

KIPAC ANNUAL REPORT 2016

KAVLI INSTITUTE FOR PARTICLE ASTROPHYSICS AND COSMOLOGY

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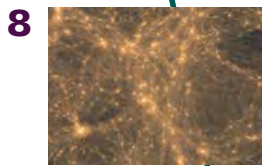
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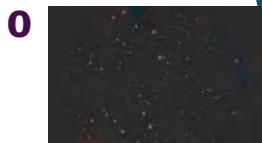
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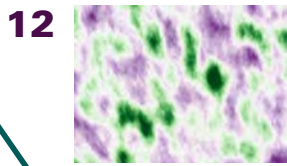
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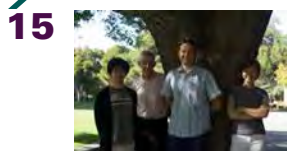
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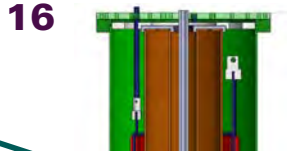
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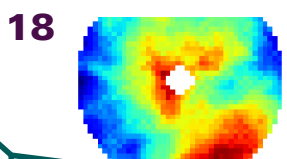
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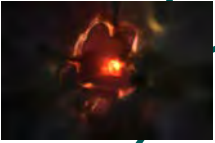
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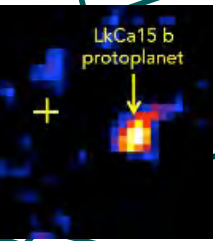
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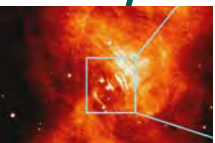
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Collaboration, in all its forms

Collaboration has always been an important part of science. The dedicated researcher making important scientific discoveries alone in a lab is a romantic image with some basis in historical fact, but that type of science is growing increasingly rare. While certain types of science can still be done very effectively with a small team, the types of questions being asked today are often too big, too complex, too interdisciplinary, or just too expensive to investigate alone.

Modern science takes its greatest strides forward when scientists work together effectively.

KIPAC embraces the idea of collaboration in all its forms, from the big-C sense of the word—a collaboration as a formal organization of scientists, often international in scope, with representatives from multiple institutions that pool resources to tackle a big research project (think the Fermi/LAT collaboration or the LSST Dark Energy Science Collaboration)—to extremely informal collaborations of a couple of KIPAC researchers who realize they can help each other, and everything in between. This issue of the KIPAC annual report will introduce you to just a few of the many joint scientific ventures KIPAC scientists are undertaking to bring a greater knowledge of the universe to everyone.

At KIPAC we like to play well with others.

Tom Abel



Hack Day at the spring LSST-DESC Collaboration meeting on the SLAC campus. Photo courtesy KIPAC.

Elliott Bloom Retirement Symposium

KIPAC hosted the Elliott Bloom Symposium on Friday, March 18, 2016 to celebrate our colleague's long and very distinguished tenure as a physicist, and congratulate him on his retirement. During the symposium Elliott's colleagues and former students discussed his work in particle physics, where he began his career, including deep inelastic scattering and development of the Bloom-Gilman duality, the BC42 bubble chamber experiment, and the development and long life of the Crystal Ball detector, which has traveled from SPEAR, at SLAC, to DESY, and finally to Mainz, Germany, where it is closing in on 40 years of service. (But Elliott still has it beat by a decade!)

We also covered the growth of particle astrophysics at SLAC, where Elliott made many more contributions, including the USA experiment and the Large Area Telescope, the main instrument on the Fermi Gamma-ray Space Telescope (previously known as GLAST). We talked about the results from these space experiments, including progress in indirect detection searches for dark matter.

We are grateful that Elliott continues to contribute to the Institute's intellectual life now as well as for all he has done to make the Institute a reality and the wonderful place to work it is today.

Tom Abel



Counting up our collaborations

KIPAC is fast approaching its 15th anniversary—quite a milestone to many of us who have been here from the beginning—but KIPAC is still a very young institute compared to our host institutions; Stanford University is 125 years old this year, while SLAC National Accelerator Laboratory is a respectable 54.

We benefit greatly from our association with these two institutions, renowned for fostering collaborations that advance science. Stanford is internationally known as a research powerhouse, and SLAC holds decades of experience supporting collaborations in the field of particle physics, from the Nobel Prize-winning SLAC-MIT collaboration that scattered electrons off neutrons and protons, thus confirming the quark model, to BaBar, the multi-national collaboration that used B and anti-B quarks to confirm CP violation.

KIPAC has earned leadership roles in several compelling astrophysics collaborations, in many cases contributing to the design and construction of cutting-edge scientific instruments and the analysis of the data they return. Some of these collaborations are hard at work now. The Fermi-LAT Collaboration is using the Fermi Gamma-ray Space Telescope's main instrument, the Large Area Telescope (assembled at SLAC), to map the universe in gamma rays. The Cryogenic Dark Matter Search (CDMS) Collaboration is looking for dark matter particles, and the BICEP and Keck Array Collaborations are studying the cosmic microwave background with instruments at the South Pole. The Dark Energy Survey (DES), one of the first big projects to investigate dark energy, relies on KIPAC-provided technology to optimally focus DECam—its giant CCD camera—and software to improve data analysis.

Dark energy is also the focus of two collaborations that are key to the future of research in astrophysics and cosmology. The Dark Energy Spectroscopic Instrument (DESI) will be used to make a 3D map of tens of millions of galaxies and quasars. The LSST Dark Energy Science Collaboration (DESC) will use data from the Large Synoptic Survey Telescope (LSST), soon to be deployed in Chile.

With SLAC serving as both the lead national laboratory for the LSST Camera and the host laboratory for the LSST DESC, it's not surprising that KIPAC members hold major roles in the collaboration, either in the DESC management or as co-conveners of working groups, and sometimes both. SLAC is the permanent site of the DESC winter collaboration meetings, and provides computing support, space for visitors and meetings, and a home-away-from-home for far-flung collaboration members.

KIPAC also has a big stake in the future of dark matter research with the LUX-ZEPLIN and Super CDMS Collaborations. A recent smaller scale collaboration between KIPAC members Kent Irwin and Peter Graham that the institute is supporting is leading to a novel experiment they call "DM radio." It will look for a particular type of dark matter candidate and rule out large amounts of parameter space—or if we're very lucky, discover new physics there.

KIPAC members recently deployed a new instrument for millimeter spectroscopy, called Argus, at the Green Bank Radio Telescope in West Virginia. The Argus detector array, constructed at Stanford, will vastly improve mapping speeds and allow rapid surveys of substantial areas of the sky with high spectral resolution.

KIPAC members also participate in the analysis of data from the Hitomi Japanese–US X-ray astronomy satellite. Although this satellite-based mission stopped functioning, the analysis of the early data is ongoing and is providing important insight into the structure of clusters of galaxies, which are important tools in measuring cosmological parameters, and establishing limits on the properties of potential dark matter candidates such as sterile neutrinos. Since the early Hitomi data proved very compelling, a reflight of a similar mission is being considered, and KIPAC members intend to collaborate in such an effort. For the more distant future, KIPAC scientists are members of the definition team planning for the next, European-led major X-ray observatory ATHENA, which should provide new insight into the growth and structure of galaxy clusters as well as massive black holes inhabiting the centers of most galaxies in the Universe.

This by no means comprises an exhaustive list of collaborations in which KIPAC plays a significant role. The majority of KIPAC researchers, from graduate students to faculty, thrive within organized collaborations, and the reasons are simple: collaboration is often how science is done, and science is why KIPAC exists.

Pat Burchat, Greg Madejski, and Risa Wechsler



Roger Blandford wins Crafoord Prize

Black holes captivate us with their very existence. The idea that an object can be so massive that not even light can escape its gravitational pull is awe-inspiring; if that were the only characteristic known about these cosmic behemoths, it would still be enough to earn them a place in our collective imagination.

Black holes not only devour any matter that ventures too close to their event horizons, certain types of black holes are the most energetic engines in the universe. These active galactic nuclei (AGN), supermassive black holes feeding on clouds of gas and dust at the centers of galaxies, can shine more brightly than the combined light of hundreds of Milky Ways. They can propel tremendous jets of particles across distances of light years at speeds approaching that of light.

KIPAC member Roger Blandford has contributed significantly to our understanding of how such engines work, and thus to our understanding of the lives of the rotating, supermassive black holes that give rise to them. His work was recognized this year with the 2016 Crafoord Prize in Astronomy, which he shared with New Zealand mathematician Roy Kerr, for “fundamental work concerning rotating black holes and their astrophysical consequences.”

Blandford, in collaboration with a succession of colleagues, built on the work of Kerr, who, in 1963, solved Albert Einstein’s equations of general relativity for rotating black holes. In an important step, Blandford and graduate student Roman Znajek used Kerr’s mathematical description to model how the extreme environment of a supermassive black hole’s accretion disk—with intense gravitational fields, extremely high rates of spin, rotating magnetic fields, and exotic fluid dynamics—could extract energy from the black hole’s rotation. With other colleagues, Blandford continued to extend and refine that description to include relativistic jets.



2016 Crafoord Laureates (L to R): Roy Kerr (Astronomy), Yakov Eliashberg (Mathematics), and KIPAC’s Roger Blandford (Astronomy). Credit: Markus Marcetic.



KIPAC's Roger Blandford, delivering his Crafoord Prize Lecture, "Revealing the Black Hole."
Credit: Hans Reuterskiöld.

In May, Blandford traveled to Sweden for Crafoord Days, a three-day celebration of the 2016 Crafoord laureates and their scientific achievements, where he lectured on black holes and accepted his award from Carl XVI Gustaf, the King of Sweden.

"I and my family had a wonderful time and everyone we met in Sweden was very kind and hospitable, and I enjoyed the opportunity to talk with Roy Kerr and [2016 Crafoord Laureate in Mathematics] Yakov Eliashberg," Blandford said. The timing of the event held a special significance, he added, because the first detections of gravitational radiation from merging black holes had been announced just a few months prior.

"The future is bright for black hole research," Blandford said. "Two new avenues of investigation are very promising; gravitational wave astronomy is a new frontier in astronomy and we'll learn a lot from it, and the Event Horizon Telescope project, which harnesses radio telescopes around the world to image black holes, will tell us if our theoretical descriptions of the environment surrounding them are correct." Black holes and their roiling accretion disks are only one area interest for Blandford. He has also studied neutron stars and white dwarfs, gamma-ray bursts, gravitational lensing, and the evolution of the universe, and garnered many other awards for his work, including the Dannie Heineman Prize from the American Institute of Physics and the American Astronomical Society, and the Gold Medal of the Royal Astronomical Society.

And, of course, he was the director of KIPAC from its inception in 2003 to 2013. Blandford says he's enjoying the extra time and opportunity he has now to do more science, including research on black holes with his KIPAC colleagues.

