety percent of survey respondents reported a significant increase in their physics identity and sense of belonging over the summer due to this advising support.

**Stanford PIE Workshop**

In an effort to demystify the field of Physics and broaden participation, KIPAC graduate students and staff, working with others in the Physics Department, organized a two-day, in-person workshop for nearly 40 undergraduate students (primarily underrepresented and first-generation students) in the Bay Area in July 2022. Aiming to provide the participants an introduction to the major subfields of Physics, the academic science environment, and possible career options with a Physics degree, the inaugural Stanford Physics, Identity, and Equity (PIE) workshop consisted of lab tours, research presentations by KIPAC members and participants themselves, graduate school and industry panels, professional development sessions, and social events. Through interactive activities, peer advising, and discussions, participating students excitedly shared that they felt motivated to pursue a Physics-related major and became more confident in applying for a research or degree program in Physics.
KIPAC Members

Senior Members
Faculty
Tom Abel
Daniel Akerib
Steve Allen
Roger Blandford
Pat Burchat
Susan Clark
Peter Graham
Todd Hoeksema
Kent Irwin
Steve Kahn
Chao-Lin Kuoh
David MacFarlane
Bruce Macintosh
Peter Michelson
Vahe Petrosian
Roger Romani
Aaron Roodman
Rafe Schindler
Laura Schaefer
Dustin Schroeder
Tom Shutt
Eva Silverstein
Risa Wechsler

Emeritus Faculty
Elliott Bloom
David Burke
Phil Scherrer
Bob Wagoner

Scientific Staff
Zeesh Ahmed
Rob Cameron
Eric Charles
Jim Chiang
Hsiao-Mei (Sherry) Cho
Seth Digel
Frederico Fuiza
Shawn Henderson
Tony Johnson
Ralf Kaehler
Noah Kurinsky
Brian Lantz
Rebecca Leane
Dale Li
Enrique Lopez Rodriguez
Steffen Luitz
Greg Madejski
Adam Mantz
Stuart Marshall
Phil Marshall
Maria Elena Monzani
Glenn Morris
Igor Moskalenko
Nicola Omodei
Peter Orel
Richard Partridge
Troy Porter
Andrew Rasmussen
Kevin Reil
Eli Rykoff
Keith Thompson
Dan Wilkins
W.L. Kimmy Wu

Graduate Students
Andrew Ames
Jadyn Anczarski
Tyler Anderson
Diogo Braganca
Dylan Britt
Elise Darragh-Ford
Taj Dyson
Andrew Eberhardt
Sydney Erickson
Anthony Flores
Geoge Halal
Claire Hebert
Ares Hernandez
Bryn Irving
Dinesh Kandel
Nicholas Kokron
Stephen Kuenstner
Minjie Lei
Ryan Linehan
Tom Lui
Alex Madurowicz
Sidney Mau
Guillem Megias i Homar
Jamie McCullough
Matwiws Mrbratu
Justin Myles
Yuka Nakato
Marta Nowotka
Abel Lawrence Peirson
Agustin Romero
Theo Schutt
Mahlet Shiferaw
Aviv Simchony
Jyotirmai Singh
Zoe Smith
Josh Tong
David Thomas
Bahrudin Tribač
Cady van Assendelft
Sebastian Wagner-Carena
Yunchong (Richie) Wang

Members
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Alden Fan
Agnès Ferté
Christina Ignarra
Maria Salatino
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Xinnan Du
Mandeep Gill
Bryné Hadnott
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Tanmoy Chattopadhyay
Ari Cukierman
Mia de los Reyes
Martijn De Vreis
Niccolò Di Lalla
Adi Foord
Neil Goeckner-Wald
Lucas Grosset
Johannes Lange
Shuang Liang

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2021-2022
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Director
Bruce Macintosh
Deputy Director
Andrea Davies
Managing Director

