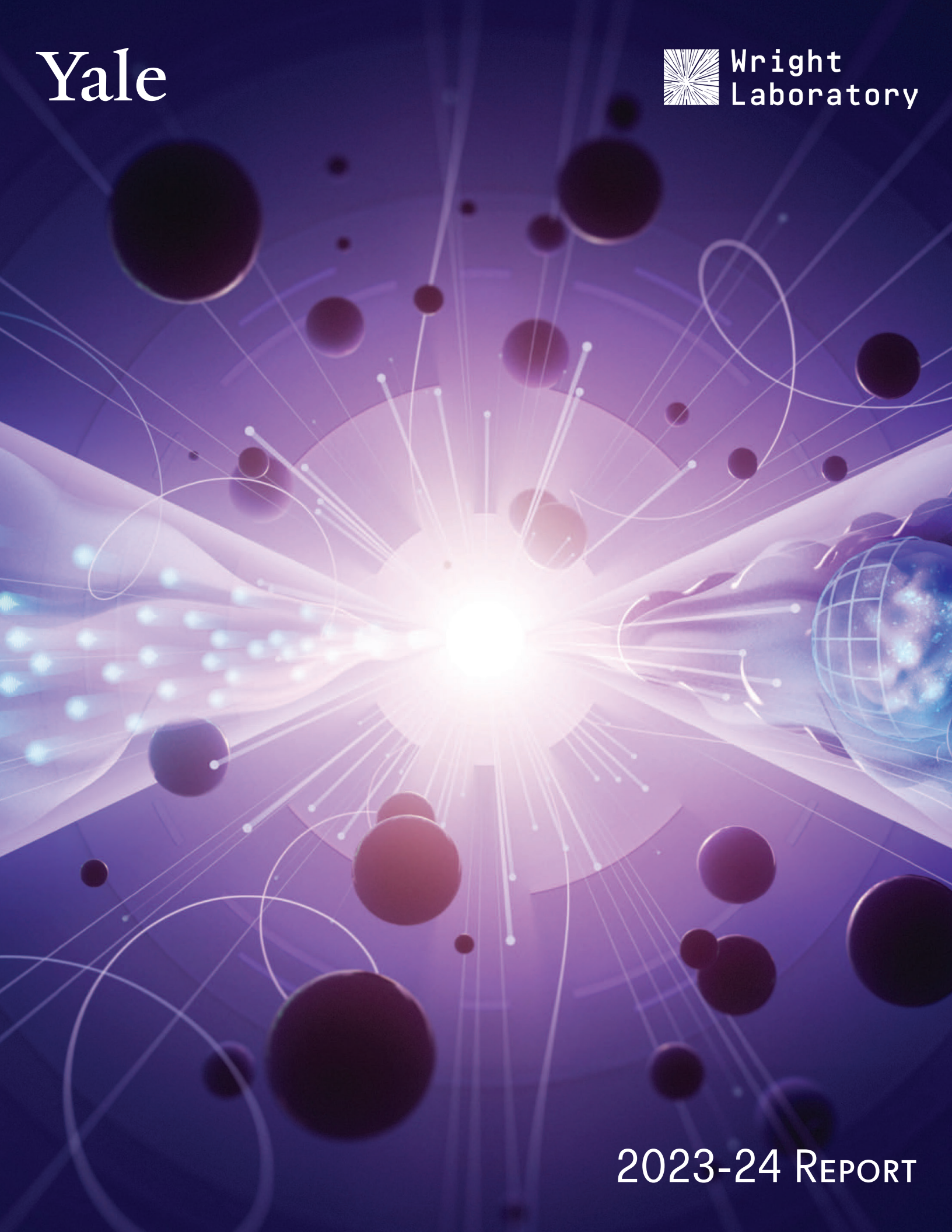
Yale

Wright Laboratory



2023-24 Report

Exploring the Invisible Universe

The last couple of years have been an exciting time for Wright Lab and Physics on Yale's Science Hill. Since transforming the Wright Nuclear Structure Laboratory into Wright Lab in 2017, the laboratory has become a hub for fundamental physics, instrumentation development, and training the next generation of scientists. Wright lab supports a broad program in experimental nuclear physics, particle physics, and astrophysics, with particular emphasis on instrumentation development and quantum sensing for fundamental science. Wright Lab houses state-of-the-art technical facilities and a vibrant community of over one hundred scientists, students, and postdocs. It also supports the collaboration and work of Yale scientists on six continents. The lab is an essential element of the experimental program of the Yale Physics Department.

Wright Lab scientists lead experiments to further our understanding of the Universe, from elementary particles to the evolution of the cosmos at the largest scales. Our researchers play a critical role in national science initiatives, lead international projects, and advance Yale's strategic science priorities. Wright Lab is playing a central role in developing the university's instrumentation initiative, using quantum science and AI/ML to leverage the power of advanced detectors, and is a leader in building a diverse and inclusive community of students and scholars in the physical sciences at Yale.

We have recently welcomed new faculty to the Physics Department and Wright Lab and are excited to build several new experiments here on campus and with partners at international facilities worldwide.

Education is a core element of our mission. Wright Lab trains a broad group of students and scientists at all career stages. Through hands-on research experiences, specialized workshops, mentoring, and career development activities, we train the next leaders in science and technology with a broad set of technical, computational, and management skills. In 2023-24, over 45 research scientists, postdoctoral associates, graduate students, and undergraduates completed their training at Wright Lab. Wright Lab alums have gone on to positions in academia, national laboratories, government, industry, law, medicine, and science communication.

The start of the construction of Yale's Physical Sciences and Engineering Building (PSEB) on Upper Science Hill marks an exciting milestone for the lab's future. The first phase of this building complex will add new lab space to Wright Lab and house an Advanced Instrumentation Development Center (AIDC), while the second phase will add modern cleanrooms, materials characterization facilities, and co-locate research groups in quantum and material science. Wright Lab will be an integral part of this exciting new research complex at Yale and will benefit from the enhanced on-site facilities and close interactions with colleagues in physics and engineering.

I invite you to browse this annual report and look forward to sharing more exciting news through our website and digital media. —Karsten Heeger, Director

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Wright Laboratory

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Discover what's in the report

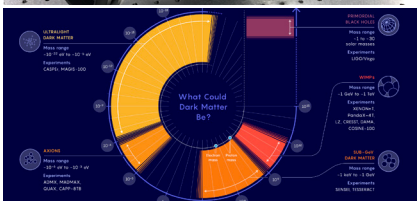
Astrophysics & Cosmology

Charlie Baltay
Eugene Higgins Professor Emeritus

Experiments: DESI, LS4, QUEST, Roman Space Telescope

Keith Baker
D. Allan Bromley Professor

Experiments: ALPHA, ATLAS, Axions, Hidden Sector Photons, Quantum Entanglement

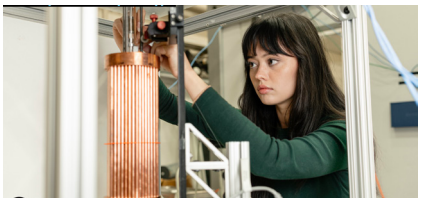


Charles Brown
Assistant Professor

Experiments: ALPHA, RAY, Single/Few/Many Body Quantum Physics

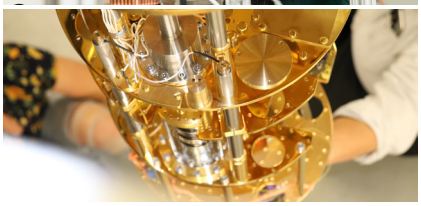
Karsten Heeger
Eugene Higgins Professor and Chair of Physics, Director Wright Lab

Experiments: ALPHA, CUORE/CUPID, Daya Bay, DUNE, Project 8, PROSPECT



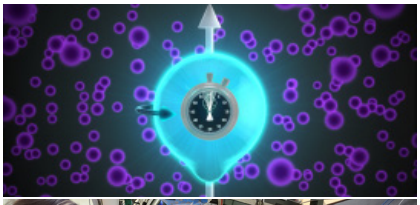
Steve Lamoreaux
Eugene Higgins Professor

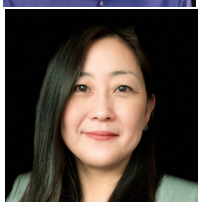
Experiments: ALPHA, HAYSTAC



Konrad Lehnert
Eugene Higgins Professor of Physics

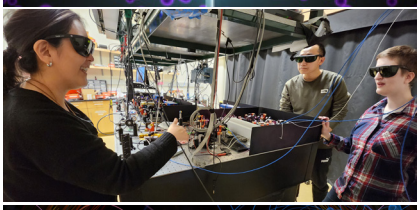
Experiments: ALPHA, HAYSTAC





Reina Maruyama
Professor

Experiments: ALPHA, CUORE/CUPID, COSINE-100, HAYSTAC, IceCube, RAY

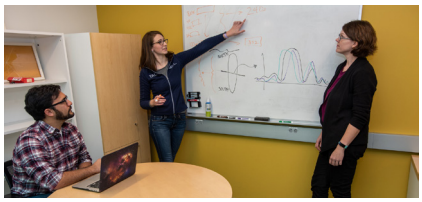


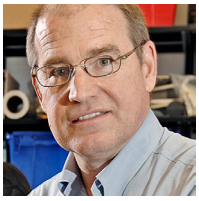
Ian Moult
Assistant Professor

Theory

Laura Newburgh
Associate Professor

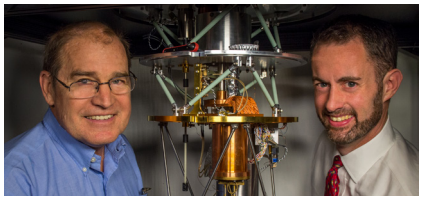
Experiments: CHIME, CMB-S4, Green Bank Observatory, HIRAX, Simons Observatory



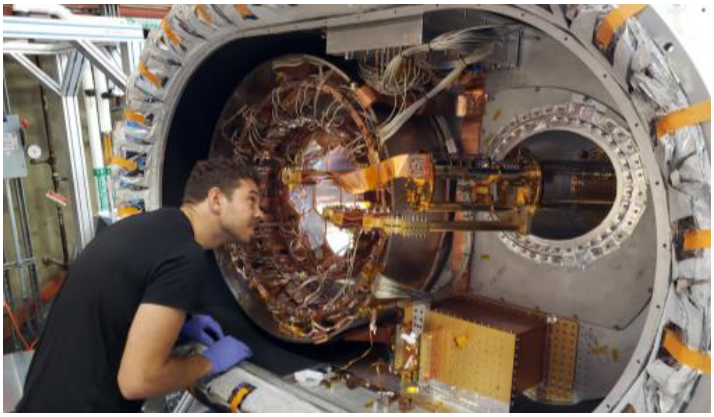


Harvey Moseley
Visiting Fellow

Experiments: COBE, JWST, KAO, SOFIA, Spitzer, Japan's X-ray astronomy



Investigating the beginning & expansion of the Universe



Newburgh Group

Laura Newburgh, PI; Brian Koopman, research scientist; Max Silva-Feaver, postdoctoral fellow; Michael McCracken, Pranav Sanghavi, postdoctoral associates; Jack Lashner, software engineer; Mallory Helfenbein, postgraduate associate; Sanah Bhimani, Morgan Cole, Tom Morris, David Nguyen, Alex Reda, Lauren Saunders, Will Tyndall, graduate students; Eli Bader, Audrey Cesene, Éle Donegan, Jordan Davidson, Spencer Greenfield, Ana Maria Melián, Andrew Tejada-Vega, Audrey Whitmer, undergraduates

The Newburgh group has been deploying **Simons Observatory (SO)** in Chile—two out of four telescopes are now running initial science observations, with the other two in a commissioning phase. The group leads and builds software for SO control and data acquisition, and they have been enjoying working out the "real-world" issues they have run across. The group is transitioning to more data analysis, and has completed the first maps of the Cosmic Microwave Background (CMB), as well as cross-correlations with both internal and external (Planck) data to understand the survey depth and calibrations thus far. *See article, p. 6 for more information.*

Alex Reda published work describing analysis and results using holography to map the beam shape of **CHIME** in Canada for CHIME's analysis pipeline (ApJ 976, 163, 2024). The group also flew their drone over CHIME to begin the process of understanding how to use drones to map CHIME's beam shape (submitted for publication).