Award-winning ideas for exploring the birth of the universe

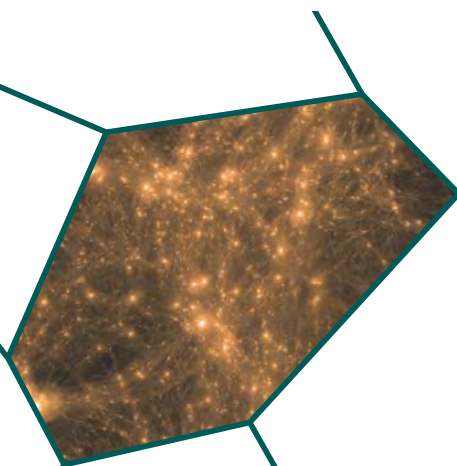
For the past 400 years—ever since Galileo pointed his telescope at the night sky and saw four pinpricks of light orbiting Jupiter—astrophysicists and astronomers have been pushing the boundaries of the observable universe back in both space and time, finding tiny galaxies and nascent supermassive black holes from less than a billion years after the Big Bang. But there's a hard limit to how far back they can see using known technology, because until about 380,000 years after the Big Bang, all of expanding space was filled by a super-hot cloud of charged particles that kept all the photons—the light we see—bouncing around inside.

KIPAC faculty member Leonardo Senatore has been developing tools for peering through that impenetrable cloud and back to the epoch of inflation, an unimaginably brief fraction of a second during which our known universe expanded from smaller than an atomic nucleus to about the dimensions of a soccer ball (by some estimates). His work adapting a powerful analytical technique from particle physics for use on a cosmological scale garnered him the 2016 New Horizons in Physics Prize “for outstanding contributions to theoretical cosmology.”

Among other ideas, Senatore has developed what's called an effective field theory (EFT) to explain the evolution of large-scale cosmological structures. At first glance, an effective field theory covering phenomena at cosmological scales might seem a bit off-base, as the technique was first developed to create useful low-energy, large-scale approximations of physical processes, such as particle interactions, which take place at energies too high or distances too small to easily grasp. Subatomic particles are many, many orders of magnitude away from superclusters of galaxies connected by filaments of dark matter, which are the biggest classifiable objects in the known universe, forming sheets of intermingled matter and vacuum separated by immense voids.

But Senatore's theory has already demonstrated its efficacy with predictions that are in better agreement with observation than the cosmological perturbation theories in standard use. He's also working on EFTs for other cosmological phenomena, such as inflation itself.

The chief value of an EFT is in its descriptive power; using his EFT of large-scale cosmological structures, Senatore wants to describe the origin of these structures so completely he can follow the process back to the first instants of the universe, just after inflation had locked into the fabric of space the quantum fluctuations of matter and energy density that provided the template for the cosmic web we see today.



A simulation of the “cosmic web,” the network of dark matter filaments and halos that provides the scaffolding for the baryonic (normal) matter making up the objects we see in the universe. Visualization: Ralf Kaehler, Tom Abel. Simulation: Oliver Hahn, Tom Abel.



Leonardo Senatore

“I’m very interested in understanding the origin of the universe,” says KIPAC faculty member Leonardo Senatore. “And inflation is the biggest mystery of the beginning of the universe.”

One of the biggest mysteries of inflation since Alan Guth first proposed it in 1980 has been how to test it. The theory explains some nagging problems with the Big Bang version of the birth of the universe and remains a favorite of cosmologists, but most of the evidence for inflation remains circumstantial—progress has been made matching predictions based on various inflationary models to the results we see in the night sky, but the process itself is as perplexing as ever.

“Any understanding of inflation must be informed by our understandings of large-scale cosmological structures,” Senatore says. “I realized we don’t understand these larger structures well enough—that’s why I wanted to develop a theory to do reconstruct the quantum primordial fluctuations that gave rise to them. The theory reconstructs them in a very accurate way.”

Senatore’s effective field theory treats the cosmos on its largest scales as a fluid—taking such a distanced view causes individual galaxies, like individual atoms in a fluid, to disappear into the ebb and flow of the whole. (One intriguing discovery: the cosmos has the viscosity of chocolate syrup.) The theory can drill down, showing more and more detail, by adding more data from galactic surveys and cosmic microwave background observations, for example.

He doesn’t intend to stop at inflation. “Inflation had to talk to quantum gravity and vice versa,” Senatore says, “so inflation is the probe closest in energy to the scale of quantum gravity that we have at our disposal.”

The techniques he used to develop his theory are “very solid” in high energy physics, but applying them to astrophysics was a new development, Senatore says. He credits colleagues at the Stanford Institute for Theoretical Physics (SITP) for their help and Stanford University and KIPAC for their support and efforts to spread the word. “Stanford and KIPAC together make one of the best places in the world for doing this kind of science,” he says. “The work on these larger structures would have been impossible to do without the resources of SITP and KIPAC.”

Getting ready for the dark energy data deluge

In 2023, a 3.2-gigapixel camera mounted on the Large Synoptic Survey Telescope (LSST) will begin to capture images of a stunning variety of cosmological phenomena for a world-wide audience of astrophysicists, astronomers, and cosmologists. The LSST will harvest 15 trillion bytes of data per night for objects ranging from near-Earth asteroids to the oldest, farthest galaxies illuminating the universe with their faint red glow—and everything in between.

Nine different science collaborations have already formed to take advantage of the coming wealth of data. KIPAC plays a major role in the largest: the Dark Energy Science Collaboration (DESC). But one result of the LSST's unique role as agnostic information gatherer is that it can't play favorites with the data it delivers—no special cuts for solar system scientists; no custom analyses for exoplanet hunters. And the data itself will be public from Day One of a 10-year science mission.

What this means for the members of DESC is simple: The time to prepare for the LSST data deluge is now.

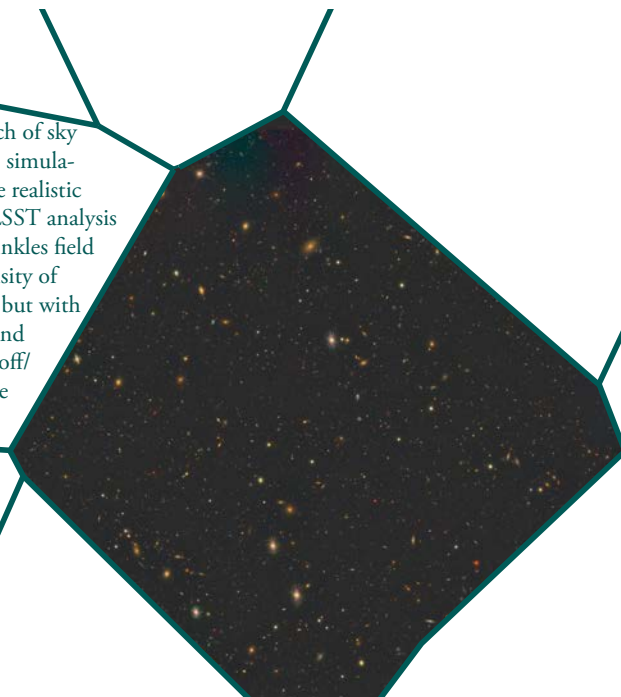
Before dark energy can be deciphered it must be described. How much has it contributed to the expansion of the universe from the Big Bang to the present? When, during the last 13.8 billion years, did it win the battle with gravity and start causing the rate of expansion to increase? Creating a clear, detailed description against which dark energy models can be compared will require the most accurate measurements of the structure of the universe ever attempted, and the LSST, with its petabytes of data about billions of galaxies, will be a big player in this game

Achieving that high accuracy will require researchers to understand everything that could go wrong with their measurements and build in fixes—and crucially, this needs to be done before they start analyzing LSST data, so that they can efficiently disentangle new problems from old ones.

Simulations are key to this effort, and several KIPAC scientists are leveraging their extensive experience with simulations to help identify and compensate for such errors in measurement, called systematic errors. By the time the LSST starts delivering data, DESC scientists will have vetted their analysis software against not only realistic simulations of the cosmic objects of study, but also against a virtual LSST, called phoSim, created using the telescope's specifications and designed to make simulated astronomical images as realistically as possible.

By the time the real data come along, they'll be ready.

The Twinkles field, a small patch of sky generated by the LSST photon simulator PhoSim, which will provide realistic simulated data against which LSST analysis tools can be validated. The Twinkles field contains an unrealistic overdensity of supernovae and lensed quasars but with realistic observing conditions and cadence. Credit: Simon Krughoff/ The LSST Dark Energy Science Collaboration.





Phil Marshall

Phil Marshall is uniquely qualified to play a lead role in DESC efforts to prepare for LSST data. He has been a member of the collaboration from the beginning, helping lay out the science case for DESC and plot the course the collaboration has been following in its pursuit of dark energy. Marshall is chair of the Collaboration Council, co-convenor of the Strong Lensing working group, and busy developing a simulation called Twinkles, which packs a tiny patch of sky with supernovae and gravitational lenses to see how well they can be measured with LSST. He has run mock data challenges where different groups analyze the same simulated data, mentored undergraduate students, and run Hack Days, communal prototyping sessions for fun and (scientific) profit.

But some of Marshall's qualifications are more philosophical in nature, going beyond dark energy to the pitfalls of investigating it—or any phenomenon ostensibly beyond our current reach, whether physical or conceptual. “What I'm most interested in is how we make measurements of things in the universe,” he says. “Our job in DESC is to analyze the LSST dataset and make discoveries about just a few of the parameters describing the universe. How do you measure something that's so hard to measure you need hundreds of people to do it?”

“Everyone in the collaboration knows that we somehow have to make this extremely difficult measurement [of cosmic expansion],” Marshall says, “but they are also aware that we're a group of hundreds of people, all with different biases and different ideas. Finding ways to work together is going to be a very important aspect of solving this problem.”

For example, DESC can use several different methods to measure the expansion of the universe and then compare the results. “But to do that well, we have to make sure we don't end up guaranteeing that they agree. The measurements have to be kept separate from each other and allowed to disagree.”

Marshall is one of a number of cosmologists advocating the adoption of a particle physics technique called blinding, in which the actual values of the inferred cosmological parameters are concealed until the analysis is declared complete.

“We must think of ourselves as part of the system,” Marshall says. “We can't allow ourselves to pretend that we're objective. The thing to do is to admit that subjectivity will creep in and then take steps to mitigate against it.”

Survey says—

Much of observational astronomy has centered on pointing progressively bigger telescopes at ever-farther objects in an effort to understand the more exotic denizens of the universe. But, in the same way trying to learn about a bustling city by studying a single house is problematic, trying to learn about the universe by studying individual objects—even in great depth and detail—is not sufficient.