Advisory Committee
Daniel Akerib
Steve Allen
Pat Burchat

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Philip Mansfield
Eric Miller
Jorge Morales Mendoza
Meredith Powell
Taweewat Somboonpanyakul
Wren Suess
Ann Wang
Sihan Yuan
Homer Neal
Martin Nordby
Blair Ratcliff
Massimiliano Turri
Brian Van Klaveren

Associate Members

Postdocs
Sebastian Baum
Micah Buuck
Anirban Das
Fedja Kadribasic
Amon Patwardhan
Davide Racco
Maria Simanovskaia

Graduate Students
Zach Bogorad
Jason Corbin
Saarik Kalia
Anirudh Prabhu
Nicholas Rapidis
Jediah Thompson
Henry Zheng
Tony Zhang

2021-2022 FELLOWSHIPS

Postdoctoral Fellows
Kavli Fellows
Jelle Aalbers
Simon Birrer
Taweewat Somboonpanyakul

Porat Fellows
Adi Foord
Meredith Powell

Stanford Science Fellow
Mia de los Reyes

Stanford-Santa Cruz Cosmology Fellows
Johannes Lange
Wren Suess

KIPAC Fellows
Phil Mansfield
Ann Miao Wang
Sandy (Sihan) Yuan

Graduate Student Fellows
Chabolla Fellows
Bryen Irving
Sidney Mau

Giddings Fellow
Dylan Britt

NSF Graduate Fellows
Sydney Erickson
Sebastian Wagner-Carena

HEPCAT Fellow
Jason Corbin

Lieberman Fellow
Nickolas Kokron

Stanford Graduate Fellow
Mahlet Shiferaw

DARE Fellows
Claire Hebert
Justin Myles

Physics Fellow
Theo Shutt

Siemann Fellows
Justin Myles
Cyndia Yu

Data Science Scholars
Lawrence Peirson
Sebastian Wagner-Carena

Senior Associate Members

Post-baccalaureate Scholar
Arlene Aleman

Scientific Staff
Joanne Bogart
Sasha Buchman
Paul Brink
Concetta Cartaro
Richard Dubois
Tom Glanzman
Sven Herrmann
Heather Kelly

Josephine Wong
Cyndia Yu
To Chin Yu
Alvaro Zamora

Faculty
Bob Byer
Blas Cabrera
Sarah Church
Lance Dixon
Giorgio Gratta
Alex Friedland
Michael Peskin
Lauren Tompkins

KIPAC

Year in Review 2021-2022 | KIPAC
This past June, celebrated physicist, former Rubin Observatory Project Director, and KIPAC’s inaugural deputy Steve Kahn became the new dean of the Division of Mathematical and Physical Sciences at the University of California, Berkeley.

Kahn has crisscrossed the country (and the Bay Bridge) many times throughout his career, but his biggest leap was shifting from a decades-long career in X-ray astronomy to building the world’s largest digital camera for the Legacy Survey of Space and Time (LSST).

During the early 1990s, Kahn developed the first reflection grating spectrometer (RGS) to ever fly on an X-ray mission for the European Space Agency’s X-ray Multi Mirror Mission (XMM-Newton). Kahn’s prominence in X-ray astronomy led to a position on the steering committee for the 2000 Astronomy Decadal Survey. It was there that he was introduced to a novel proposal for the then-named Large-aperture Synoptic Survey Telescope. The goal of the project was unprecedented: survey the entire Southern sky every week to uncover the previously hidden structures unique to our dark energy-dominated Universe.

“The confluence of this new revolution in cosmology at the turn of the century and this new way of thinking about building a telescope as an experiment with particular measurements in mind, got me thinking, ‘this is what I want to do,’" says Kahn.

“I’m more of a physicist than an astronomer and the way a physicist thinks about a project like LSST is starting with what you’re trying to measure.” adds Kahn. “When KIPAC started, we defined it to be the ‘physics of astrophysics’ to fit in better with SLAC and the rest of the physics department.”