The Newburgh group has submitted a paper presenting results from drone measurements made at **Green Bank Observatory (GBO)** in West Virginia and recently performed flights over a 3m radio dish here at Yale (see below) to test a new digital calibration source based on new Radio Frequency System-on-Chip (RFSoC) technologies.

In 2025, the Newburgh group will also be making measurements with drone beam mapping to validate the first **HIRAX** dishes in South Africa and check the beam shapes match the requirements.

Newburgh Group develops testbed radio telescope at Wright Lab

Wright Lab's Will Tyndall (Ph.D. '24) and other members from the Newburgh group developed a radio telescope that they can use as a testbed for instruments, technologies, and measurement techniques they are developing to calibrate telescopes at observatories around the world, including in the United States, Canada, Chile, and South Africa. Tyndall explained further in a 2023 interview posted on our website at: wlab.yale.edu/radiotelescopeatWL.

Newburgh's expertise helps probe the 'infant universe'

The new Simons Observatory (SO) in northern Chile—funded by the Simons Foundation and the National Science Foundation—will test whether the Universe experienced a massive growth spurt in the instant after the Big Bang. The observatory currently features four telescopes and offers an unprecedented scientific opportunity to probe the primordial light known as the cosmic microwave background (CMB). But it won't be able to do its work without software designed, built, and tested by Newburgh and her team at Yale.

"It's an incredibly ambitious experiment," said Newburgh, an assistant professor of physics and member of the observatory's technical community. "We'll make the most precise measurements of the infant Universe and might even capture the physics of an elusive period when the universe was less than a second old."

Newburgh explained that SO has two main science goals. "First. . . to study the Universe in its most infant stage, when it was much less than one second old. We think the Universe expanded much faster than the speed of light, during a period we call 'inflation.' This is theorized to exist, but it hasn't been proven. So, at the new observatory, we are going to look for a signal from this 'inflation' period, embedded in the CMB."

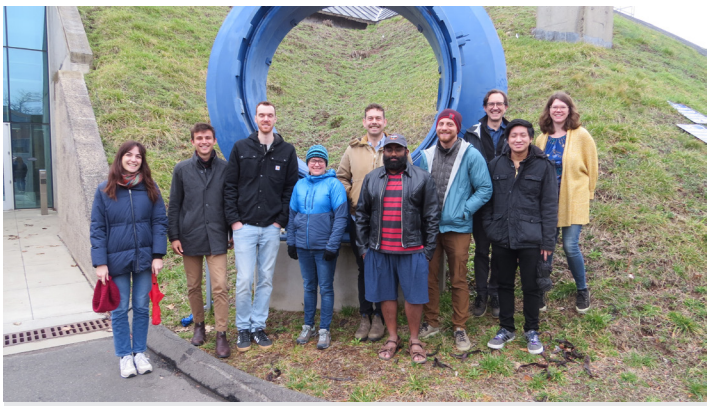
"The second goal is to search for additional early particles in the Universe. Around the time the CMB formed, when the Universe was about 400,000 years old, it was an incredibly energetic period, with particles being produced in copious amounts. These are what we call "light relativistic particles." Ground-based particle accelerators and other experiments can't look for these particles — but we think we can."

"Lastly, we want to do a better job of measuring some things via the CMB that we already know about, such as how the Universe is expanding today."

"We built the software architecture to control all of the systems on the telescopes and acquire the data from the 60,000 detectors across the observatory—a factor of four more than any other CMB experiment! It is an entirely new scale of operation for this field. In addition to the detector data, this scale of observatory comes with many, many more auxiliary components that we must interact with to observe the sky. The telescopes have to move and track and scan, the calibration equipment must work seamlessly, and the detectors have to be chilled to 0.1 degrees Kelvin above absolute zero with a fancy helium refrigerator—so we are also acquiring data, and in some cases making commands, from all of these subsystems."

"In addition to the scale, the truly revolutionary thing we did was making our software easy enough to use so that any of our collaborators could easily add their components to the system using just a snippet of readily available code."

This article has been adapted and condensed from a Yale News article by Jim Shelton from July 26, 2024.

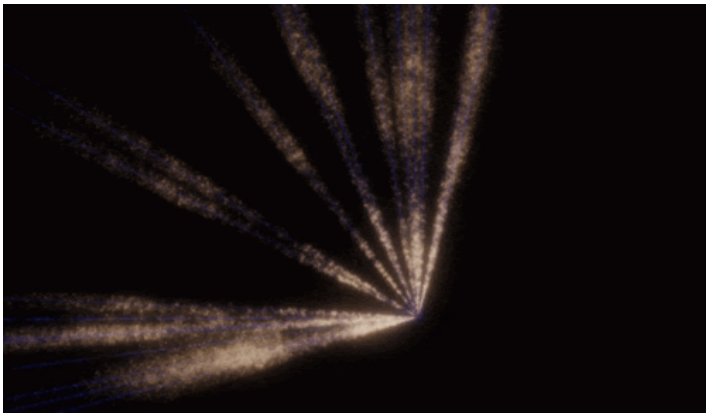


Wright Lab hosts SO Hackathon

In March 2024, researchers from Yale, Princeton, the University of Pennsylvania, the Flatiron Institute, and Argonne National Laboratory convened at Wright Lab to participate in a SO "hackathon" to improve the code that is used to take raw telescope data and process into maps of the CMB.

Read more at: wlab.yale.edu/so-hack-24

Investigating the expansion of the Universe



Baltay Group

Charlie Baltay, PI; David Rabinowitz, senior research scientist; Will Emmet, senior mechanical engineer; Tom Hurteau, research & development technician; Sasha Safanova, grad student; Forrest Hutchison, Kohsuke Sato, undergraduates

LaSilla/QUEST Southern Hemisphere survey

Because the Hubble Constant appears to be changing, scientists now theorize that the Universe is expanding and that there must be a new form of energy in the Universe, which scientists call Dark Energy.

The Baltay group is working to resolve unexplained discrepancies in Hubble constant measurements using both Type Ia Supernovae and RRLyra variables, and has recently submitted two papers with results of these studies for publication.

The results from the survey show the success of new methods of measuring the Hubble Constant using supernovae and RR Lyrae variables as "standard candles" to calibrate measurements. Because of the Baltay group's work, the precision of the Hubble Constant measurement has improved such that it is now better than the discrepancy. Furthermore, the group, including researchers from Yale Astronomy Department, has been able to detect traces of structure in the Milky Way galaxy that will lead to more understanding of the history of the formation of the galaxy.

The Baltay group recently upgraded the QUEST camera for the next generation of the survey, LS4 (La Silla Schmidt Southern Survey). The upgrade, which is being packed up at Wright Lab to travel to Chile, will optimize LS4 for discovering and following transients that will not be targeted by larger telescopes; enabling study of closer, brighter, and rapidly changing supernovae.

Yale Fiberview Camera contributes to success of DESI

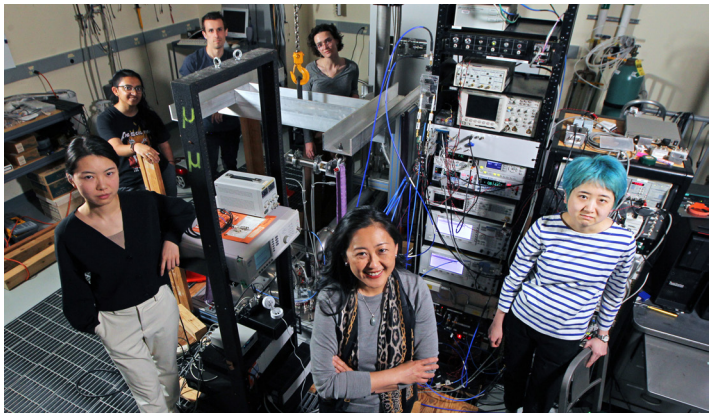
The Dark Energy Spectroscopic Instrument (DESI) is designed to create a 3-D map of the sky that will allow researchers to measure the effects of dark energy on the expansion of the universe. The Yale Fiberview Camera, designed, built, and installed by the Baltay group at Wright Lab, is an integral part of the efficiency and precision of DESI.

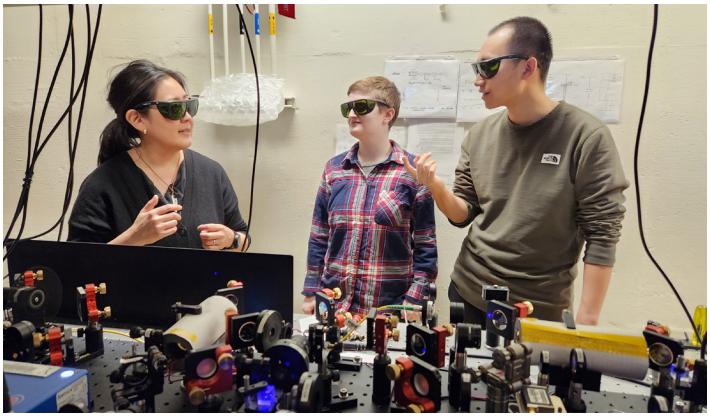
DESI released data sets in both 2023 and 2024, demonstrating DESI's ability to accomplish its scientific goals. Recent papers show a change in the dark energy component of the Universe over time. The expansion and growth of galaxies observed by DESI is nicely consistent with general relativity without modifications. *See also wlab.yale.edu/23-desirelease.*

Nancy Grace Roman Space Telescope Mission

Baltay, along with Saul Perlmutter from U.C. Berkeley, has advised NASA for many years on how best to design and use the Roman Space Telescope for a supernova survey that, when combined with data from Baltay's southern hemisphere surveys, will provide imporant new information about the nature of the mysterious acceleration of the expansion of our Universe and Dark Energy. Baltay will continue efforts developing the survey and the telescope will launch in 2026.

Searching for dark matter





Maruyama Group

Reina Maruyama, PI; Govinda Adhikari, Eun-Joo Ahn, Michael Jewell, Tyler Johnson, Jorge Torres, Sabrina Zacarias, Yuqi Zhu postdocs; Xiran Bai, Eunice Beato, Sumita Ghosh, Eleanor Graham, Sophia Hollick, Benjia Li, Ridge Liu, Maya Moore, Claire Laffan, graduate students; Kelly Dai, Matthew Dobre, Elsa Durcan, Quinn Ennis, Din-Ammar Tolj, Iffat Zarif, undergraduates; Vedant Aryan, Maxwell Mazo, Swarna Navaratnam-Tomayko, HARPS high school students

Axion Dark Matter (ALPHA, HAYSTAC, RAY)

The Maruyama group is using three different experiments, all located at Wright Lab, to search for dark matter in the form of axions, which are very low mass particles that are a theorized candidate for dark matter.

For more information on ALPHA, see p. 11.

HAYSTAC (co-led with Steve Lamoreaux) searches for axion dark matter in the galactic halo by searching for a resonant photon signal produced by axion conversion in a magnetic field. The experiment is moving into a new phase (III). The results of phase II have been published in a Phys. Rev. D paper led by Michael Jewell, which also includes details of the design and operation of the experiment and its upgrades. While HAYSTAC has not yet detected the axion, using a squeezed state receiver it has achieved sub-quantum limited noise as well as defining an upper limit on where the axion can be found in the mass regions in which it is searching.

Yuqi Zhu has led a paper in Rev. Sci. Instrum. that describes the effectiveness of a new technique the team has developed to inject synthetic axion signals into HAYSTAC and to calibrate them.

Xiran Bai has also led a paper in JINST exploring the use of dielecric elements in axion searches with microwave resonant cavities, such as HAYSTAC; leading to the conclusion that the technology creates reduced sensitivity for detecting axions.