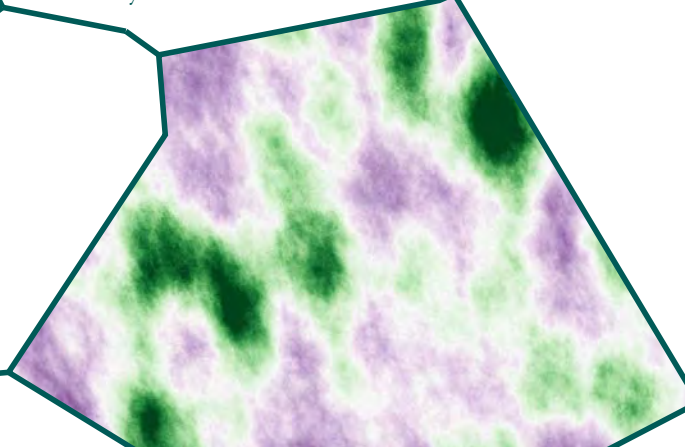
To truly understand the cosmos—its growth and evolution, the dark energy that may someday pull it apart, and the dark matter that currently holds much of it together—researchers need to see the big picture. They need to see how all the matter in the universe has organized itself under the influence of gravity into stars, galaxies, clusters of galaxies, clusters of clusters, out in space and back in time. Astronomical surveys are beginning to provide the data they need.

Several KIPAC members and alumni are currently participating in one such survey, called the Dark Energy Survey (DES), which will ultimately map millions of galaxies. For the past three years, DES has been spending part of each year taking exquisitely detailed images of one-eighth of the night sky above Chile with a 570-megapixel camera called the Dark Energy Camera (DECam).

DES is a photometric survey; researchers use the color and intensity of the light DECam collects to glean information, such as distance and recession rate, about the objects it surveys. But a lot happens to a photon during its journey across billions of light years from its origin in one of the first stars in one of the earliest galaxies. An expanding universe stretches its wavelength, as does traveling through immense gravitational wells. And even if a photon makes it to the Milky Way relatively unscathed, the final journey through our galaxy's dust clouds and our Earth's own atmosphere skews the view further.

KIPAC scientists have used their expertise in computational astrophysics to virtually remove these obstacles between ancient photons and DECam's silicon detectors. From creating simulations to test against, to modeling everything that can ruin the view from the Earth's surface to the edge of the Milky Way, to using known redshifts to calibrate photometric approximations, members of KIPAC have embraced the role of cosmic cartographer.

This image shows the relative density of redMaPPer galaxy clusters from a 256 square degree patch of the DES first-year data. Green regions show projected over-densities relative to the average matter density (white), and purple regions show voids. DES uses these galaxy clusters to track the growth of structure of the Universe over billions of light-years to probe dark energy and general relativity. Credit: Eli Rykoff/DES Collaboration.





Eli Rykoff

The Dark Energy Survey (DES) is taking a four-pronged approach to investigating dark energy, the mysterious force that's causing the expansion of the universe to accelerate.

In addition to looking at supernovae, weak gravitational lensing, DES will map hundreds of thousands of galaxy clusters. These clusters are made of old, red stars, built up from some of the earliest forming galaxies in the densest regions of the Universe.

These regions started out as primordial clouds of hydrogen and helium, pulled together by the force of gravity as the plasma soup served up by the Big Bang cooled. Different cosmological models posit differing numbers of these overly dense clouds of gas, and how they grow over cosmic time. Counting the galaxy clusters can help rule out incorrect models.

KIPAC Staff Scientist Eli Rykoff's primary responsibility as a member of the DES collaboration is to develop ways to find these clusters, and he says it's a satisfying job.

"I love looking at the pictures of these distant galaxy clusters," he says. "I love discovering something that no person has looked at before."

He's so enamored of these far, faint, fuzzy red objects that he first started working on the question in his spare time before he joined KIPAC. During that time, Rykoff developed the first version of a tool he calls redMAPPer (for "red-sequence MAtched-filter Probabilistic Percolation"), which evaluates the millions of galaxies imaged by the Dark Energy Camera (DECam) and determines the probability that each is red-sequence galaxy—a type of old, red elliptical or lenticular galaxy that has a certain color related to its distance. This property makes such a galaxy into a yardstick that can be used to calculate the distance to its cluster.

After joining KIPAC, Rykoff worked with Eduardo Rozo, who is now an assistant professor of physics at the University of Arizona, to refine his cluster-finding tool. "We spent a long time developing a smarter, more systematic way to find clusters," he says.

The benefits are many: "We get better photometric redshifts, so we know the distances to these clusters better, and can make better estimates of mass. We can watch the growth of structure over time, which tells us about dark energy, general relativity, and the future and fate of the universe."

An X-ray eye reveals the secrets of a galaxy cluster

This year KIPAC researchers were privy to some tantalizing hints about the behavior of immense clouds of hot gas that fill the Perseus Cluster. Made up of hundreds of galaxies, such clusters are the most massive gravitationally bound objects in the universe and can tell us a lot about the evolution of large-scale structures, while the hot gas filling them has a lot to tell us about the growth and evolution of these clusters themselves.

With more mass than all the stars in the Perseus Cluster's member galaxies and a temperature of more than 100 million degrees Fahrenheit, the gas is an integral component of the cluster. Part store of raw material, part eddying bath of thermal and kinetic energy, the gas is an archeological record of the cluster's history and a shaper of its future. All that researchers need to do is learn to read it.

The recent glimpse of the gas afforded by the Soft X-ray Spectrometer (SXS) on the Hitomi X-ray satellite was the first to give a reliable indication of the dynamics of such clouds. Previous X-ray spectrometers could only take high-resolution spectra of point sources or lacked the energy resolution of the SXS, and thus were unable to gain a clear picture of gas motion through analysis of Doppler shifts. Such a picture could help clear up a number of questions, such as why the gas doesn't cool and form new stars as quickly as expected. Gas dynamics also contribute to mass calculations for galaxy clusters; unseen turbulence could skew the calculations.

The SXS data confirmed that the active galactic nucleus (AGN) of NGC 1275, the cluster's central galaxy, has been pumping energy into the surrounding gas via particle jets—enough energy to stir the gas and keep it from condensing, but the data also revealed that this energy is not enough to cause appreciable amounts of turbulence in the cluster at large.

The data also show the chemical composition of the cluster, which KIPAC scientists are continuing to analyze in order to gain insight into cluster supernovae populations.



Leading members of the KIPAC Hitomi team (l to r): Hirokazu Adaka, Greg Madejski, Norbert Werner, and Irina Zhuravleva. Photo courtesy KIPAC.

A Chandra X-ray Telescope image of the Perseus Cluster with Hitomi's field of view indicated. The white data show the spectral lines of iron as seen in the cluster by Hitomi. Credit: Hitomi Collaboration/JAXA/NASA/ESA/SRON/CSA.

The persistence of vision

KIPAC researchers Norbert Werner, Irina Zhuravleva, Hirokazu Odaka, and Greg Madejski all agree that the data from the Soft X-ray Spectrometer (SXS) on the Hitomi satellite were of unprecedented quality, and the insights already gained from the data have added to our knowledge of cluster—and thus cosmic—evolution, but there's a bittersweet edge to their enthusiasm.

The data, consisting of about 64 hours of observations, were taken during the commissioning phase and through a covering only partially transparent to X-rays which protected the instrument during and immediately after launch. Before the actual science mission could begin, a series of technical glitches caused the craft to begin rotating uncontrollably, eventually tearing itself apart.

Werner, Zhuravleva, and Odaka had been looking forward to all the data Hitomi would provide during its three-year mission, supplied by the SXS and three other instruments. Madejski had looked forward to the data as well, but his unique position as one of the original collaborators working on an SXS prototype during his time at NASA's Goddard Space Flight Center added an extra poignancy—Hitomi was the third mission to send up this innovative version of an X-ray spectrometer and the third lost opportunity to put it to use.

“Goddard developed a novel technique where you can measure the energy of an X-ray photon by measuring the amount of heat in a detector,” Madejski says. Spectrometers based on this technology, called microcalorimeters, are able to resolve finer differences in energy, resulting in a much more detailed observations of X-ray sources—even diffuse sources, such as the hot clouds.

“The instrument worked better than expected, even with the cover on,” Zhuravleva says.

With fewer than three days of data, Hitomi was still able to give the researchers the clearest look yet at the movements of hot gas near the center of the Perseus Cluster of galaxies, and also provided data about its chemical composition—data they're still analyzing.

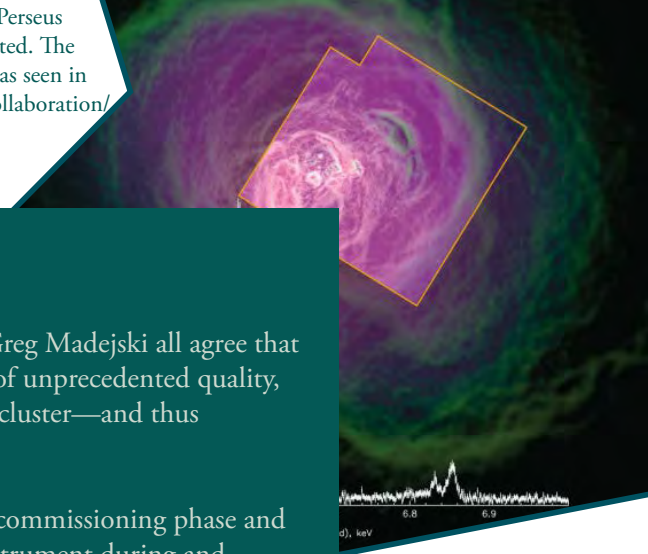
“The gas is a fossil record of how exploding supernovae have chemically enriched the cluster,” says Werner. Supernovae are the cosmic foundries of elements heavier than iron. “We can determine how many supernovae there have been and how much energy they have deposited in the cluster,” because the majority of the heavy elements remain in the intra-cluster gas. “It's all very interesting.”

“First light for Hitomi was very, very successful,” Odaka says. “If Hitomi had been successful, it could have provided a lot of valuable information on not just clusters, but black holes, supernova remnants, and neutron stars.”

There are two concrete benefits to the mission other than the data. One is that the SXS has demonstrated once and for all the efficacy of microcalorimeter-based spectrometers. All of the researchers are eagerly looking forward to the next such mission to go up. They're not sure when it will be, but they are determined to help make it happen.

“The first month's worth of data gave us an unbelievable appetite for more data from similar instruments,” Madejski says.

The second benefit is in the ongoing collaboration with Japan's space agency, JAXA. “These missions have built very strong bridges between the U.S. and Japan,” Odaka says—bridges that will last far longer than a single mission.