The study of the “physics of astrophysics” was a driving force in Kahn’s approach to designing LSST and growing KIPAC into a community of top-tier researchers, featuring rising stars like current KIPAC Director Risa Wechsler, Steve Allen, and Tom Abel. After serving as KIPAC’s deputy director from 2003 to 2007, Kahn became the director of Particle Physics and Astrophysics at SLAC, where he continued to garner support for LSST from private donors—including Microsoft billionaires Charles Simonyi and Bill Gates—the National Science Foundation (NSF), and the Department of Energy (DOE).

It wasn’t until 2011, after LSST was ranked at the top of the 2010 Astronomy Decadal Survey’s list of ground-based telescopes, that Kahn and the LSST team at SLAC received “Critical Decision 0” approval from the DOE. Finally, they could start construction on the eye of the telescope, a five-foot-wide, 3,200-megapixel camera able to image the deepest and faintest objects in the night sky. Kahn served as the LSST Project Director and the Camera Lead Scientist at SLAC for nearly a decade, guiding the development of the camera’s heart: a more than two-foot-wide focal plane made up of 189 individual imaging sensors.

“The camera was technically super challenging on almost all fronts. That’s one of the reasons I liked it,” says Kahn. “Every element of it was beyond the state of the art. It’s fundamentally different in architecture than all other astronomical cameras and of course, we had crises. Everything that could be broken, broke.”

“We learned from all of these tough starts and that really gave us a different perspective. You’re always trying to do something that’s by definition harder—it makes it exciting.”

While he won’t miss the three and a half hour commutes between his home in Berkeley and Palo Alto, Kahn will continue to remain involved at Stanford as a professor emeritus and as a core member of Rubin Observatory’s Project Science Team.

“We learned from all of these tough starts and that really gave us a different perspective,” reflects Kahn. “You’re always trying to do something that’s by definition harder—it makes it exciting.”
Alexandra Amon, now a Kavli Senior Fellow at the Kavli Institute for Cosmology in Cambridge, won the Tollestrup Post-Doc Award presented by the University Research Association in June 2022.

Kirk Barrow started as a Hubble Fellow at the Center for Astrophysics at Harvard University in November 2021, and joined the faculty at the University of Illinois, Urbana Champaign in Fall 2022.

Marusa Bradac has moved on from UC Davis to start a new faculty position at the University of Ljubljana in Slovenia. She received the prestigious European Research Fund in May 2022 to explore the first galaxies.

Jodi Cooley, professor of physics at Southern Methodist University and Deputy Operations Manager for the SuperCDMS Collaboration, has been selected to serve as the next Executive Director of SNOLAB, a deep underground research laboratory in Canada that studies neutrino and dark matter.

Carlos Cunha, now a Senior Data Scientist at Bosch Center for Artificial Intelligence, has acquired three patents since September 2021. He contributed to a driver-assistance algorithm deployed in major car brands.

Simon Foreman, now a PI-NRC Postdoctoral Fellow at the Perimeter Institute for Theoretical Physics in Canada, will be starting a new position as a postdoctoral associate at the MIT Kavli Institute for Astrophysics and Space Research in September 2022.

Lea Hirsch started a faculty position at the University of Toronto, Mississauga in Fall 2021.

Ryan Keisler joined KoBold Metals as a staff data scientist in March 2022.

Elisabeth Krause, now a faculty member at the University of Arizona, won the Early Career Award presented by the Universities Research Association in June 2022.

Ranjan Laha, an assistant professor at the Indian Institute of Science, Bangalore, has been awarded the Infosys Young Investigator fellowship, which recognizes high performing, early-career faculty.

Manuel Meyer, now a research group leader for high-energy astroparticle physics at the University of Hamburg, will start as an associate professor at the Centre for Cosmology and Particle Physics Phenomenology at the Southern Danish University in Denmark in January 2023.

Jessie Muir is now a Postdoctoral Fellow at the Perimeter Institute.