The **Rydberg Atom at Yale (RAY)** experiment is developing a single-photon detector for haloscope experiments based on microwave transitions between highly excited Rydberg states in potassium atoms. The experimental concept for RAY has been published in a Phys. Rev. D paper led by Eleanor Graham. The next phase will focus on achieving Rydberg state readout at room temperature using selective ionization detection.

COSINE-100

In March 2023, the **COSINE-100** experiment, for which Maruyama is both Principal Investigator and co-spokesperson, was decommisioned. The experiment produced about 6 years of quality physics data to test the DAMA/LIBRA collaboration's claim that they had made a direct detection of dark matter, based on an annual modulation they observed in their data. Govinda Adhikari led two papers published in 2023 about the results. The experiment's run confirmed that DAMA/LIBRA's modulation signal cannot be from spin-independent weakly interacting massive particles (WIMPs) within the standard halo model (SHM). COSINE-100 did find a significant annual modulation, but it was almost the opposite to that of the DAMA/LIBRA result, so this phenomenon will be studied further in COSINE-200, which is being developed to verify or refute the DAMA/LIBRA signal without any ambiguity, as well as to further improve the sensitivity of COSINE-100's technology that has been found to have advantages in searching for low-mass dark matter.

Explaining the unexplained with HAYSTAC and ALPHA

As physicists, cosmologists, and astronomers coax the unseen to reveal itself, one question keeps creating another. The pursuit of mysteries like how black holes work, what dark matter and dark energy are, and how the Universe arose gives rise to strange contradictions. Much of the experimental work is done in superlatively cold, dustless, or dry conditions. Unimaginably small particles could explain the most titanic of cosmological phenomena. The most abundant forms of matter and energy are the hardest ones to observe. Being wrong can be almost more rewarding than being right.

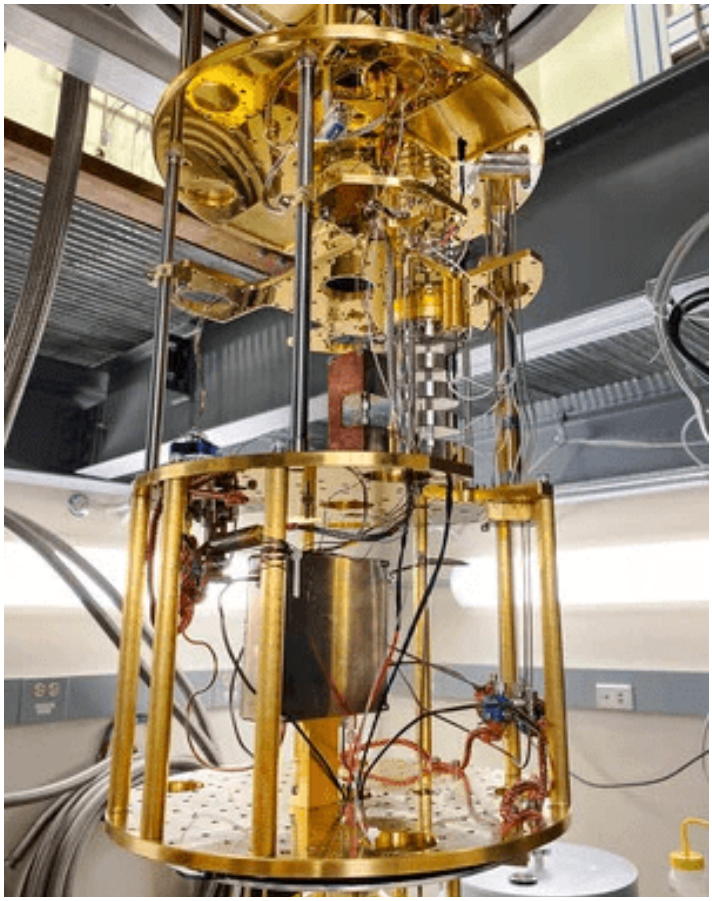
"The Universe. . . is made of regular matter like you and me. But that matter only constitutes something like five percent of the Universe," said Reina Maruyama, professor of physics and astronomy. "The rest is made up of things that we don't understand."

There is matter, there is antimatter, and then there is dark matter. Dark matter might be said to haunt the other kinds. The Milky Way itself is sitting in a cloud of the stuff. Yet we know it exists only because the mass we can measure in stars, gas clouds, and galaxies isn't enough to keep them from flinging themselves apart. Something invisible and abundant must be investing those grand and luminous structures with extra gravity. Indeed, dark matter interacts only with gravity; it neither gives off nor absorbs electromagnetic radiation of any kind, making it seemingly impossible to find.

Scientists do have dark-matter particle candidates in mind. One hypothetical class of particles is called weakly interacting massive particles (WIMPS). If they exist, WIMPs could interact with ordinary matter via the weak nuclear force, giving nuclei what Maruyama calls "a little momentum kick."

To have any hope of detecting such a collision, physicists build detectors out of dense target material and protect them from extraneous particles, cosmic rays, gamma rays, etc. The whole package must be situated deep underground to take advantage of the Earth's ability to act as a shield. (Or under deep ice in a neutrino observatory at the South Pole, where Maruyama recalls setting a water bottle on the floor of her quarters, then finding its contents frozen soon afterward.)

After years of chasing WIMPs, though, researchers have come up short. Axions are another hypothetical



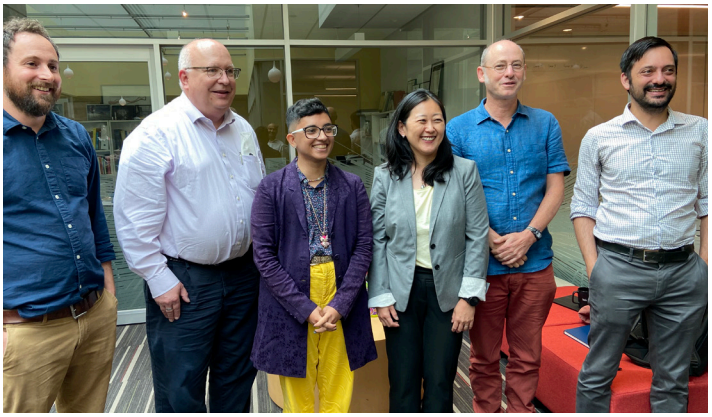
dark-matter candidate. Axions were named for a cleaning detergent— because if they turn out to exist, they would "clean up questions that we don't understand in particle physics," Maruyama explained. The search for axions does not need to take place in an isolated location. One experiment, aptly called HAYSTAC (Haloscope At Yale Sensitive To Axion CDM), is underway on campus at the Wright Laboratory. In addition, a new experiment called ALPHA (Axion Longitudinal Plasma Haloscope) was just funded and is currently being built.

Whatever dark matter's nature, scientists will recognize it because it will make sense of observations that are currently baffling, such as how light bends around massive objects and the way stars behave.

"We need to be able to describe the observed universe as we see it," Maruyama said. "Dark matter particles need to make the stars move and evolve in the way that we see them. All that needs to fit together."

This article has been adapted and condensed from a Faculty of Arts and Sciences news article by Jenny Blair from March 1, 2024.

Searching for dark matter



Lamoreaux Group

Steve Lamoreaux, PI; Eustace Edwards, Varun Jorapur, Jakob Kastelic, Sukhman Singh, Oksari Timgren, grad students

Axion Dark Matter (ALPHA, HAYSTAC)

Steve Lamoreaux has been involved in pioneering the development of haloscope experiments to search for the axion candidate of dark matter at Wright Lab for many years. HAYSTAC, which he now co-leads with Reina Maruyama, completed its first data run in 2016, and the Lamoreaux and Maruyama groups continue to develop new technologies to keep HAYSTAC a leading experiment in the field today. *For more information on HAYSTAC, see p. 8*.

In 2023, Wright Lab agreed to host the Axion Longitudinal Plasma Haloscope (ALPHA) experiment. Lamoreaux—along with Maruyama, who is the ALPHA PI, and the groups of Yale faculty members Keith Baker, Charles Brown, Sean Barrett, Karsten Heeger, and Konrad Lehnert—are leading efforts to develop and build the ALPHA detector at Yale, along with collaborators from other institutions (*see p. 11*).

Electron Dipole Moment (EDM) experiment

Lamoreaux is also contributing to a new experimental neutron electric dipole moment experiment at Los Alamos National Laboratory, which is a follow-up to his previous work at the Institut Laue-Langevin in Grenoble, France. The optically pumped mercury magnetometry system he developed there is being improved and applied to the new experiment, with research being done at Yale to reduce cell wall interactions that lead to atomic spin depolarization.

The Historical and Physical Foundations of Quantum Mechanics

Steve Lamoreaux, professor of physics at Yale, and a member of Yale's Wright Lab, has recently published; with co-author Robert Golub, professor of physics at North Carolina State University; "The Historical and Physical Foundations of Quantum Mechanics" (Oxford University Press, 2023).

In May 2023, Wright Lab hosted a book launch, where Lamoreaux gave a 30-minute overview talk, followed by food and refreshments for celebration and casual discussion. Lamoreaux said, "The idea behind our book is that to gain a real understanding of the subject, some acquaintance with the historical development is essential; after all, that history is the narrative of how humanity learned quantum mechanics."

Read more at: wlab.yale.edu/lamoreauxbook23

A big lift for a new dark matter search at Wright Lab

In March 2024, a team of researchers, technicians, and contractors was on campus to move a powerful (15.3 Tesla) superconducting magnet from professor Sean Barrett's lab in the basement of Sloane Physics Laboratory (SPL) to Yale Wright Laboratory (Wright Lab). The magnet, including parts installed to secure it for transport, weighed 12,000 lbs.

The magnet move was the first step in developing the new Axion Longitudinal Plasma Haloscope (ALPHA) experiment, located at Wright Lab. ALPHA will extend the search for a hypothetical dark matter candidate—a very low-mass particle called the axion—to a higher mass range than has been searched for previously.

Reina Maruyama, professor of physics, deputy spokesperson of the ALPHA experiment, and a member of Wright Lab said, "I am excited we can do this experiment at Yale. I am grateful to Professor Barrett for offering to share this magnet with us, and Yale's leadership and facilities teams for enabling this science. I am looking forward to turning on the magnet and starting to look for axions with this new instrument ALPHA."

Karsten Heeger, Eugene Higgins Professor of Physics, director of Wright Lab, and a member of the Yale ALPHA team, said, "We are excited to host the next step in the axion search for dark matter at Wright Lab."

According to Wright Lab research and development technician Frank Lopez, before Saturday's move, contractors did preparatory work in SPL, such as removing a window of SPL, setting up stacked pieces of wood to safely secure an object at a height so a worker will not have to go under a suspended load, and installing the parts needed to protect the magnet during travel.

On the day of the move, Smedley Crane & Rigging handled the lifting from the basement, roll through the window, crane flight (including over the top of SPL), and delivery to Wright Lab.

Images of the magnet move are available on the Wright Lab Flickr page here.

ALPHA complements two existing experiments at Wright Lab that are searching for axion dark matter, Haloscope At Yale Sensitive To Axion CDM (HAYSTAC) and Rydberg Atoms at Yale (RAY) (*see p.8 for more*).

ALPHA will build on the success of HAYSTAC and search for even higher mass axions by employing a novel axion detector called a plasma haloscope. ALPHA will comprehensively investigate how new experimental ideas using plasmas can be used to detect the axion; pushing the boundaries of quantum detection and microwave technology.

Michael Jewell, associate research scientist, said, "HAYSTAC has been and will continue to pioneer dark matter axion searches at high masses. However, extending HAYSTAC's reach to higher masses, where some theorists predict the axion to be, is a challenging problem and requires innovative ideas. ALPHA provides exactly that by breaking the typical requirement that a high-mass search requires a small detection volume and opens up the door to previously un-explored axion parameter space."

The ALPHA experiment includes researchers from UC Berkeley, Yale, University of Colorado Boulder, MIT, Johns Hopkins, Wellesley, Arizona State University, Stockholm University, ITMO University, Cambridge and Oak Ridge National Laboratory.