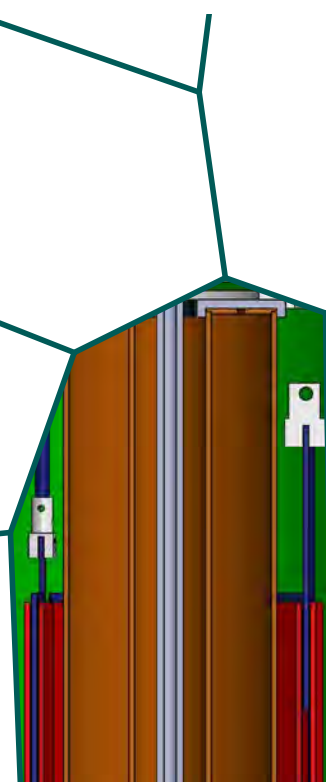
Tuning in to dark matter

Most searches currently under way for dark matter, that mysterious stuff thought to provide the scaffolding upon which galaxies are constructed, focus on one particular candidate: weakly interacting massive particles (WIMPs). But even after decades of looking for them, WIMPs continue to play hard to get. Attempts to detect them have been based on finding their decay and annihilation products, detecting the particles themselves as they pass through the Earth, and making them at the Large Hadron Collider by slamming protons together at close to the speed of light. So far, these have given inconclusive results; we're still dependent on the gravitational effects of dark matter for clues about its behavior and properties.

However, there are no guarantees that dark matter is made up of WIMPs. Another candidate has the equally whimsical name WISP: weakly interacting slim particles, infinitesimal blips of matter so small they are more wave-like than particle-like, resulting in a bosonic (light-like) field oscillating at a frequency set by the particles' mass. Two examples of this type of matter are called hidden photons, which behave much like regular photons, except for their mass and weak interaction with charged particles, and axions, a field that could explain another unsolved problem in modern physics called the strong CP problem.

The slight but measurable coupling of these hypothetical hidden photons and axions to charged particles has certain ramifications—such as the ability to weakly excite electromagnetic systems, yet penetrate shielding. These properties have inspired two KIPAC groups—Peter Graham's theory group and Kent Irwin's experimental group—to design and build a prototype instrument to detect them. Consisting of a high-efficiency antenna and a tunable LC circuit shielded from external electromagnetic fields, it strongly resembles an extremely sensitive, high-tech radio receiver—so much so that it's been dubbed the "Dark Matter Radio"—DM Radio for short.

DM Radio as envisioned by these groups has several advantages. It can search for particles over a much greater mass range than any existing dark matter search, whether it's for WIMPs or axions. The prototype will concentrate on frequencies ranging from 100 kHz to 10 MHz, and focus on hidden photons. But a full experiment could probe both hidden photons and axions, and cover the frequency range of 100 Hz to 700 GHz, which translates to particle masses between 10^{-3} and 10^{-12} eV. (In comparison, the mass of an electron is about 5×10^5 eV, while the mass of a WIMP is thought to be in the range of 100×10^9 eV.) It could also provide information about the physics of inflation in the early universe by detecting the frequency spread.



Hidden photons generate an oscillating, circumferential magnetic field inside the superconducting shield. Many loops of wire (not shown) are wrapped around a toroidal, niobium slitted sheath (orange) to form a pickup coil which is connected to niobium plate capacitors (red). If this LC resonator is matched to the oscillation frequency of the hidden photons, an oscillating current will be created in the wire. This induces a screening current in the superconducting sheath whose path is interrupted by the slit. The current is measured by a SQUID amplifier connected across the slit, with wires leading to room temperature passing through the central support tube (gray). Credit: DM Radio Collaboration.



Kent Irwin

With a title like Professor of Physics and of Particle Physics and Astrophysics and of Photon Science, it's obvious that KIPAC faculty member Kent Irwin is a busy man. His area of expertise—building extremely sensitive sensors that exploit quantum effects—is in high demand by several collaborations of varying sizes, and not just collaborations with KIPAC involvement.

That's because the technologies pioneered by Irwin, transition-edge sensors (TES) and multiplexed SQUIDs capable of reading out large sensor arrays, offer high precision and low noise at extreme sensitivities, and, “the sensors can be tuned to respond to everything from microwaves to X-rays,” Irwin says.

On the KIPAC side, Irwin is involved in developing sensors for the next generation of cosmic microwave background (CMB) observatories at the South Pole and on the Atacama Plateau in Chile and the next-generation space-based X-ray observatory, the Advanced Telescope for High Energy Astrophysics (ATHENA) in addition to his work on DM Radio.

On the non-KIPAC side, Stanford University and SLAC National Accelerator Laboratory are eager to use Irwin's sensors in a variety of areas, including materials analysis at SLAC's two X-ray light sources, the Linac Coherent Light Source and the Stanford Synchrotron Radiation Lightsource (SSRL). In fact, an X-ray spectrometer based on Irwin's sensors is already deployed at SSRL.

But it seems as though Irwin's smallest collaboration, DM Radio, is particularly close to his heart right now. The group is currently at six members, including a postdoc, two graduate students, and a SLAC staff scientist, and was initially funded by a grant from KIPAC. “We can do all the science internally,” he says. “It's nice to have something to work on that's back to lab scale.”

However, he doesn't want to stay that small forever. “Our goal is to grow DM Radio,” Irwin says. “We'll be doing real science with the prototype instrument but I want to do it full-scale.”

That phrase—“doing real science”—is key to understanding what makes Irwin so good at what he does. He's insatiably curious about the universe, and the sensors he has developed satisfy that curiosity in two ways: they can be used in the search for answers to some of the most mysterious questions currently faced by researchers, and they're advanced enough that figuring out how to make them has also required the doing of real science. Real science that can then be put to good use.

“The big driver behind the majority of the stuff I get involved in is understanding how the universe works at the most fundamental level,” Irwin says, “and then finding ways to use the instrumentation we develop to have a broader societal impact.”

Making every photon count

Astronomical surveys are designed to get a big picture look at the universe. Using telescopes with mirrors that are several meters in diameter and wide-field CCD cameras boasting hundreds of millions of pixels, researchers image vast swathes of the night sky in order to map billions of galaxies, follow the growth and evolution of the universe, and probe the depths of the cosmos for signs of dark matter and dark energy.

But no matter how big the telescope or how powerful its camera, it must still peer through the dust, water vapor, and turbulent air of our atmosphere. Returning to the same patch of sky over and over again and adding the images together in a process called stacking helps, but atmospheric effects are always an issue in ground-based astronomy.

As researchers have delved deeper into space and further back in time, they've developed increasingly subtle ways to maximize the amount of information gleaned from the limited numbers of photons collected by their instruments.

Two methods—active optics and adaptive optics—seek to correct for image distortions arising from both internal causes such as minute misalignments in the mirrors or telescope, and external causes such as atmospheric turbulence. The older technology, active optics, corrects basic distortions on a timescale of seconds and adaptive optics corrects atmospheric effects within milliseconds.

Now a small collaboration of KIPAC researchers have come up with a clever way to use adaptive optics data to study and improve active optics results.

KIPAC professor Aaron Roodman, who led the development of the active optics system for the Dark Energy Camera (DECam), the 570-megapixel camera used for the Dark Energy Survey, came up with the idea to use the adaptive optics data gathered by the Gemini Planet Imager (GPI), which directly images planets around other stars (the GPI project is led KIPAC professor Bruce Macintosh).

Roodman realized that GPI's data, once reverse-engineered by Macintosh's team, would provide a record of actual atmospheric conditions.

"Our data show that the atmosphere is an important source of variations for the DECam active optics, and I want to understand our data better," he says.

Initial results show significant differences between what the simulations say and what GPI measures, chief among them a temporal variation in atmospheric turbulence seen in GPI data but not in the simulations.

Ultimately, the mini-collaboration hopes to improve the active optics system for the Large Synoptic Survey Telescope.

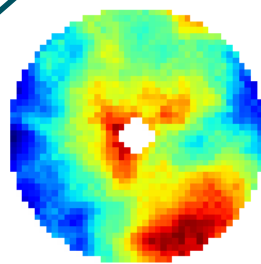


Image of atmospheric turbulence across the 8-meter Gemini South telescope pupil, reconstructed from the Gemini Planet Imager's adaptive optics telemetry. These images are generated 1000 times per second, and are used to study how the atmospheric turbulence evolves over the course of the exposure. Credit: Adam Snyder/KIPAC.



Adam Snyder

KIPAC graduate student Adam Snyder has a turbulent project, but he doesn't seem too stressed out about it. That's because his project—comparing data from the Gemini Planet Imager (GPI) about how the atmosphere has actually been behaving against atmospheric simulations—hasn't exactly been a breeze, but, "I'm pretty pleased with how it's going so far," he says. "I've gotten some cool, interesting results."

According to Snyder, the KIPAC-funded project arose because attempts by the Dark Energy Survey to offset atmospheric turbulence ran into some snags. "DES results didn't exactly fit what was expected," he says. He's been looking at the atmosphere using GPI data to see if it matches predictions based on a well-developed, commonly used way to simulate the atmosphere.

"It turns out they disagree in the area that's most relevant to LSST (the upcoming Large Synoptic Survey Telescope) and DES," Snyder says, with GPI data showing atmospheric fluctuations on longer time scales that don't appear in the simulations at all—fluctuations that could affect the focus of the system.

As for next steps, since LSST will use a similar method to correct for atmospheric and optical effects, better understanding DECam's system could help LSST.

Snyder says, "The majority of the differences between the GPI data and the simulations are likely due to some aspect of the telescope. If we can pin down the cause of the difference we can determine its relevance to LSST."

He's also looking forward to adjusting the simulation inputs in an attempt to reproduce the actual behavior reported by GPI. "That may not work with this sim," he says. "I may have to write a new one."

Extreme computing resources for an extreme universe

KIPAC researchers have a powerful new resource to call on when it's time to crunch big numbers—big as in age-and-size-of-the-universe big. That new resource is XStream, a sleek new supercomputer funded by a grant from the National Science Foundation (NSF) and housed in the Stanford Research Computing Facility (SRCF), a state-of-the-art building that opened for business at the SLAC National Accelerator Laboratory in 2014.