Ethan Nadler, now a postdoctoral fellow at Carnegie Observatories and the University of Southern California (USC), was awarded an inaugural Carnegie DEI grant to lead the course “Dark Matter & Data Visualization” for USC Hybrid High School students in Spring 2022, in collaboration with the Los Angeles arts education outreach organization Create Now.

Laurence Perreault-Levasseur, now a faculty member at Université de Montréal in Canada, was awarded the Canada Research Chair in Computational Cosmology and Artificial Intelligence in April 2022.

Jeff Oishi has been promoted to Associate Professor of Physics at Bates College in Maine.

Miguel Sánchez-Conde was tenured as an Associate Professor at Universidad Autónoma de Madrid in Spain in May 2022.

Sam Skillman, founder of the Outer Loop LLC, and Kyle Story, Climate Solutions Strategist at Muon Space, led a paper in Nature that made the first global inventory of photovoltaic solar energy generating units in October 2021.

Luigi Tibaldo, now a Staff Astronomer in the Institut de Recherche en Astrophysique et Planétologie in France, is serving as the coordinator of the Science Working Group of the Cherenkov Telescope Array (CTA) Consortium in 2022.

Samuel Totorica has been appointed as an Associate Research Scholar in the Department of Astrophysical Sciences in Princeton University since December 2021.
Discussions during the retreat covered science frontiers in the next decade, such as:

• The Legacy Survey of Space and Time, to take place at the Vera C. Rubin Observatory in Chile;
• High-energy astrophysics;
• Continuing efforts to extract information about the beginning of our Universe from the cosmic microwave background;
• The hunt for dark matter; and
• Facilitating satellite missions.

Of equal importance are efforts to ensure that the time spent at KIPAC is enriching for all members, no matter where they are in their academic or administrative careers. Breakout discussions were centered on building a more supportive community for everyone, refining graduate-level coursework, providing more professional development training for junior members, and better communicating our amazing science to the general public.

In addition to informal science presentations and discussions about goals and priorities, KIPAC members also enjoyed social hours and outdoor activities, with walks to the beach and biking in the Santa Cruz Mountains as particular favorites. We shared many exciting ideas and created many fond memories, and look forward to more community-building events in the future!

Top: KIPAC members gathered at the 2022 retreat, enjoying some time in the sun. (Photo: KIPAC.) Bottom: KIPAC members broke the ice on Day 1 of the retreat with a round of "speed collaboration"—sharing information about themselves and their research for five minutes before breaking and going to the next potential collaborator. (Photo: KIPAC.)
A warm welcome to our new staff members! We are thrilled to have Dr. Andrea Davies on board as our new Managing Director. Andrea was the Associate Director of the Stanford Humanities Center for seven years, and has extensive experience managing a strong staff team and building community. We are also excited to have Dr. Xinnan Du as our new Outreach and Engagement Manager. In addition to having a professional background in astronomy, Xinnan also has a strong track record in leading large outreach and public engagement projects. Last but not least, we are delighted that Bryné Hadnott joined us as a Data Curator and Storyteller. Bryné contributes to KIPAC’s efforts in outreach, communications, and student engagement, as well as managing data presentation for the Galaxy Formation & Cosmology group.

The “new-hire trio” (from left to right: Bryné, Andrea, and Xinnan) on the Stanford campus. (Photo: KIPAC)

KIPAC is sad to say goodbye to two administrative staff members this past year. Ryan Auer, our research administrator, helped many KIPAC members with their research proposal budgets. Kelly Carson, assistant for KIPAC director, played an essential role in supporting internal KIPAC events including community lunches, socials, and retreats. Ryan and Kelly were valued members of our team, and we wish them best of luck in their future endeavors!

Ryan (left) and Kelly (right) getting some Christmas treats from Santa (David Stricker, KIPAC admin) at the KIPAC holiday party in December 2021. (Photo: Martha Siegel)