Maruyama is the deputy spokesperson of ALPHA and Principal Investigator (PI) of the Yale ALPHA team, which includes Yale Physics faculty Keith Baker, Barrett, Charles Brown, Heeger, Konrad Lehnert, and Steve Lamoreaux. Jewell is the ALPHA project technical coordinator.

ALPHA is funded by a partnership of The Gordon and Betty Moore Foundation, the Simons Foundation, the Alfred P. Sloan Foundation, and the John Templeton Foundation.

Elementary Particles

Keith Baker
D. Allan Bromley Professor

Experiments: ALPHA, ATLAS, Axions, Hidden Sector Photons, Quantum Entanglement

Charles Brown
Assistant Professor

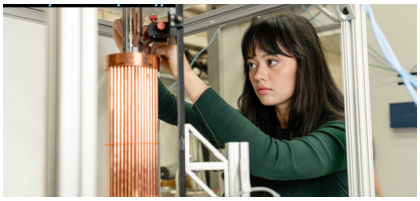
Experiments: ALPHA, RAY, Single/Few/Many Body Quantum Physics

Sarah Demers
Professor of Physics, Director of Undergraduate Studies in Physics

Experiments: ATLAS, Mu2e

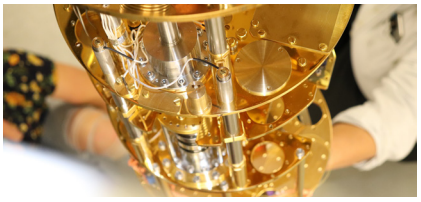
Karsten Heeger
Eugene Higgins Professor and Chair of Physics, Director Wright Lab

Experiments: ALPHA, CUORE/CUPID, Daya Bay, DUNE, Project 8, PROSPECT



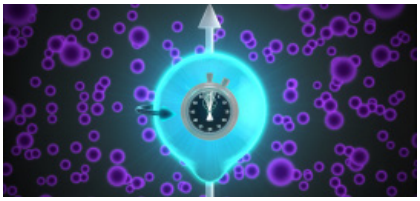
Steve Lamoreaux
Eugene Higgins Professor

Experiments: ALPHA, HAYSTAC



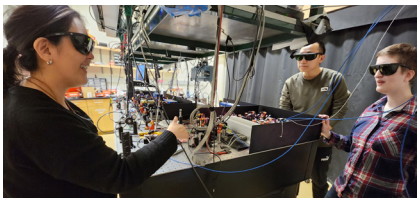
Konrad Lehnert
Eugene Higgins Professor of Physics

Experiments: ALPHA, HAYSTAC



Reina Maruyama
Professor

Experiments: ALPHA, CUORE/CUPID, COSINE-100, HAYSTAC, IceCube, RAY

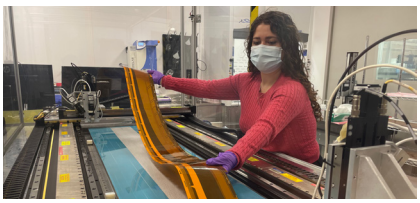


Ian Moult
Assistant Professor

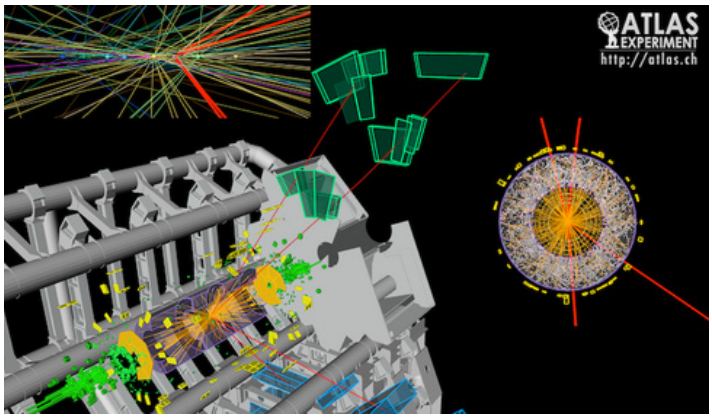
Theory

Paul Tipton
Eugene Higgins Professor of Physics

Experiment: ATLAS



Exploring the fundamental nature of the Universe



Baker Group

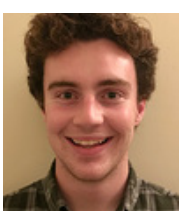
Keith Baker, PI; Theodota Lagouri, research scientist; Nathan Borak, Colin Coane, Jingjing Pan, Daniel Qenani, Nathan Suri, Mira Varma, graduate students; Seojun Lee, Argyris Giannisis Manes, Gabriel Marous, undergraduates

The Baker Group sets new limits on Quantum Information Science (QIS); searches for physics that is beyond the Standard Model of particle physics using data from the ATLAS Experiment at the Large Hadron Collider at CERN. The Baker group is also developing a quantum computer algorithm for Higgs decay to vector bosons.

Keith Baker is the Yale ATLAS team leader and Yale ATLAS Institute representative. He mentors and collaborates with the Baker group members. He also serves as an online data quality transition radiation tracker shifter for ATLAS.

Theodota Lagouri is carrying out research in QIS as well as searches for physics that is beyond the Standard Model of particle physics using ATLAS. Lagouri has a strong leadership role in both of these studies.

Nathan Borak is carrying out research on the Eigenstate Thermalization Hypothesis (ETH) applied to detector scenarios. ETH can explain when a pure quantum state leads to the emergence of thermal behavior. This line of research will hopefully shed light on why the transverse momentum spectrum of hadrons produced in accelerators obeys a Boltzmann-like distribution at low p_T.



Colin Coane is carrying out research on Quantum Entanglement, which includes new QIS in High Energy Physics using the Higgs boson decays to vector bosons in ATLAS.

Jingjing Pan (Ph.D. '24)'s dissertation focused on both data analysis for dark sector searches in exotic decays of the Higgs boson and jet definitions in ATLAS and the performance and resolution of the di-jet samples.

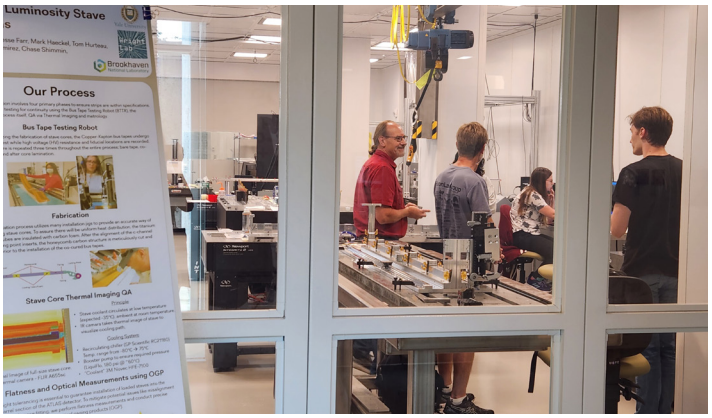
Daniel Qenani is interested in exploring quantum information, focusing on its intersections and applications in high-energy physics.

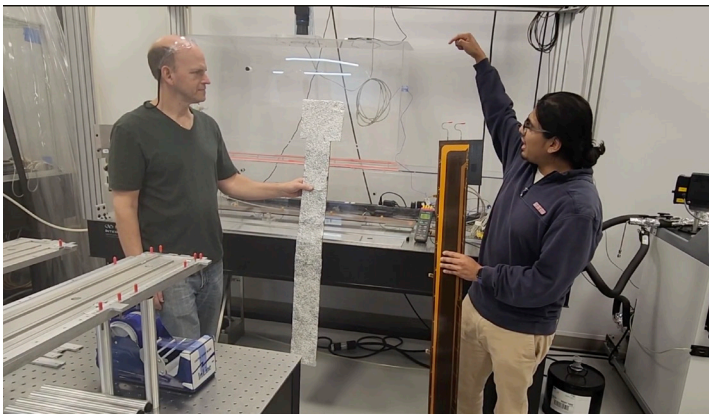
Nathan Suri worked on constituent-based pileup mitigation, which may improve the jet energy, jet substructure, missing momentum, and lepton isolation in ATLAS events. This includes a new computer algorithm—SoftKiller—for both small- and large-radius jets. Suri's work has contributed to three presentations at international conferences and workshops. Suri transferred to the Demers group in 2024.

Mira Varma is carrying out research in QIS, specifically Entanglement Entropy in High Energy Physics in ATLAS. Her work has contributed to two published papers and three presentations at international conferences and workshops.

See also p. 51 for more.

Exploring the fundamental nature of the Universe





Tipton Group

Paul Tipton PI; Jeff Ashenfelter, project manager; Mark Haeckel, Tom Hurteau, Brandon Ramirez research and development technicians; Arianna Garcia Caffaro, graduate student; Nikita Mazotov, Pev Vail, undergraduates

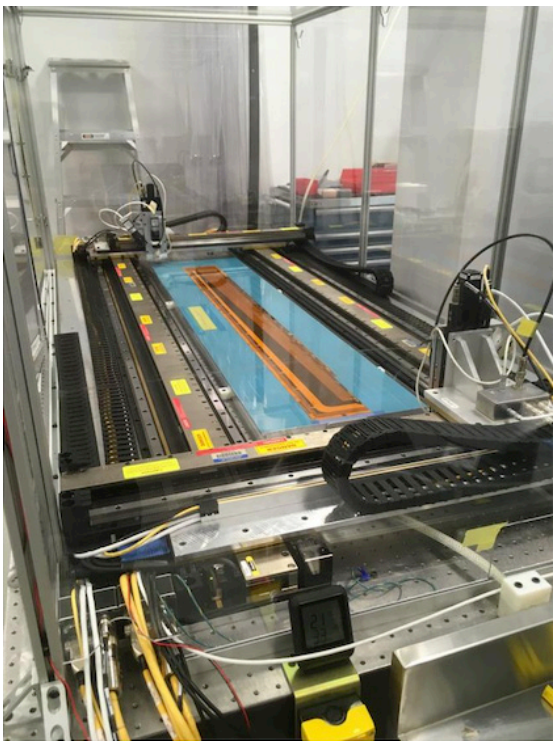
Paul Tipton questions existing scientific models of the physical Universe and searches for new understanding of how the Universe works, discovering and characterizing new particles and searching for other phenomenon beyond the Standard Model of physics.

Within Wright Lab, a research team led by Tipton is fabricating essential components of a new particle detector that will track the path of charged particles as they leave the collision point of the Large Hadron Collider, or LHC at CERN. Tipton's team, part of the ATLAS collaboration, is working on a schedule such that the new particle tracker will be installed at CERN in approximately 2026.

At Wright Lab, Tipton's team is fabricating support structures called stave cores, that hold the actual particle sensors. On a day-to-day basis, the project is managed Jeff Ashenfelter, who supervises the three technicians and two undergraduate team members. The work at Yale managed by Ashenfelter is funded by DOE through a $5M sub-contract from Brookhaven National Lab.

Highlights of our work from 2023-24 include:

- Hired and trained two new technicians.
- Developed Quality Assurance/Quality Control (QA/QC) test stations and procedures in anticipation of the start of stave core production.
- Fabricated pre-production stave cores, with very good success in these cores passing our QA/QCI tests.
- Finalized a contract with CERN to produce bus tapes; the last remaining needed stave core part previously without a signed supplier contract.
- Pursued ways to increase stave core production through-put so that we can shorten the production time. Currently we plan to fabricate the 227 needed stave cores at a maximum rate of 2 per week, and are working toward a capacity of roughly 2.5 per week.