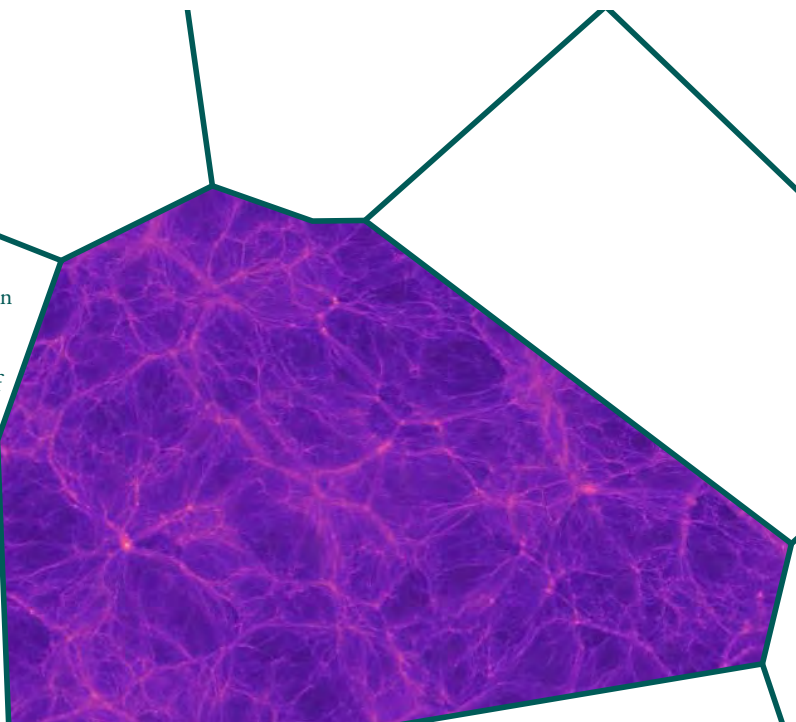
The grant was the result of a collaboration between several members of KIPAC, including Director Tom Abel, faculty members Risa Wechsler and Steve Allen, and visualization specialist Ralf Kaehler, and Stanford scientists from other computationally intensive areas of research, such as chemistry, biology, medicine, and geosciences, with the effort as a whole led by Stanford professor Todd Martinez, an expert in quantum chemistry. Everyone listed as a principal investigator on the NSF grant can use the machine. Some time on XStream is also available to researchers from around the world through the NSF's XSEDE (Extreme Science and Engineering Discovery) program.

The name "XStream" does double duty as a straightforward description of the system and as an indicator of its abilities. "One reason it's called XStream is because that's the type of computing it does—stream computing, in the extreme," Phil Reese, Research Computing Strategist, says. In stream computing, massive amounts of data, sometimes from several different sources, can be pulled in, divvied up, analyzed in parallel, and recombined into one output stream.

"The other reason we called it XStream is because it's an extreme system in many ways," Reese continues. "It's extreme in what it can do for its size, it's extremely energy-efficient, and it's being used to investigate some extreme questions about the universe."

Extreme questions about the universe are KIPAC's specialty. Members are involved in modeling dark matter distribution and the growth of large-scale structure, the birth of the earliest stars and galaxies, and the extreme environments around such exotic objects as supermassive black holes and spinning neutron stars. KIPAC Director Tom Abel says they're putting XStream to work. "We're doing analysis and visualizations of some of the largest N-body structural formation simulations ever," he says. These large simulations model all the mass in the universe as billions of separate points; by programming in physical forces like gravity, computational astrophysicists can roll back the universe to the Big Bang, start the clock, and watch the stars and galaxies form.

Large-scale distribution of dark matter extracted from an N-body simulation using 16 nodes and 256 GPUs of the XStream cluster. Credit: Ralf Kaehler.





The XStream “green” supercomputer, located in the Stanford Research Computing Facility. Photo courtesy SRCF.

Yet XStream’s physical presence is modest. The computational heart of the machine is a cluster of 65 nodes, with each node comprising two CPUs, which are essentially souped-up versions of what’s in your laptop. The CPUs handle all the administrative chores a computer must perform, like data input and output, caching, and memory allocation. However, unlike the CPUs in your laptop, XStream’s CPUs don’t handle the actual calculations making up the bulk of the work. They hand these off to eight graphic processing units, or GPUs, which were originally developed to handle the fast numerical calculations required by video games. XStream’s GPUs are also souped-up versions that pack two GPUs in one.

The result is a blazingly fast machine capable of “embarrassingly parallel” computations, which, says Reese, is an actual term in the realm of high-performance computing. “It means ridiculously easy to separate tasks and compute them in parallel,” he says.

The cluster’s energy footprint is also extremely modest. Much of that has to do with the facility itself. “The SCRF was designed to be an energy-efficient building from the get-go,” Reese says. “It’s even oriented to take advantage of the prevailing winds.” The building’s infrastructure supports higher-density racks, which means packing more computing power into a smaller volume, thus saving even more energy.

The combination of a supercomputer with advanced capabilities housed in a building with an advanced design has landed XStream at #6 on the June 2016 edition of the Green500, a list of the top 500 energy-efficient supercomputers.

Collaborating with the community

It may not result in ground-breaking discoveries or scientific papers in the leading journals, but one of KIPAC's most important collaborations is with the broader community, and in today's era of social media, "broader community" can be as close as the grade school down the street or as far away as a curious teenager in Japan with an email account.

KIPAC scientists spend many hours of their own time each year reaching out to the public through various channels, including a yearly on-site open house, the most recent of which drew about 800 people from across the Bay Area to learn more about dark matter, exoplanets, gamma-ray astronomy, atomic spectra, and more. KIPAC members give public lectures in various venues, visit students of all ages, participate in community science festivals, and entertain and educate at the always-popular Astronomy on Tap talks, which are short, informal talks at local pubs.

The KIPAC blog gives an inside scoop on some of the most interesting research being done by members, KIPAC Facebook and Twitter feeds keep fans informed, and anyone with a question about the cosmos can email KIPAC to Ask an Astronomer.

Outreach Coordinator Mandeep Gill, who is also a member of the DESC collaboration, explains why the institute considers public outreach an important part of its charter, starting with the practical.

"It's important that citizens be informed about technological and scientific issues so we can make informed decisions politically and where policy is concerned," Gill says. "That won't happen without scientists who can translate their work into something anyone can understand, and citizens who understand the fundamental analytical processes by which scientists come to their conclusions."

Capturing the interest of the next generation is also important, for a variety of reasons, Gill says. The same education that enables a physicist to develop an advanced CCD camera for a telescope enables her to do the same in private industry.

"Our entire world is dependent on technology," he says. "And in the case of the U.S., our economy is dependent on technology. There are whole books about tech spinoffs from space—for example, NASA puts out a report about this every year!"

But the simplest motivation for conducting outreach is the strongest: Gill and his KIPAC compatriots want to share the amazing things they've discovered with anyone who cares to listen.

"Who has not looked up at the night sky and wondered? Where did we come from? Where did all of this come from?" asked Gill. "Who doesn't have a romantic notion of just how tiny we are compared to how humongously, endlessly expansive the whole shebang looks, after all?"

"Like" the Kavli Institute for Particle Astrophysics on Facebook and follow @KIPAC1 on Twitter.





Perspectives on outreach from KIPAC members

We are privileged to have society supporting us to do this fantastically cool stuff. It's just obvious that we've got to share that.

—Tom Shutt

Society funds science, and consequently it is the responsibility of scientists to share their findings with society.

—Yashar Hezaveh

It is so incredibly uplifting to be able to inspire a real sense of curiosity and wonder in people, and to know that non-scientists really care about what we do.

—Devon Powell

I personally enjoy public science events as a way to share the excitement of discovering the beauty of nature and the universe around us.

—Kyle Story

I organize Astronomy on Tap because I believe people need to see that scientists are real people who work hard, make mistakes, and have passions.

—Sean McLaughlin

Science is fundamentally a social exercise. What makes it joyful is the sharing of our discoveries with one another.

—Jonathan Zrake

Sharing our work with the public is a great way to be able to say thank you! It's also tremendous fun to share what you are really excited about.

—Dan Akerib

I think it is important to communicate with the general public to entice young people to this cool arena and share what we are studying about our world we live in.

—Jae Hwan Kang

For me there is one key aspect which is quite simply that outreach and teaching are the most direct ways that we as fundamental physics researchers can give back.

—Rebecca Canning

Outreach is important. When you're doing science, it's your responsibility to explain. Your moral responsibility—astronomy gives people a sense of perspective.

—Sowmya Kamath

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.

Rebecca Canning and Norbert Werner touch the edge of space in SOFIA

<http://j.mp/upabove>

...some of the most interesting events in the Universe, such as the birth of stars from cold gas and dust clouds, are too obscured or too cool to shine in visible light, but emit infrared radiation instead. This infrared light, with wavelengths of between about 1 millionth to 300 millionths of a meter (or 1-300 microns) is difficult to observe from the Earth. The longer wavelengths in this range are referred to as the “far infrared,” and as most of this type of light is absorbed by water vapor and carbon dioxide, we need to make observations from high altitudes where the atmosphere is thin. But even the highest mountains on Earth (~29,000 ft)—where the atmosphere is too thin for humans to live—are not high enough to avoid all of the absorption.

Canning in front of SOFIA.
Credit: R. Canning.



To see the far-infrared light from the cosmos, we must go even higher. Space-based telescopes offer fantastic sensitivity to the infrared—however, these missions are very expensive and less versatile than ground-based instruments where one can easily change or upgrade a detector. Another innovative approach is to fly a telescope in the highest parts of the Earth’s atmosphere, high above the absorbing water vapor. This is the purpose of SOFIA: the Stratospheric Observatory For Infrared Astronomy.

SOFIA is an airborne observatory, a Boeing 747SP with a 2.5 meter-diameter telescope on board. Recently, we were fortunate enough to observe on this very special airplane operated jointly by NASA and the German Aerospace Center (DLR) from the Armstrong Flight Research Center in Palmdale, California.

We were granted 5 hours of observing time on SOFIA to look at six nearby giant elliptical galaxies. This type of galaxy has been historically described as “red-and-dead,” owing to its light coming primarily from old reddish stars and the lack of any bright, blue, young star formation. While cold gas is abundant in spiral galaxies with lively star formation, the lack of it in giant ellipticals seemed to explain the absence of new stars. However, our previous observations with the now defunct Herschel Space Observatory (which took data in the far infrared and submillimeter wavelengths) showed that some of the ellipticals do host large reservoirs of cold and molecular gas—the vital raw material from which stars are born. These observations left us with more questions we wanted to address with our SOFIA observations.

We arrived at Palmdale the day before our flight for safety training. SOFIA must fly much higher than commercial airplanes (42,000-46,000 ft compared with 28,000-35,000 ft) in order to escape the majority of the infrared-absorbing atmosphere, and therefore the safety requirements are somewhat different than we are normally used to. At these altitudes the air is so thin that if the cabin accidentally depressurizes, a human will remain conscious for only a few seconds compared with a minute or so on a commercial flight.

We observed with an instrument called the Far Infrared Field-Imaging Line Spectrometer (or FIFI-LS). FIFI-LS is an integral field spectrometer which means that it not only produces an image but for every image pixel we also get a spectrum of the dispersed infrared light that hit that pixel. The camera on the telescope needs to stare at an object for a long time to see faint emission and during the time the camera is collecting the light it must be held steadily on the target to produce a sharp image. Steadying a camera is a non-trivial task on Earth, let alone on an aircraft bouncing in turbulent air more than 13 km high in the sky. The pointing is stabilized using gyroscopes which use thin layers of air and oil as lubrication, and sensitive measurements of the torques on the telescope. Amazingly, the telescope on SOFIA can maintain a pointing accuracy of 0.5 arc seconds (the equivalent of the width of a dime seen from 2.5 miles away)—even in substantially choppy atmosphere!



Werner in front of SOFIA. Credit: N. Werner.

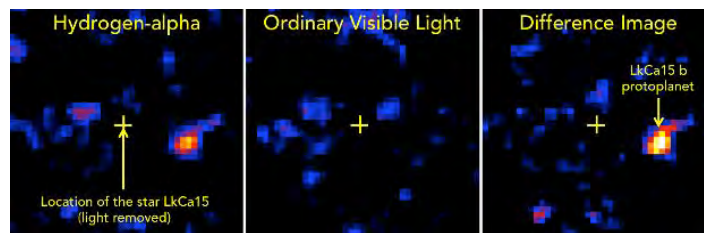
SOFIA is an incredible feat of technology enabling a unique access to the infrared sky. It is also ever-improving; as time passes new instruments are added, further increasing its capabilities. For us, hopefully, these observations were just the beginning—there is so much more that this instrument can teach us about how the largest galaxies in the Universe evolve and why they remain red-and-dead.

Kate B. Follette shares first baby pictures of an infant planet

...we've managed to take the first baby picture of a planet still in the process of growing. Our team was able to image the protoplanet with the Magellan telescope in Chile, taking advantage of the high-speed adaptive optics of the telescope to correct for blurring by the Earth's atmosphere. This allowed us to take a super-high-resolution image of the system and, after subtracting the light from the central star, isolate light coming directly from the protoplanet.

<http://j.mp/babyplanetphotos>

More specifically, we isolated light emitted by ultra-hot hydrogen gas falling onto the protoplanet, which is named (systematically, if not super-creatively) LkCa 15 b after its star, LkCa 15 A. LkCa 15 A is a very young Sun-like star which is about 460 light years away in the Taurus-Auriga star-forming region. At the deep-red wavelength we observed with (called Hydrogen-alpha, or $H\alpha$), the planet is very bright compared to fully-grown planets that we directly image with instruments like the Gemini Planet Imager (GPI)—it is just hundreds rather than millions of times fainter than its host star. While all previous direct imaging detections have observed the leftover heat from (or starlight scattered off of) already fully-formed exoplanets this is the very first time we've managed to snap a baby picture of a planet that's still growing.



A residual image (right) showing that protoplanet LkCa 15 b is brighter in a specific wavelength of light called Hydrogen-alpha, or $H\alpha$ (left) when the ordinary visible light (center) is subtracted. $H\alpha$ is exactly the wavelength where we expect ultra-hot hydrogen falling onto a forming protoplanet to emit very strongly. Credit: Kate Follette.

Like many young stars, LkCa 15 A is surrounded by a pancake-shaped disk of gas and dust made up of leftover material from the star formation process. The disk material is transient, and within a few million

years will be either blown away by stellar winds from the star or will fall onto it. Though short-lived (at least astronomically speaking), this disk-bearing epoch is important because we believe that disks provide the raw material (solids and gas) to form planets.

Many young stars have disks, but LkCa 15 A is one of just a handful of systems that host transition disks, distinguished by solar-system-sized holes at their centers (think pancake with a giant bite taken out of the center, or a squashed donut). We think these holes are carved as newly-formed planets sweep up disk material, and that the outer disks can't survive for long after this happens. That makes gaps in transition disks very popular places to look for actively forming protoplanets. But this is the first time that astronomers have managed to directly image one....

Although LkCa 15 b is only a few hundred times fainter than its host star, the detection was still very difficult because the planet is about five times closer to its star in angular separation (~ 0.1 arcseconds) than most of the exoplanets that we image today (~ 0.5 arcseconds). Like the young planet 51 Eridani b (or "51 Eri") that we discovered with GPI and announced in 2015, the distance of this newly-discovered protoplanet from its star is tens of AU (where one AU, or astronomical unit, is the distance from the Sun to the Earth.) However, the star itself is much farther away from us than 51 Eri, so that same physical separation of the planet from the star translates to a much tighter angular separation as observed from Earth. This is fundamentally the reason that a planet had not been directly imaged inside of a transitional disk gap before.

The nearest star forming regions in our galaxy (and therefore the nearest transitional disks) are all about 500 light years away, much farther than the region within about 170 light years where we search for young fully-formed planets in the near-infrared with GPI. In fact, in near-infrared light where young planets glow brightly because of residual heat from their formation process, it's not even possible to separate the light from two objects this close together on the sky. It's only by taking advantage of the Magellan telescope's ability to correct for the blurring of the atmosphere at visible wavelengths that we were able to separate the planet's light from the starlight.

This discovery was part of the Giant Accreting Protoplanet Survey (GAPplanetS), and follows on our discovery of an accreting M-dwarf stellar companion inside of the HD142527 disk gap (Close et al. 2014). I have eighteen more disks in my sample, and hope to be able to find a few more of these baby worlds!

Kevin Reil explains what makes the Dark Energy Camera such a superlative instrument (hint: it's the people)

<http://j.mp/desdecam>

...DECAM is a 570-megapixel camera installed on the 4-meter Victor Blanco telescope atop Cerro Tololo, a mountain in the Chilean Andes. The science mission for the Dark Energy Survey, of which I'm a member, is nothing less than to use this camera to understand dark energy. Which is a tall challenge, since the phrase "dark energy" itself is, as some cosmologists say, simply words we use to describe our profound ignorance about the current-day accelerating expansion of the universe.

Though this accelerating expansion was a theoretical possibility and predicted by a minority of astrophysicists in the later part of the last century, its actual confirmation through observations of Type Ia supernova in 1998 came as a big surprise to the majority of the community (and the larger world). It has continued to puzzle the entire community of astronomers and physicists ever since, with mysteries like how we square the paradigm of an ever-expanding Universe with a specific start time for it in the past. Thus we forge ever onwards, observing more and more of the Universe, in the hope that probing further will elucidate the why and wherefore of this most recent profound cosmological mystery.

DECAM is one of the tools we use in this grand endeavor, and it first opened its camera shutter in

September 2012 and has thus far completed three of its planned five seasons of observation. During the five years of the survey, the instrument will collect information on millions of galaxies and look for and study thousands of supernovae.

We published a paper last year about the details of the camera's construction and operation which was rather aptly titled, "The Dark Energy Camera." My favorite part of the paper is really the author list. It summarizes a rule called STP that I know best from the volunteer world. It stands for the "Same Ten People" who show up every time and make sure things happen. For an instrument like DECam that number is actually slightly over 100 people (so we'll alter the rule to "SHP") but the idea remains the same: If you want to do great science, one way is to surround yourself with people like those listed as authors on this paper, then do the best work you can as part of an excellent team.



DECam at the Blanco telescope—I am one of the small humans on the left, DECam is the large black cylinder next to us, and what's on the right is not a crashed cousin of the Millennium Falcon but the actual telescope mechanism that holds the mirrors and focuses the light that ends up being imaged in DECam.

The work done by KIPAC faculty member Aaron Roodman and myself is covered in section 7.3.3 of the paper, "Active Optics System (AOS)." The DECam's AOS is not to be confused with the adaptive optics system the Gemini Planet Imager, another instrument with a lot of KIPAC involvement, uses. The DECam's active optics corrects focus and alignment between exposures while the Gemini Planet Imager's adaptive optics makes corrections while exposures are being taken.

The AOS is just one small piece of a very complex system, but a rather critical one. It keeps the camera in focus and optically aligned, without any manual intervention. This allows observers to focus their attention on taking data. The AOS works by using eight wavefront sensors to continuously correct the camera's focus and alignment and needs no human intervention. With it, instead of the camera drifting out of focus by hundreds of microns through the night, the system quickly and automatically moves to better than 30 microns defocus, and the shapes of the images remain very stable.

The system is working well; a few years of effort and several months on the mountain (Cerro Tololo) are captured in the summary sentence of our section: "Closed loop operation [of the automatic focus and alignment] was made the default condition for all observers at the end of DES SV [Science Verification time, in early 2013], and it has remained in stable problem-free operation since that time." Phew! A huge lot of hard work is summarized in those few words, and for us it meant mission accomplished—at least for that stage of the experiment!

But the AOS is just one piece of DECam; a collection of really smart, dedicated people, each contributing a little piece like this, is necessary for science to work. That's what I love about it. So you don't have to read our entire paper, but I encourage you to look at the list of authors and think about all the other contributions that went into building a state-of-the-art scientific camera.

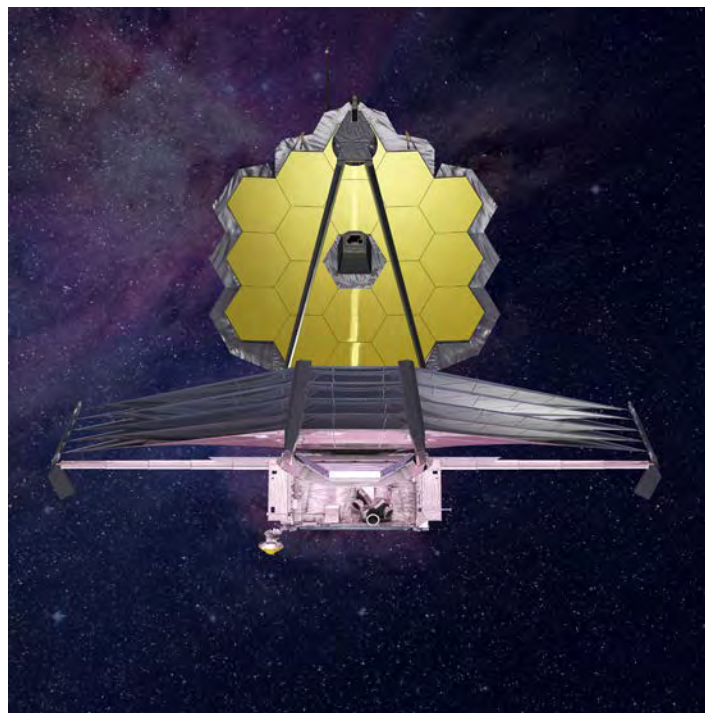
Bruce Macintosh checks in on Astro2010 at the five-year mark

...for the past 50 years, once each decade the astronomy and astrophysics community in the US takes a good, long look in the mirror. During this comprehensive self-assessment, scientists from across the country and around the world come together to hash out issues of scientific priorities and resource

<http://j.mp/middecadal>

allocation, enabling the field as a whole to face the future together. “This is a good thing,” Macintosh says—the democratic process results in a community that is more supportive of the resulting priorities, even if personal favorites didn’t rank as highly as some scientists wanted. Everybody knows they had a chance to be heard.

Fully deployed JWST.
Credit: Northrop Grumman.