Neutrinos & Fundamental Symmetries

Karsten Heeger

Eugene Higgins Professor and Chair of Physics, Director Wright Lab

Experiments: ALPHA, CUORE/CUPID, Daya Bay, DUNE, Project 8, PROSPECT

Reina Maruyama

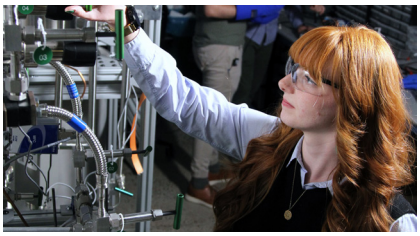
Professor

Experiments: ALPHA, CUORE/CUPID, COSINE-100, HAYSTAC, IceCube, RAY

David Moore

Associate Professor of Physics

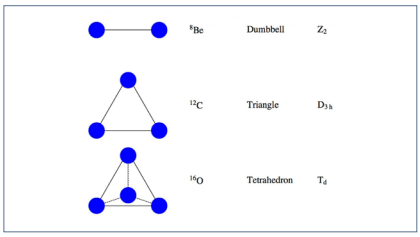
Experiments: EXO-200, MAST-QG, NEXO, QuIPS, SIMPLE



Francesco Iachello

JW Gibbs Professor Emeritus and Research Professor of Physics

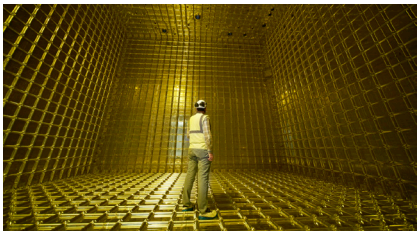
Theory



Flavio Cavanna

Professor (Adjunct) of Physics and Fermilab and University of L'Aquila

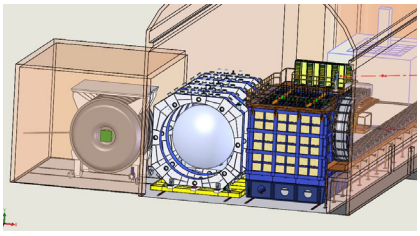
Experiments: DUNE, LAr detector R&D



Sandro Palestini

CERN, Research Affiliate in Physics

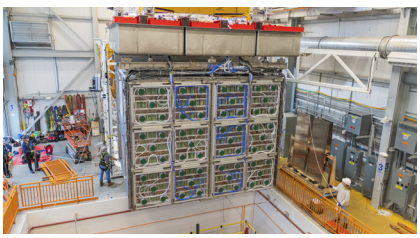
Experiment: DUNE



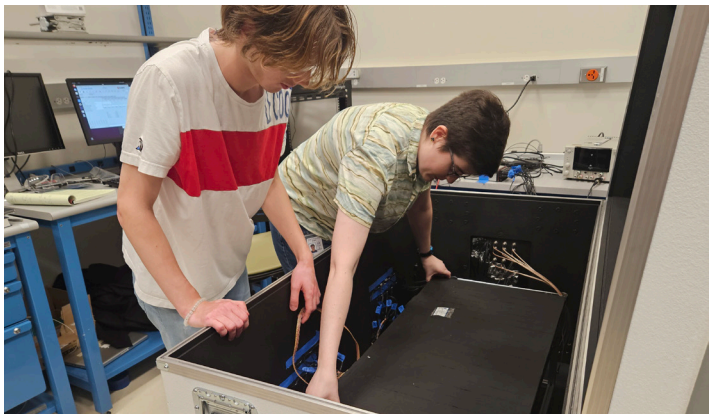
Ornella Palamara

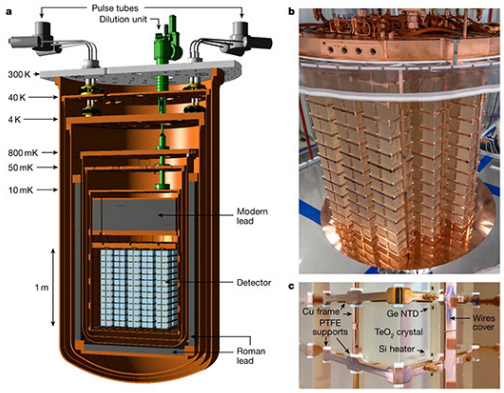
Professor (Adjunct) of Physics and Fermilab and Laboratori Nazionali del Gran Sasso

Experiments: SBND, DUNE



Searching for neutrinoless double beta decay





Cryogenic Underground Observatory for Rare Events (CUORE)

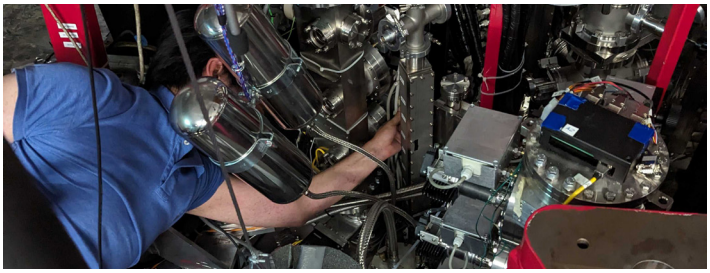
Karsten Heeger and Reina Maruyama, PIs; Pranava Teja Surukuchi and Jorge Torres, postdoctoral associates; and Ridge Liu, Maya Moore, Samantha Pagan and Emily Pottebaum, graduate students; Aaron Chizhik, Diya Naik, Din Tolj, and Iffat Zarif, undergraduates

CUORE, and its successor CUORE Upgrade with Particle Identification (CUPID), both located in Italy, are searching for a previously undetected process called neutrinoless double beta decay. If such a process is observed, it would demonstrate that neutrinos are their own antiparticles, offering a possible explanation for why we live in a Universe of matter, not antimatter.

Heeger and Maruyama are co-Principal Investigators of CUORE. Maruyama is co-spokesperson of the CUORE experiment and Heeger is the international co-spokesperson of CUPID. Maruyama and Heeger have been involved in CUORE since 2004.

The Yale CUORE/CUPID team has been responsible for detector calibration, the study of cosmogenic backgrounds, double beta decay analysis, and the search for solar axions, and is currently preparing for the CUPID upgrade.

CUORE recently released its latest result setting the most stringent limits on neutrinoless double beta decay in 130Te with half-lives of > 4x10^25 yr, orders of magnitudes larger than the age of the Universe.



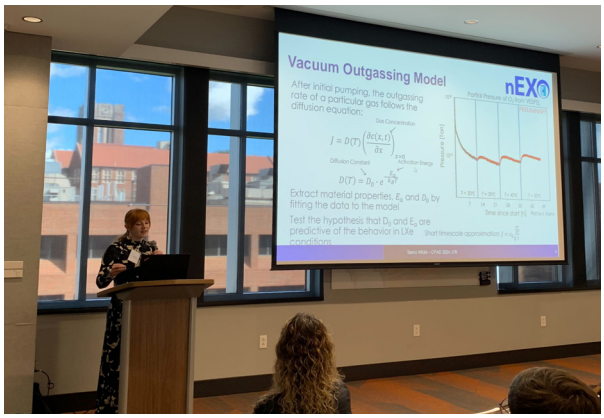
An Ancient Roman Shipwreck May Explain the Universe

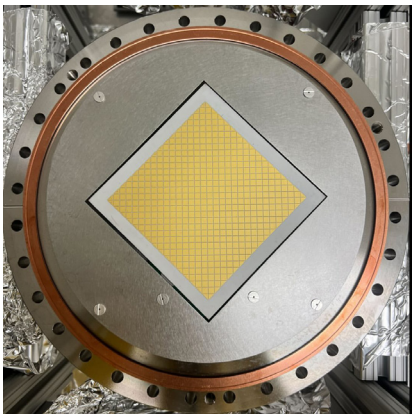
SciShow, a YouTube channel with over 8 million subscribers that, according to their tagline, "explores the unexpected," recently featured the CUORE (Cryogenic Underground Observatory for Rare Events) and CUPID (CUORE Upgrade with Particle IDentification) experiments in a video about how "An Ancient Roman Shipwreck May Explain the Universe".

The video, hosted by SciShow's Hank Green, explains how and why the CUORE experiment and its successor CUPID have been able to use artifacts found in an ancient Roman shipwreck to enhance the ability of their physics experiment that seeks to understand the mysterious nature of the fundamental physical processes that have shaped our Universe as we know it.

See the video on YouTube (https://www.youtube.com/watch?v=o0A9M5wHBA4) to learn more.

Searching for neutrinoless double beta decay





nEXO

David Moore, PI; Avinay Bhat, Lucas Darroch postdoctoral associates; Glenn Richardson, Molly Watts, and Sierra Wilde, graduate students; Wayne Ariston, Coryell Smith, Ronald Thorpe, and Barkotel Zemenu, undergraduates

The Moore group has been among the leaders of the development of large-scale liquid xenon detectors—such as the planned nEXO (next Enriched Xenon Observatory) experiment at SNOLAB in Ontario, Canada—to search for neutrinoless double beta decay. If this process is observed, it may answer why we live in a Universe made of matter, not antimatter.

nEXO is an international collaboration involving 10 countries and 36 institutions. Moore is the subsystem scientist for the nEXO photon detector. The Moore group is leading efforts to build photon detectors for nEXO and studying ways to capture xenon directly from the atmosphere to enable even larger, more sensitive detectors.

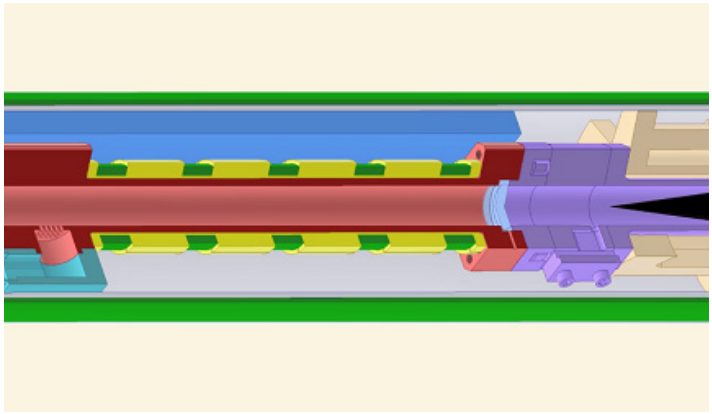
Richardson awarded DOE SCGSR grant

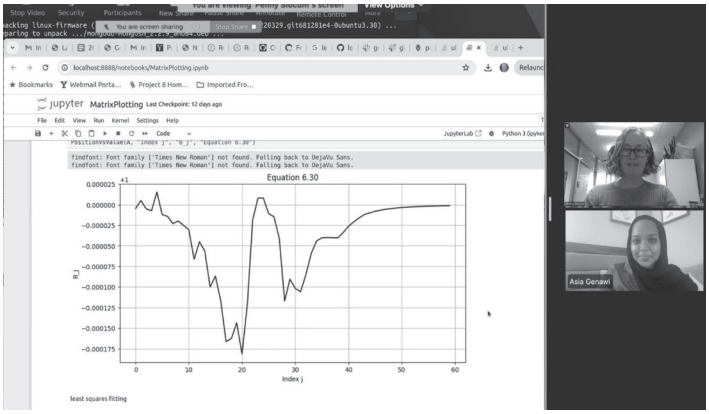
Wright Lab graduate student Glenn Richardson was awarded a Department of Energy (DOE) Office of Science Graduate Student Research program (SCGSR) grant to develop and test nEXO's cryogenic Application Specific Integrated Circuits (Cryo-ASICS) at the SLAC National Accelerator Laboratory with SLAC associate scientist Brian Lenardo.

At the conclusion of the program, Richardson was featured on the nEXO Experiment's Instagram. The post read, "Glenn and the electronics team built our first working prototype charge readout module. The final version of this device will be used in nEXO to detect electrons produced within the detector by particles. Precisely measuring these electrons can help us to determine if the rare signal of neutrinoless double beta decay is present."

See the post at: www.instagram.com/p/C_y8JEQxCpa/?img_index=4

Investigating the properties of neutrinos





Project8

Karsten Heeger PI; James Nikkel, research scientist; Penny Slocum, associate research scientist; Pranava Teja Surukuchi, postdoctoral associate; Luis Saldana, research associate; Celin Hidalgo, Sergio Nuñez Silva, postgraduate associates; Arina Telles, Talia Weiss, graduate students; Aaron Chizhik, undergraduate

An international team of researchers from the Project 8 experiment, including the Wright Lab team, reported the first measurement of neutrino mass using a novel technique called Cyclotron Radiation Emission Spectroscopy (CRES). Once fully scaled up, Project 8 could provide the most sensitive method for a direct laboratory measurement of neutrino mass.

The Project 8 collaboration has spent years figuring out how to accurately tease out the electron signals from electronic background noise. Wright Lab has played a leading role at the very last stage of the process: placing an upper limit on how heavy the neutrino can be. Project 8 published a paper in Physical Review Letters, which includes the Wright Lab analysis, that places limits on the neutrino mass derived from the CRES technique for the first time.

In addition, the group has been involved in various aspects of the experiment, including: operating the CRES apparatus, developing algorithms for data analysis, working on detailed simulations, and developing the next prototype experiment on the way to a future full-scale Project 8 experiment.

Wright Lab graduate student Talia Weiss explained, "The neutrino is incredibly light. It's more than 500,000 times lighter than an electron. So, when neutrinos and electrons are created at the same time, the neutrino mass has only a tiny effect on the electron's motion. We want to see that small effect. So, we need a super precise method to measure how fast the electrons are zipping around." Project 8 has developed a highly precise CRES detector that can tell what energy an electron has to a precision of about one electron-volt. (If you eat a single Cheez-It, your body will gain 100,000,000,000,000,000,000 electron-volts.)"

The next step is to develop an experiment sensitive enough to reach beyond the sensitivity of current laboratory experiments at a fraction of an electron volt. This will require scaling up the CRES technique.

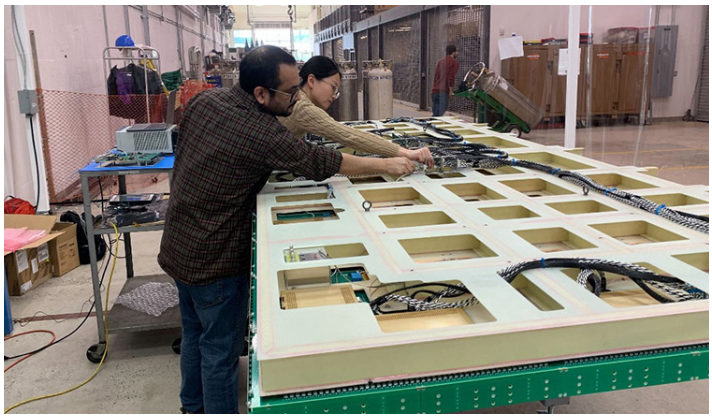
Heeger said, "This work will require innovative technical, computing, and analysis solutions, and we are excited to build the first large-volume demonstrator here at Wright Lab in the coming years."

This section is adapted from a PNNL press release by Kathryn Hede and a Yale News article by Jim Shelton.

Project 8 hosts high school internship

The Yale Project 8 team hosted Asia Genawi, a rising senior at the Indiana Academy for Science, Math, and the Humanities at Ball State University, for a May Term Internship. Genawi is working on the computing project "Project 8 trap integration studies". The two-week intensive internship gave Genawi an opportunity to become more familiar with the configuration and analysis involved in a computing project that is ongoing within Project 8. Read more: tinyurl.com/p8intern

Wright Lab assembles components for international neutrino experiment



Deep Underground Neutrino Experiment (DUNE)

Karsten Heeger PI; Sandro Palestini, research affiliate; Christopher Macias, associate research scientist; Govinda Adhikari, postdoctoral associate; James Wilhelmi, research support specialist, Jeff Ashenfelter, operations director; Tom Hurteau, Frank Lopez, and Craig Miller, research technicians; Lee Hagaman, graduate student

A team of researchers and technical staff from Yale's Wright Laboratory (Wright Lab), in collaboration with researchers from the Department of Energy's Brookhaven National Laboratory's (BNL) Electronic Detector Group, the University of Chicago; and the University of Iowa, has successfully assembled and tested the first Charge Readout Planes (CRPs) at Wright Lab for the international Deep Underground Neutrino Experiment (DUNE) at the Sanford Underground Research Facility (SURF) in Lead, South Dakota. The readout planes are an integral part of the novel liquid-argon detector to study the interactions of neutrinos. The completed CRP was shipped to CERN, the European Organization for Nuclear Research, in February 2023 for testing in CERN's ProtoDUNE facility.

Wright Lab is one of two CRP assembly sites in the international DUNE collaboration. The recent CRP assembly effort at Wright Lab has been a collaboration, led by Heeger, between Yale University, Brookhaven National Laboratory (BNL), the University of Chicago, and the University of Iowa.

Heeger said, "Wright Lab's unique facilities and infrastructure—including high bay assembly space, expert technical professionals, and dedicated support personnel—were critical for the recent successful work for DUNE."

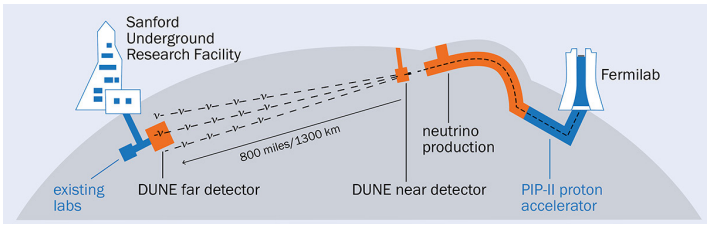
Charge Readout Planes (CRPs) are assembled with perforated printed circuit boards (PCBs) and attached to a composite frame that provides mechanical support and planarity. Warm and cold test electronics and cables are mounted, and the whole assembly is placed inside a "cold box" for testing at both room and cryogenic temperatures. Once the tests are successful, the CRP is packaged and sent to CERN for testing at the ProtoDUNE facility. The team is eagerly anticipating the test results from the ProtoDUNE setup at CERN.

Adhikari said, "I am pleased with the hands-on experience and lessons learned from setting up a clean room, conducting the assembly, and testing of CRPs in various temperatures. Wright Lab is equipped with the necessary resources, and provided an exceptional environment for the successful production of one of the vital components of the far detector for DUNE."

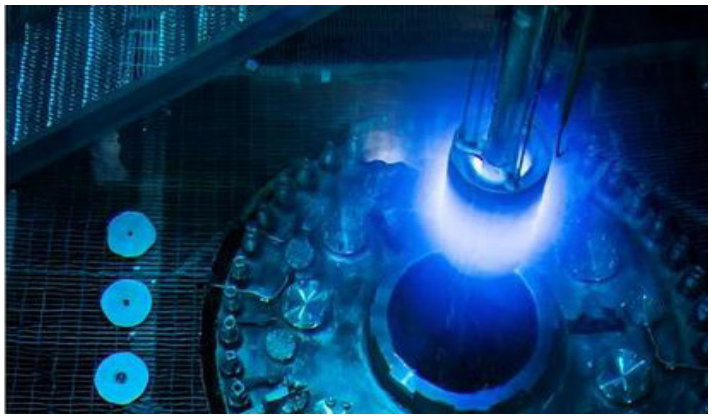
Adhikari continued, "Our team has developed the necessary competencies and confidence to consistently produce charge readout planes, which is critical in meeting the goals of the collaboration."

Collaborators from other institutions include Augie Hoffman, Hanjie Liu, and Matt Worcester from BNL; and Avinay Bhat, a recent Wright Lab postdoctoral alumnus who is now at the University of Chicago.

Read more at tinyurl.com/yaledune23



PROSPECTing new perspective on reactor-produced neutrinos



Precision Reactor Oscillation and Spectrum Experiment (PROSPECT)

Karsten Heeger PI; James Nikkel, research scientist; Pranava Teja Surukuchi, postdoctoral associate; Arina Telles, graduate student

Scientists in the PROSPECT collaboration, including members of the Heeger group, have produced final results from measurements of neutrinos emitted by a nuclear reactor at the Oak Ridge National Laboratory. (Heeger is principal investigator and co-spokesperson of PROSPECT.) Their work, recently published in Physical Review Letters and highlighted as an Editor's Suggestion, provides new insight into a puzzling and persistent difference that scientists have encountered between predictions and measurements of neutrinos emitted by nuclear reactors.

Neutrinos are nearly weightless, have no electric charge and come in three types, or "flavors." The type of neutrino produced in abundance by nuclear reactors does not stick to or bounce off of atoms, but passes through matter effortlessly, leaving almost no trace of its existence. Despite the feebleness of their interactions, neutrinos play an essential role in processes as small as radioactive decay and as large as the clumping of matter in the Universe.

In 2018 at the High Flux Isotope Reactor (HFIR) in Oak Ridge, Tennessee, a tiny fraction of those neutrinos (around a thousand per day) were detected by PROSPECT, a specialized ton-scale particle detector. Every so often, a single hydrogen nucleus in the detector's four-ton liquid center was transformed into a neutron by an interacting neutrino, creating unique pairs of light flashes that were captured by surrounding sensors.

"PROSPECT built a detector that uses unique features of the neutrino signal to find 'the needle in the haystack' and overcome a challenging background environment," said Nathaniel Bowden, PROSPECT co-spokesperson. "This was the first time an experiment has been able to do physics with reactor antineutrinos on the earth's surface, without being underground."

In their new results, PROSPECT used their entire 2018 neutrino dataset, carefully cleaned of backgrounds, to map the energies of neutrinos emitted by the unstable nuclear fragments in the HFIR core, which burns only highly-enriched uranium fuel. They then compared their map to a model formed from large nuclear databases containing decades' worth of measurements of the properties of these rare elements, many of which only exist on Earth inside burning nuclear fuel.

This comparison revealed a significant discrepancy also seen by previous neutrino efforts: higher-energy reactor neutrinos are more common than models predict. By noting that a similar difference is seen by neutrino experiments at commercial reactor cores burning a mix of uranium and plutonium, PROSPECT collaborators proved that models are likely wrong for fragments from both of these fuel components.

Bowden said this conclusion is relevant to nuclear physicists and reactor experts, who rely on these same nuclear databases, among other things, to model and validate other aspects of nuclear reactor behavior.

The PROSPECT detector was designed, built and operated by dozens of scientists from twelve universities, including Yale, and four US national laboratories. The final assembly took place at Wright Lab in 2017.

"PROSPECT was a unique opportunity to fully design and assemble a neutrino detector at Wright Lab and give students and postdocs the opportunity to be involved in all aspects of experimental design, construction and data taking," said Heeger.

Read more at: tinyurl.com/wlpros23

This article was adapted from a PROSPECT Collaboration press release of November 6, 2023. Previous Yale PROSPECT team members include staff, postdocs, and students: J. Ashenfelter, L. Baker, I. Bhalla-Ladd, B. Foust, J. Gaison, T. Langford, D. Norcini, J. Roth, and N. Stemen.