The most recent survey culminated in the fall 2010 release of “New Worlds, New Horizons in Astronomy and Astrophysics,” by the National Research Council, the research arm of the National Academies of Science, Engineering, and Medicine. The committee of distinguished scientists leading the effort, chaired by KIPAC’s own founding director Roger Blandford, distilled the survey results into a report informally known as Astro2010—300+ pages laying out the big questions facing researchers today, such as the natures of dark energy, dark matter, and inflation, and recommendations for new tools to help answer them. But now, five years in, it is time for the mid-decadal assessment....

The mid-decadal assessment is “an important part of the process,” Macintosh said. “The world has changed in so many ways even in just the past five years—for good and bad.” The good changes are primarily due to the fact that science is a moving target which regularly discovers significant things, he added—the recent announcement by the Laser Interferometer Gravitational-Wave Observatory (LIGO) of the direct detection of gravitational waves is a perfect example. One question the committee asked was whether any such changes call for a course correction in established priorities.

Funding has been and continues to be the biggest challenge, Macintosh said. Funding has never reached even the modest levels forecast by the Astro2010 committee, while the burgeoning budget for the James Webb Space Telescope, the highest-priority space-based project from the previous survey, has caused delays in other NASA projects—most notably, Astro2010’s top pick for space-based projects, the Wide-Field Infrared Survey Telescope (WFIRST)....

Other funding agencies have their own challenges. The National Science Foundation (NSF), which is responsible for supporting much of the ground-based astronomical and astrophysical research in the US, has seen budgets remain mostly flat for the last several years. The situation has required them to make some hard choices when divvying up the pot among research grants, operating existing facilities, and building and operating new facilities.

The Department of Energy (DOE), which funds fundamental physics research through its Office of Science arm, has its own funding woes to consider. High-energy physicists also went through their own exercise in soul searching which informed their own list of priorities that the DOE has to juggle.

But dedicated people create opportunities, and both NASA and the NSF have plenty of dedicated people. NASA also got a surprise gift—two telescopes from the National Reconnaissance Office—that kickstarted the current design for WFIRST. Plugging a different telescope into the WFIRST design has required a certain amount of flexibility, but the benefits to the mission of a larger telescope, especially for studying exoplanets, outweigh the costs, and the project is now on the march....

The NSF is looking for other partners besides the DOE, especially for funds to operate existing facilities. Astro2010's top priority for ground-based projects, the Large Synoptic Survey Telescope (LSST) is currently under construction on a mountaintop in Chile (you can even watch it go up via the LSST summit webcam). The people building LSST are aware of this prioritization and are getting a jump on finding operating funds for when the telescope goes into operation—currently scheduled for 2022–23.

In addition to checking in on the current decade's progress, Macintosh said the mid-decadal assessment committee is also concerned with laying the groundwork for the 2020 survey. "One recommendation that hasn't happened is the US government getting involved in 30-meter-class telescopes,"—i.e., giant ground-based telescopes with primary mirrors which span 30 meters in diameter, which is nearly 10 times the collecting area of the current largest telescopes on the Earth today.

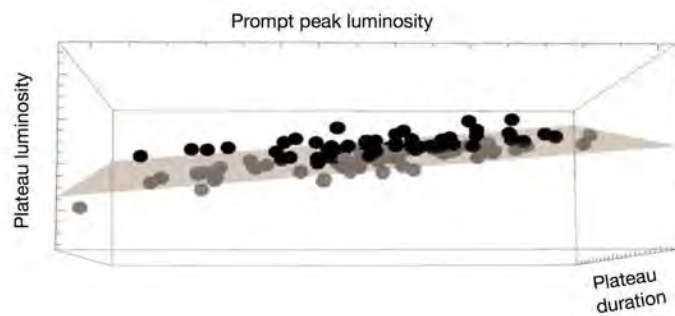
...“I was glad to get involved because I believe these issues are important,” he said. “Astronomy is a science that has lots of popular interest, because we grapple with questions that are both big and fundamental and direct enough that almost anyone can understand them, like ‘What is the universe made of?’ or, ‘Is there another planet like Earth?’ In part due to that broad interest, we get a lot of resources from people and the government, and it's the job of the Decadal Surveys—and this mid-decadal check-in—to make sure we use those resources sensibly and keep doing really groundbreaking science.”

Maria G. Dainotti comes one step closer to putting gamma-ray bursts to work as cosmic yardsticks

...If the intrinsic brightness of GRBs were known, a comparison with their detected brightness would yield their effective distance, and given their observed recession velocity or redshift, GRBs could then be used as accurate distance estimators for cosmology. This would enable researchers to arrive at solid estimates for the distances of all manner of extremely faint, old objects, such as very early galaxies.

<http://j.mp/grbcandles>

Unfortunately, as the SWIFT satellite has revealed, GRBs do not present uniform features: all their critical parameters vary widely over orders of magnitude. As the saying goes, if you've seen one GRB, you've seen one GRB. This applies not only to the prompt emission (the main event in gamma rays), but also to the extended X-ray afterglow phase (the counterpart, which follows the prompt emission and can occur in several wavelengths). To complicate matters further, no single clear explanation as to their physical nature exists. Possible origins range from the collapse of massive stars, to magnetars in the process of spinning down, to the collapse of supernovae, to binary mergers.



Adding in a third parameter (the peak luminosity of the prompt phase), and testing a particular GRB subclass. Choosing only the class of long GRBs not associated with supernovae (points shown in gray) dramatically reduces the scatter, as shown in the plot of 122 long GRBs (all dots together).

Over the past decade, efforts have been made to find correlations between some characteristic parameters but existing correlations are very noisy, with GRBs showing a large dispersion related to the best fit of the correlations, very likely due to the fact that GRBs do not come from the same type of objects. Conversely, tighter correlations can be seen in objects which have more in common. Isolating a single GRB class (as much as possible) gives hope of identifying a type-specific sample where correlations will be much clearer and hence provide better cosmological information and constraints on GRB emission mechanism scenarios.

Previous efforts looked for relationships among two parameters in the afterglow, such as the rest frame end time of the plateau phase, called T_a , and its corresponding luminosity, L_a . Our idea was to search for and identify a tighter correlation by introducing a third parameter, the peak prompt luminosity, L_{peak} , in order to further reduce the scatter of this correlation. This new 3D correlation $L_a - T_a - L_{\text{peak}}$ forms a plane in parameter space.

In this paper, we have taken all long GRBs (i.e., having a duration > 2 s) from Swift with measured redshifts, and removed all of those classified as X-ray flashes (with the ratio between X-ray and gamma-ray flux in their spectra greater than 1), having associated supernovae, or showing a steep decline in their X-ray afterglows. The resulting high-quality data sample shows a correlation between L_{peak}, T_a , and L_a . This correlation is more than twice as tight as the corresponding one for the full sample. We also controlled through Monte Carlo simulations that the reduced scatter of this correlation is not randomly produced.

To sum up: Through careful study, what we find is that identifying and isolating class-specific GRB samples raises the possibility of significantly reducing the scatter in GRB correlations, which, together with more solid and testable physical modeling for understanding these enigmatic and powerful events, opens the door wide for using GRBs as reliable and powerful cosmological tools.

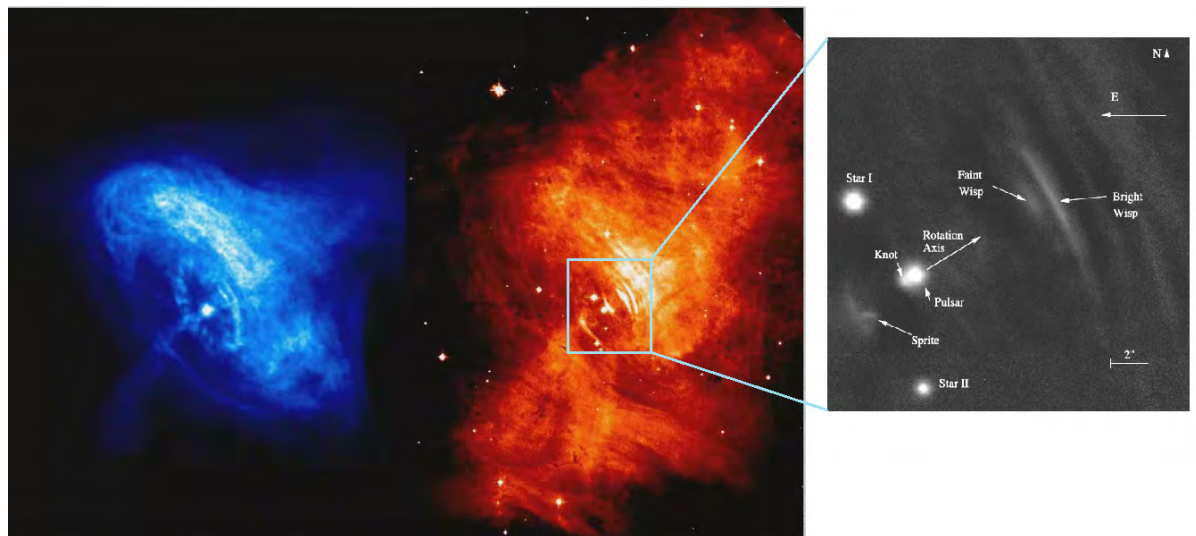
Yajie Yuan checks in with a crabby supernova remnant

<http://j.mp/crabsurprises>

...as we have learned in recent times, the Crab Nebula produces powerful, short-duration gamma-ray flares about once per year. In the most dramatic event, the gamma-ray luminosity (i.e., the brightness) of the nebula during these phases rose rapidly within 10 hours and outshone its quiescent state by a factor of 30. How can this be possible from a source that was previously thought to be so rock-solidly stable?

To understand the origin of the flares, the first pressing question to be addressed is this: Where in the nebula does a gamma-ray flare originate?

Inner part of the nebula captured by Chandra X-ray telescope (left) and Hubble in optical (middle). The right panel is the blowup of the central region near the pulsar, in near-infrared (from Melatos et al. 2005). Credit: NASA.



The fast variability time scale of ~ 10 hours in these flare events indicates that the radiation should come from a relatively small region, not much larger than a light-day across—this is less than 0.05% of the size of the entire nebula, which is some 11 light years in diameter. Unfortunately, because of resolution limitations, the whole nebula only appears as a point in gamma-ray telescopes, so we cannot directly pinpoint the location of the gamma-ray emission.

We do know that the emission cannot be altered by the central pulsar or anything causally connected to it, otherwise we would have observed changes in the pulsed emission, contrary to what has been recorded so far. Thus, the origin should be somewhere in the body of the nebula—and the hints are pointing to the most likely location being the inner part of the nebula.

Now, another way to try to track down the flare origin is to observe the flaring nebula concurrently with telescopes in other wavelengths that have better resolution. Since we believe that the flares are quite likely produced by a local reconfiguration of magnetic structures that releases electromagnetic energy to accelerate particles, we also would expect that such an event could have an impact on lower-energy particles and show up in longer wavelengths as well....