Quantum Science & Sensing

Keith Baker
D. Allan Bromley Professor

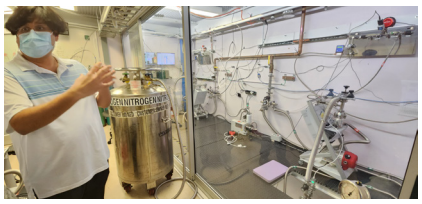
Experiments: ALPHA, ATLAS, Axions, Hidden Sector Photons, Quantum Entanglement

Charles Brown
Assistant Professor

Experiments: ALPHA, RAY, Single/Few/Many Body Quantum Physics

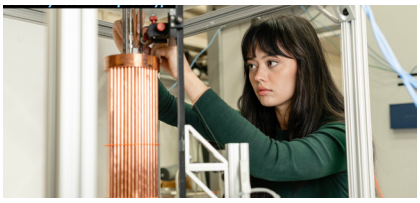
Jack Harris
Professor of Physics

Experiments: Quantum Mechanics



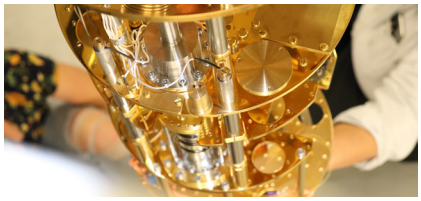
Karsten Heeger
Eugene Higgins Professor and Chair of Physics, Director Wright Lab

Experiments: ALPHA, CUORE/CUPID, Daya Bay, DUNE, Project 8, PROSPECT



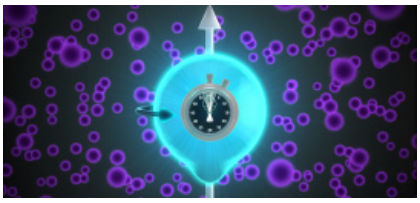
Steve Lamoreaux
Eugene Higgins Professor

Experiments: ALPHA, HAYSTAC



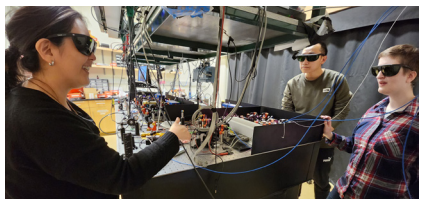
Konrad Lehnert
Eugene Higgins Professor of Physics

Experiments: ALPHA, HAYSTAC



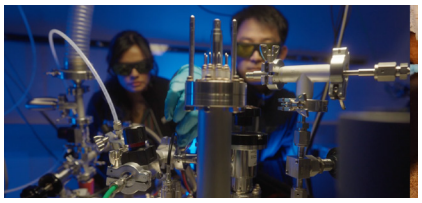
Reina Maruyama
Professor

Experiments: ALPHA, CUORE/CUPID, COSINE-100, HAYSTAC, IceCube, RAY



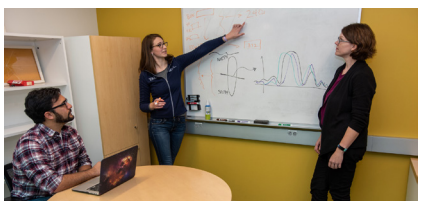
David Moore
Associate Professor of Physics

Experiments: EXO-200, MAST-QG, NEXO, QuIPS, SIMPLE



Laura Newburgh
Associate Professor

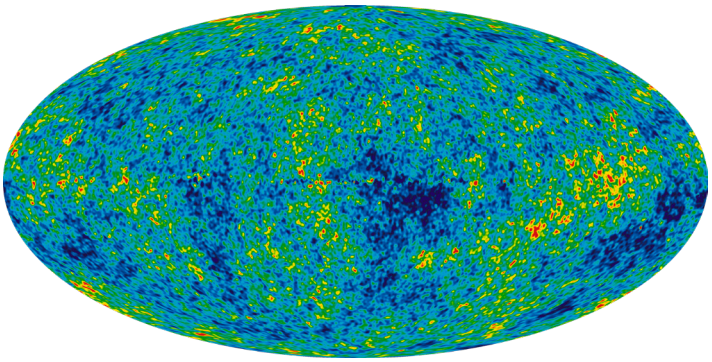
Experiments: CHIME, CMB-S4, Green Bank Observatory, HIRAX, Simons Observatory



Quantum Science at Wright Lab

Search for Axion Dark Matter at Yale

Three experiments located at Wright Lab are searching for axion dark matter using quantum technologies. The experiments include: HAYSTAC (Haloscope At Yale Sensitive To Axion CDM), ALPHA (Axion Longitudinal Plasma Haloscope), and RAY (Rydberg Atoms at Yale). *See pp. 8-11 for more*.

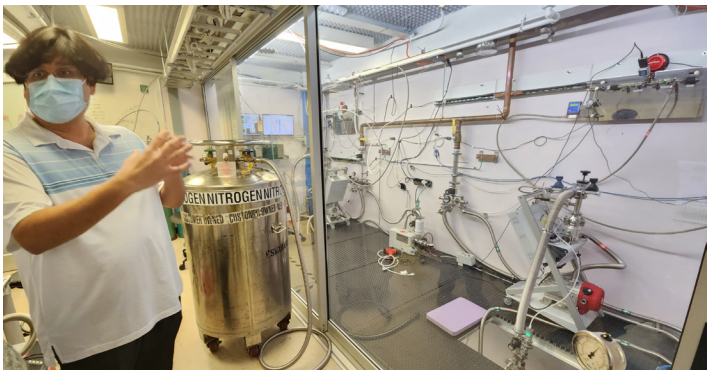


Probe the early Universe with quantum sensors

Associate Professor Laura Newburgh is part of Simons Observatory and CMB-S4, which use sensors that sit on the transition between the superconducting and normal-metal states ('transition edge sensors') to sensitively detect photons from the Cosmic Microwave Background. They are read out with superconducting quantum interference devices (SQUIDs), using new wide-bandwidth readout crates to many more sensors in a single connection than was possible before.

Quantum science & computing in high energy physics

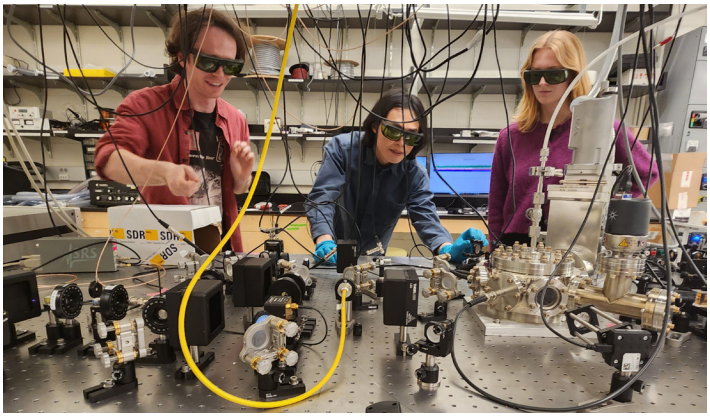
Keith Baker, D. Allan Bromley Professor of Physics, studies quantum information science in high energy physics, quantum entanglement, Bell's inequality, and entanglement entropy. The Baker group demonstrates applications of machine learning, quantum computing, and quantum algorithms in physics analyses at high energies to better understand certain anomalies in data from high energy particle physics experiments. Baker is also the academic editor and co-author of "Quantum Entanglement in High Energy Physics" (*see p. 52*).



Single phonon detection using quantum acoustics

Professor Jack Harris is developing new technologies to control and study massive objects using light, and has been among the pioneers of the emerging field of quantum optomechanics. These quantum optomechanical sensors can detect tiny excitations of quantized sound (phonons). The Harris group is exploring superfluid helium as a medium for use in ultraprecise and quantum-enabled sensors in table-top experiments. One experiment uses quantum interactions to produce phonons that are particularly well suited to test the Standard Model of physics and to search for dark matter. A second experiment uses magnetic levitation to suspend a millimeter-scale drop of helium in a vacuum to study the quantum features in the drop's motion.

Probing the nature of neutrinos, dark matter, and gravity



Moore Group

David Moore, PI; Lucas Darroch, Aaron Markowitz, Thomas Penny, postdoctoral associates; Jacqueline Baeza-Rubio, Cecily Lowe, Siddhant Mehrotra, Ben Siegel, Yu-Han Tseng, Jiaxiang Wang, Molly Watts, graduate students; Vasilisa Melenkiy, Imam Mian, Emily Peng, Juan Recoaro, undergraduates

Associate professor David Moore develops new technologies and techniques aimed at answering some of the major outstanding questions in nuclear and particle physics about neutrinos, dark matter, the preference for matter over antimatter in the Universe (*see nEXO section, p. 17*), and the nature of gravitational interactions among quantum systems.

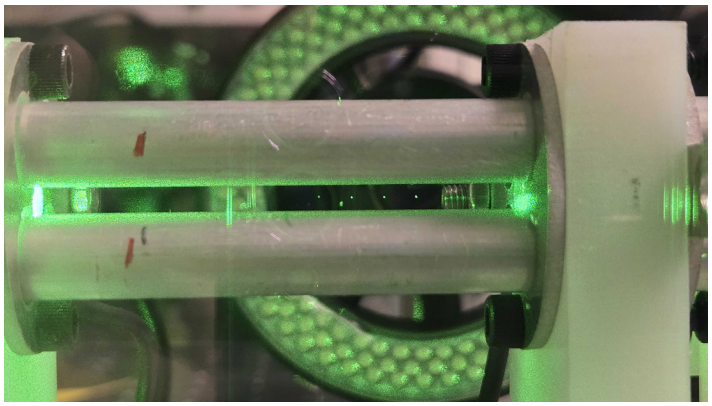
Moore is collaborating on the **MAST-QG** (MAcroscopic Superpositions Towards witnessing the Quantum nature of Gravity) experiment to test whether gravity has a quantum nature by levitating tiny diamonds in a vacuum to see if they become entangled through their gravitational interaction. The Moore group is using their expertise in precisely trapping nanoparticles in a vacuum to study the electromagnetic interactions between nanodiamonds. (See wlab.yale.edu/mastqg24.)

SIMPLE (Search for new Interactions in a Microsphere Precision Levitation Experiment) is a small-scale tabletop experiment that fits in a laboratory at Wright Lab, yet is used to study interactions involving neutrinos; to test gravity; and to search for dark matter, quantum phenomenon, and new forces.

SIMPLE uses a technique called optical tweezers, in which a laser optically levitates, controls, and measures micron-sized spheres (microspheres). By measuring the motion of the microsphere, the group can precisely detect extremely tiny impulses, which are smaller than one-quadrillionth of the momentum transferred by a feather landing on your shoulder.

The Moore group has developed the world's most sensitive micron-sized force sensors, using them to search for dark matter interactions with the microspheres.

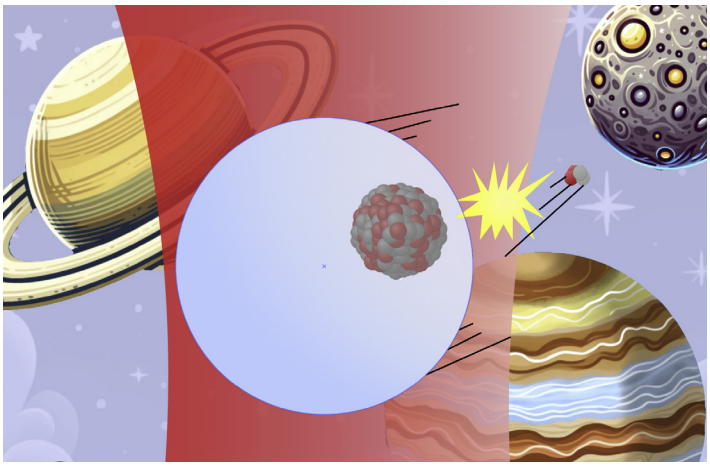
QuIPS is a new experiment at Wright Lab that extends the techniques used by SIMPLE to smaller nanoparticles and will measure the momentum kick from a single nucleus decaying within a particle. QuIPS will enable new searches for otherwise invisible particles emitted in nuclear decays, such as sterile neutrinos.



Connecting theory and experiment with effective field theory

Assistant professor Ian Moult's research focuses on developing new techniques in quantum field theory for describing high-energy particle physics experiments, ranging from dark matter detection to elementary particle and heavy ion collisions at the Large Hadron Collider (LHC). A common theme in his work is the use of effective field theories, which allow calculations relevant for complex, real world experiments to be reduced to simpler, universal problems in quantum field theory.

Moore group develops innovative technique to detect elusive particles



The Moore group has pioneered a technique that opens up possibilities for detecting dark matter, neutrinos, and other mysteries of the Universe using a small, table-top experiment located at Yale's Wright Lab called Search for new Interactions in a Microsphere Precision Levitation Experiment (SIMPLE).

A new publication led by Yale Applied Physics graduate student Jiaxiang Wang in "Physical Review Letters" called "Mechanical Detection of Nuclear Decays" explains the result. Other members of the group who contributed to the publication are Moore; physics postdoctoral associate Tom Penny; physics graduate students Benjamin Siegel and Yu-Han Tseng; and physics undergraduate student Juan Recoaro. All Moore group members are also members of Wright Lab.