The inner nebula has elaborate structures, most prominently the torus, jets and a few wisps, as can be seen in both X-ray and optical images (see Figure 1). Several of them change with time on a scale of months to years, changes which are believed to be caused by waves excited when the highly relativistic, magnetized, electron-positron pair wind from the pulsar interacts with the nebula environment. To pick out the flare counterpart from all these constantly changing features, one needs to find variations that have strong correlation with the gamma-ray flares. Past multiwavelength observations did not show any obvious evidence of such correlation.

This time our team tried to focus on one salient feature, which appears to be very close to the pulsar in sky projection at least, called the inner knot (labeled “Knot” in the figure). This compact region of emission is usually thought to come from a special, oblique portion of the termination shock—the region where the pulsar wind meets the nebular material and is abruptly slowed down.

We find that the knot characteristics have strong variability over time; for example, the knot’s separation from the pulsar changes, and its size correlates with the separation from the pulsar while its flux shows anticorrelation, consistent with the motion of the termination shock. Most interestingly, near the two large flares, the knot happens to be at extremal distances from the pulsar, furthest for the earlier flare and closest for the later one.

Here at KIPAC, we are actively engaged in getting a theoretical understanding of the process. Roger Blandford, William East, Krzysztof Nalewajko, Jonathan Zrake and myself have been advocating a new idea we call magnetoluminescence to explain the gamma-ray flares. Basically, the dramatic flares happen in the body of the nebula but the ultimate energy source comes from the central engine—the Crab pulsar. The pulsar has strong magnetic field and rotates rapidly: it winds up the magnetic field into toroidal loops and continuously injects all this magnetic energy into the nebula. The magnetic field, embedded in a relativistic pair plasma, could become highly tangled in the nebula—think of the loops as tightly tangled, highly stressed elastic ropes that can suddenly untangle and whip around upon being released from their tension, and release a large amount of magnetic energy at that point to accelerate the plasma to relativistic speeds.

Large electric fields could also then be induced, eventually reaching the point when the breakdown of ideal conductivity happens throughout a significant volume. During the dramatic process particles would be accelerated until they furiously emit gamma rays.

...With continuing observational, theoretical and numerical efforts, we look forward to eventually finding answers to the open questions brought up by the Crab. Or maybe this venerable crustacean has even deeper hidden secrets that will be revealed one day?

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>

One of the most important decisions for recent college graduates in physics or astronomy who decide to go on to graduate school is where to apply. The advisors and mentors who help them learn and grow and the other students they meet will be friends, colleagues, and collaborators, sometimes for life.

Two KIPAC graduate students, Sowmya Kamath and Sean McLaughlin, explained what brought them to Stanford University to continue their education, and why they considered the opportunities presented by KIPAC to be most in line with their education and career goals.

McLaughlin received his B.E. in Physics from the University of Illinois, with minors in Mathematics and Computer Science. Part of the reason he found KIPAC a good fit is his early involvement in research using survey data. “I’ve been doing survey stuff since working with Sloan [Digital Sky Survey] data the fall of my sophomore year,” McLaughlin says. “Now I’m working on the Dark Energy Survey with [KIPAC professor] Risa Wechsler.”

Kamath has ventured farther from home territory to come to Stanford—a lot farther. She earned a Bachelor of Technology degree in Physical Sciences with a specialization in Astronomy from the Indian Institute of Space Science and Technology, in Thiruvananthapuram on the southwest coast of India. IIST is the first Asian university to be dedicated fully to the study of space science, technology, and applications.

“It was set up by the Indian Space Research Organization,” Kamath explains. “ISRO is the NASA of India, and its aim was to get students directly in the employee pipeline, trained and ready to work at ISRO as soon as they graduated.”

At Stanford, Kamath works with KIPAC professor Patricia Burchat in LSST-DESC, preparing to use Large Synoptic Survey Telescope data to look for dark energy (the “DE” of DESC).

“I applied to a couple of U.S. schools like the University of Chicago and Cornell along with Stanford,” Kamath says. “Stanford was attractive because there are a lot of research options here.”

“I applied quite a few places,” says McLaughlin, and his choices came down to the University of Washington, Caltech, and Stanford. “This is ultimately the best place for me,” he says. “I’ve got the most opportunities here to do the science I’m interested in,” which includes computational science in addition to survey science.

A plus for both is the rotation process followed by Stanford graduate physics students. For the first few quarters, each student signs up with a professor to work on a specific project. The university is responsible for salaries during this period—advisors don’t have to dip into project funds. “It takes the weight off you,” McLaughlin says. “If you decide to leave after the quarter to try something new, that’s okay.” His second quarter was spent studying optics. “I didn’t know anything about optics before that.”

Students can stick with their first choice, or keep looking. Most, like Kamath, settle on a specific group or project by the third quarter. “It was nice to have the opportunity to look around and see what I was interested in,” Kamath says. “When I came in I didn’t really know what I wanted to work on.” She checked out radio instrumentation before settling on weak lensing cosmology with Burchat.

“But even if you don’t think you’ll stick with a project, the rotation process formalizes your goals and makes you work more in a quarter,” Kamath adds.

Stanford’s graduate school may have attracted them, but both students say KIPAC is helping make the road to a PhD fun.

“The people are so nice,” Kamath says. “Helpful, friendly, and I can ask any professor for help on a problem, not just my advisor, and they won’t say no.”

McLaughlin nods. “This is one of the nicer places I’ve worked,” he says. “Everyone works hard, but they work hard because they want to and they’re interested.”

Both students volunteer for some of KIPAC’s many public outreach activities. In fact, McLaughlin has organized a new activity, Astronomy on Tap, which brings astronomers and astrophysicists together with mellow pub crowds for an evening of suds and stars.

“I just decided one day, ‘I want to do this,’” McLaughlin says. “Everyone just started coming up to me and saying, ‘How neat—can I help?’”

Kamath appreciates the opportunity to learn from example. “It’s nice to see how people explain deep thoughts to other people,” she says. “I was especially impressed by [KIPAC staff researcher] Phil Marshall and how he properly explained weak lensing to people hearing about it for the first time at our open house.”

As for what the two will do after receiving their doctorates, it’s a little too soon to decide. Kamath would like to stay in academia but McLaughlin isn’t wedded to the idea. Regardless of what they do, both feel the education and experience they’re getting as KIPAC graduate students will be invaluable to their future careers.



For newly minted PhDs who want to stay in academia or research, or who haven't decided yet, the specter of the postdoctoral position looms large. Finding a place to do challenging research at a respected institution that enables them to shine is vital to establishing a career as a scientist.

Three departing postdocs explained why they want KIPAC on their CVs. They are: Andrea Albert, an experimentalist who combed gamma-ray data for signs of dark matter and who is now a Marie Curie Fellow at Los Alamos National Laboratory; theorist Philipp Mertsch, who is intrigued by all manner of high-energy astrophysical phenomena and is now an assistant professor at the Niels Bohr International Academy in Copenhagen; and Will East, also a theorist, who uses computers to solve Einstein's equations for clues about gravity in its most extreme forms. East is headed for the Perimeter Institute for Theoretical Physics in Waterloo, Ontario.

For Albert and Mertsch, KIPAC's leadership role in the Fermi-LAT collaboration was a big draw. Both use data from the Fermi Gamma-ray Space Telescope's main instrument, the Large Area Telescope, in their research.

Mertsch came to KIPAC as a Kavli Fellow and appreciates the freedom his fellowship offered. "A Kavli Fellowship is very open," he says. "You can do whatever you like, work with whomever you like," including experimentalists like Albert. He feels that staying connected to the people who actually do the experiments is important for a theorist. "Oxford, where I got my PhD and where my first postdoc position was, is intellectually very stimulating but unfortunately the UK missed out on some of the exciting experiments in particle astrophysics," he says. Mertsch spent his time at KIPAC looking into some of Fermi's more anomalous results. "There were lots of interesting and unexpected results like lines and bubbles," he says.

Albert came to continue her graduate research in dark matter. KIPAC also gave her the opportunity to exercise her leadership skills when she led a successful effort by two collaborations (Fermi-LAT and the Dark Energy Survey) to produce a paper on gamma-ray emissions from several newly discovered dwarf galaxies—and do it in record time. "I'm very good at harnessing the resources of a big collaboration," she says. "I feel a little strange bragging about that instead of results but it's very useful."

KIPAC's emphasis on public outreach was also a win for Albert. "I've always been a big public outreach person but at The Ohio State University, where I got my PhD, I just did school-related events. My reach at KIPAC has been much broader."

As for East, he admits that "KIPAC is not really a place where people do a lot of work on gravity," but working with people like KIPAC Director Tom Abel, former Director Roger Blandford and theoretical cosmologists like Leonardo Senatore and Andre Linde "has helped me broaden my research interests and find where they overlap with cosmology and astrophysics."

East says he also appreciated the less formal interactions. "My work is computationally intense," he says. "Most of it involves simulations at some point, and I had a lot of discussions with people who were simulating other phenomena, like dark matter."

According to Mertsch, the magic of KIPAC lies in bringing people together and "giving everyone a chance to do their thing." These interactions—with senior scientists, with other postdocs—are an opportunity for the next generation of researchers to make lasting connections, he says. "We're laying the foundation for the next era of scientific discoveries."



Pictured left to right: Yao-Yuan Mao, Langley Postdoctoral Fellow, University of Pittsburgh; Risa Wechsler, Faculty; Roger Blandford, Faculty; Richard Anantua, CA Alliance for Graduate Education & the Professoriate Postdoctoral Fellow; Ondrej Urban, Data Scientist, HAL24K; Tony Li; Simon Foreman, Postdoctoral Fellow, Canadian Institute for Theoretical Astrophysics, Toronto; Yajie Yuan, Lyman Spitzer Postdoctoral Fellow, Princeton University; Steve Allen, Faculty; Leonardo Senatore, Faculty.

Not pictured: Matt Lewandowski, Postdoctoral Fellow, French Atomic Energy and Alternative Energies Commission (CEA), Paris; Matthew Sieth, Postdoctoral Fellow, KIPAC

“It’s indeed a long journey to get a PhD. But being able to spend my time with the KIPAC family was certainly one of the best parts of the journey!”

—Yao-Yuan Mao

“At Stanford, I have had boundless opportunities to contribute meaningfully to active areas at the forefront of modern physics. KIPAC in particular has been an exciting, judgment-free environment supporting my development as a physicist and as a human being while hosting enjoyable, community-building events throughout the process. It is no coincidence that the best years of my life were the ~4.5 years I spent at Stanford.”

—Richard Anantua

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“Roger Blandford has contributed significantly to our understanding of how such engines work, and thus to our understanding of the lives of the rotating, supermassive black holes that give rise to them.”

The 2016 New Horizons in Physics Prize

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The HEAD Dissertation Prize

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



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