According to Wang, the purpose of this experiment was to see if it is possible to detect a naturally occurring nuclear decay of elements embedded in a particle just by its mechanical response, and the results showed that this was, in fact, possible.

SIMPLE is set up to use lasers to levitate a tiny micron-sized particle (a glass sphere) within a vacuum. A variety of particles that have no electric charge—such as neutrinos and candidates for dark matter—can be emitted in nuclear decays but are difficult to detect and measure with traditional experiments because they do usually not interact within a detector.

To provide a solution to the above issue, the Moore group aims to detect the tiny force imparted by the decay on the object where the decay occurred, rather than the escaping decay products themselves. To accomplish this, the group doped the particle with a radioactive lead isotope that can eventually decay to other unstable isotopes emitting alpha particles (which are relatively easy to detect mechanically), so that when the isotope naturally experiences decay, the energy transfer from the decay will "kick" the sphere and cause it to recoil. The momentum of this tiny, reactionary movement of the sphere can be measured to better understand the nature of the particle being studied and the products of its decays.

Wang said, "Detecting a mechanical recoil of a sphere larger than the particle of interest has many applications in nuclear and neutrino physics and was never considered before. This novel technique can be used on a small scale and mitigates the problem of needing large detectors for questions in nuclear science."

Wang explained that the biggest challenge for the experiment was figuring out how to dope the sphere. For future experiments, it will be necessary to make sure that the force of the lasers acting on the particle is not included in the measurements of the momentum kick.

Wang said, "When a particle exists on the planet, it always experiences gravity. If one wants to levitate a particle in a vacuum, we always have to exert a force, such as the lasers used in SIMPLE, which brings noise that needs to be characterized. We plan to utilize careful design considerations for future experiments to be able to minimize sources of noise in our data."

Wang's paper was selected by "Physics World" as one of the "Top 10 Breakthroughs of the Year" and by "Physics Magazine" as one of the "Highlights of the Year". "Physics Magazine" also turned the paper into a comic.

Wang explained the experiment described in the paper is a proof of principle that it is possible to study fundamental particles mechanically to directly measure the momentum. By using smaller nanospheres, the team can use this technique to search for sterile neutrinos. If the sensitivity could someday be improved well beyond the "standard quantum limit," it might allow even more ambitious research, such as detecting and measuring the mass of the Standard Model neutrino.

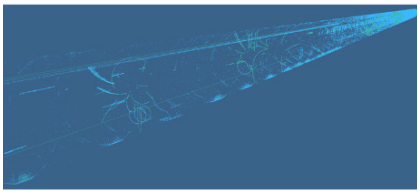
Relativistic Heavy Ions

Helen Caines
Horace D. Taft Professor of Physics, Director of Graduate Admissions

Experiments: STAR, ALICE, EIC

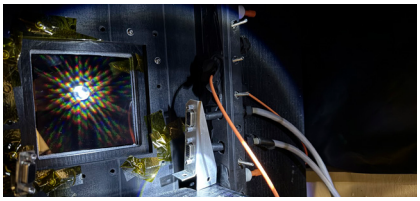
John Harris
D. Allan Bromley Professor Emeritus *of Physics*

Experiments: ALICE, EIC, STAR



Laura Havener
Assistant Professor

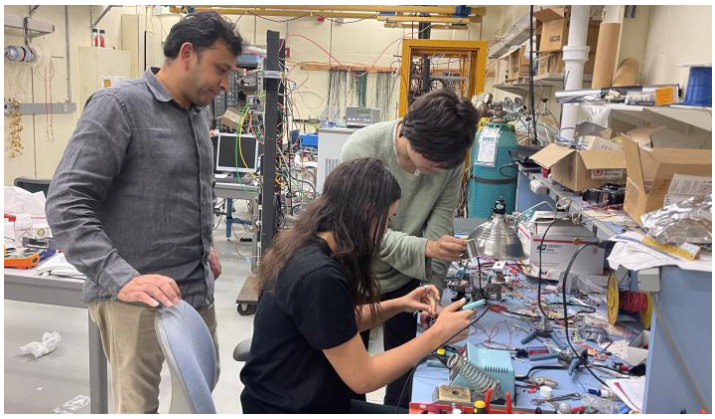
Experiments: ALICE, EIC, STAR



Ian Moult
Assistant Professor

Theory

Recreating conditions of the early Universe



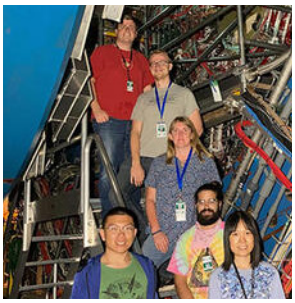
Relativistic Heavy Ion Group (RHIG)

Helen Caines, John W. Harris, Laura Havener, PIs; Jurgen Schukraft, Thomas Ullrich, adjunct professors; Mesut Arslandok, Prakhar Garg, Nikolai Smirnov, research scientists; Friederike Bock, Berndt Muller, research associates; Fernando Flor, Isaac Mooney, Michael Oliver, Zoltán Varga, postdocs; Caitie Beattie, Hannah Bossi, Sierra Cantway, Ryan Hamilton, Morgan Knuesel, Tong Liu, Daniel Nemes, Emily Pottebaum, Iris Ponce, Ananya Rai, Youqi Song, Andrew Tamis, graduate students; Maddi Brown, Grant Fitez, Ian Gill, Henry Kaplan, Joshua Kerner, Elisa Kim, Selma Mazioud, Luke Mozarsky, Jack Roche, Austin Rosypal, Yasmine Samolada, Lily Shukla, Daniel Zhang, Zihui (Mary) Zhang, undergraduates; Katie Driscoll, high school (Hopkins)

RHIG, co-led by Helen Caines, Laura Havener, and John Harris, uses experiments that accelerate and then collide particles to recreate a primordial state of matter, the quark-gluon plasma (QGP). The QGP is a hot, dense, soup-like state of the fundamental particles of nature—predicted by the Standard Model of particle physics to have existed ten millionths of a second after the Big Bang—and is one of nature's most extreme fluids. The group's research focuses on measuring jets—the spray of high momentum particles from high energy particle collisions—and jet substructure to further understand the properties and evolution of the QGP. RHIG is involved in the ALICE, STAR and ePIC collaborations.

Recreating conditions of the early Universe

Solenoidal Tracker at RHIC (STAR)



The STAR experiment is at the Relativistic Heavy Ion Collider at Brookhaven National Laboratory (BNL) in New York. As the co-spokesperson of STAR from 2017 to 2023, Caines led the successful completion of a multi-year data program called Beam Energy Scan II and the installation of a suite of forward-rapidity detectors. RHIG contributes to a diverse range of analyses, taking advantage of STAR's large variety of datasets. A recent publication by group members demonstrated that while collisions between protons and Au-ions can create a QGP droplet, these droplets do not induce energy loss in jets passing through them.

A Large Ion Collider Experiment (ALICE)

The ALICE detector at the Large Hadron Collider (LHC) at the European Organization for Nuclear Research (CERN) in Switzerland was recently upgraded to allow for the production of two orders of magnitude more data. RHIG members have contributed to various aspects of the detector upgrades and preparations. From 2022-2024, Havener was co-convener for the Jets and Hard Photons Physics Working Group. Harris serves as an elected member of the ALICE Management Board. A 2024 publication led by RHIG members exploited machine learning tools to perform the most differential measurement of jet energy loss to date, revealing evidence that the amount of energy deposited into the QGP depends on the width of the jet's cone.

Electron-Ion Collider (EIC)/Electron-Proton Ion Collider (ePIC)

RHIG has substantially increased its involvement in preparations for the future Electron-Ion Collider at BNL, with the goal of using jets and identified particles to study the 3-D structure of hadrons. Garg serves as the deputy technical coordinator of ePIC. RHIG members are assisting with research and development projects at Wright Lab for the proximity-focused ring-imaging Cherenkov (pfRICH) and the forward hadron calorimeter (LFHCal) subsystems. The pfRICH team is testing state-of-the-art High Rate Picosecond Photodetectors (HRPPD) in consultation with Incom, MA, which will enable high momentum particle identification. RHIG members are also preparing test stations to characterize the LFHCal's ~600k silicon photomultipliers and scintillating tiles that will be used to reconstruct jets close to the beam axis.

Theory Meets Experiment

In collaboration with Moult and his research team, RHIG members initiated studies of a novel jet substructure observable, energy correlators (EECs), which can be both rigorously calculated theoretically and measured with high precision in experiment. Group members have led measurements at ALICE and STAR that confirm Moult's predictions that EECs would provide a clean probe of the confinement transition from quarks and gluons to hadrons. Ongoing measurements in heavy-ion collisions will provide a multi-scale picture of how the QGP responds to the jet's presence, potentially confirming recent calculations published by Moult, Rai, and others.

A physicist's journey to the 'critical point' and the 'strong force'

Helen Caines was interviewed by Jim Shelton of Yale News in the article "A physicist's journey to the 'critical point' and the 'strong force,'" discussing her search for a better understanding of subatomic phenomena (published April 27, 2023). Related, the March 2023 edition of Scientific American (Sci Am 328, 3, 34-41) contains a feature article and video on this work. Former Wright Lab postdoctoral associate Raghav Kunnawalkam Elayavalli, now a physicist at Vanderbilt University, is quoted in the article.

For links to these two articles and video, see: wlab.yale.edu/rhig-news-23.

Office Hours with... Laura Havener

The thing Laura Havener loves about physics is the interactions — the collisions of subatomic particles she studies and the collaborations of hundreds of scientists working on a large experiment.

The North Carolina native, an assistant professor of physics in Yale's Faculty of Arts and Sciences, gets to experience plenty of both.

As a member of Yale's Wright Lab, Havener is part of a highly collaborative research community that is exploring the unseen world. As a member of the ALICE (A Large Ion Collider Experiment) collaboration, an international experiment based at the Large Hadron Collider at CERN, in Switzerland, she interacts with an ever-changing array of physicists who use the collider to investigate high energy nuclear physics.

Her own research looks specifically at quantum chromodynamics (QCD), with a focus on understanding the properties and dynamics of the deconfined state of QCD matter — known as the quark-gluon plasma — that is produced in heavy-ion collisions. She studies streams of high-energy particles, called jets, that interact with the quark-gluon plasma.

Havener joined the Yale faculty after a four-year stint as a Yale postdoctoral researcher. When she's not on campus, she can often be found kicking soccer balls with her young son, David.

How do you describe your work to a non-physicist?
Havener: What I study is the "strong" nuclear force, the force that holds together the nucleus of atoms. We look at what binds neutrons and protons, by smashing nuclei together at a high energy collider and trying to break them apart.

What was it like visiting ALICE for the first time?
Havener: I was in graduate school when I visited for the first time, and it might have been my favorite experience as a graduate student. I got to sit in the control room where you can see what are called "event displays" — essentially, you're seeing particle collisions happening in real time. It was absolutely thrilling.

Do you prefer working on big, collaborative projects?
Havener: I tend to feed off the energy and excitement of other people, and I love that I get to work with all sorts of people to solve these hard problems in physics. For me, there is nothing better than spending my day with other people, putting our heads together to answer a question.

Is there a particular part of the scientific discovery process that you like the most?
Havener: Yes, it's when you see something in the data that is unexpected. This happens a lot, because we're looking at complicated systems.

At first, when you encounter something unexpected, you think there must be something wrong in the data. Then you dig in and examine it. In those instances when the data was correct, and we had found something new, those have been some of the coolest moments ever for me.

What role models in science have you had?
Havener: Well, I had two family members who were scientists. My Aunt Tammy is a biologist and my Uncle Charlie is a physicist. So the idea of being a scientist wasn't mysterious or unusual to me.

Later on, the thing that got me interested in high energy physics research was a conference I went to in college. I heard a woman talk about how she studied the strong force and worked with all of these amazing people from around the world. That really resonated with me.

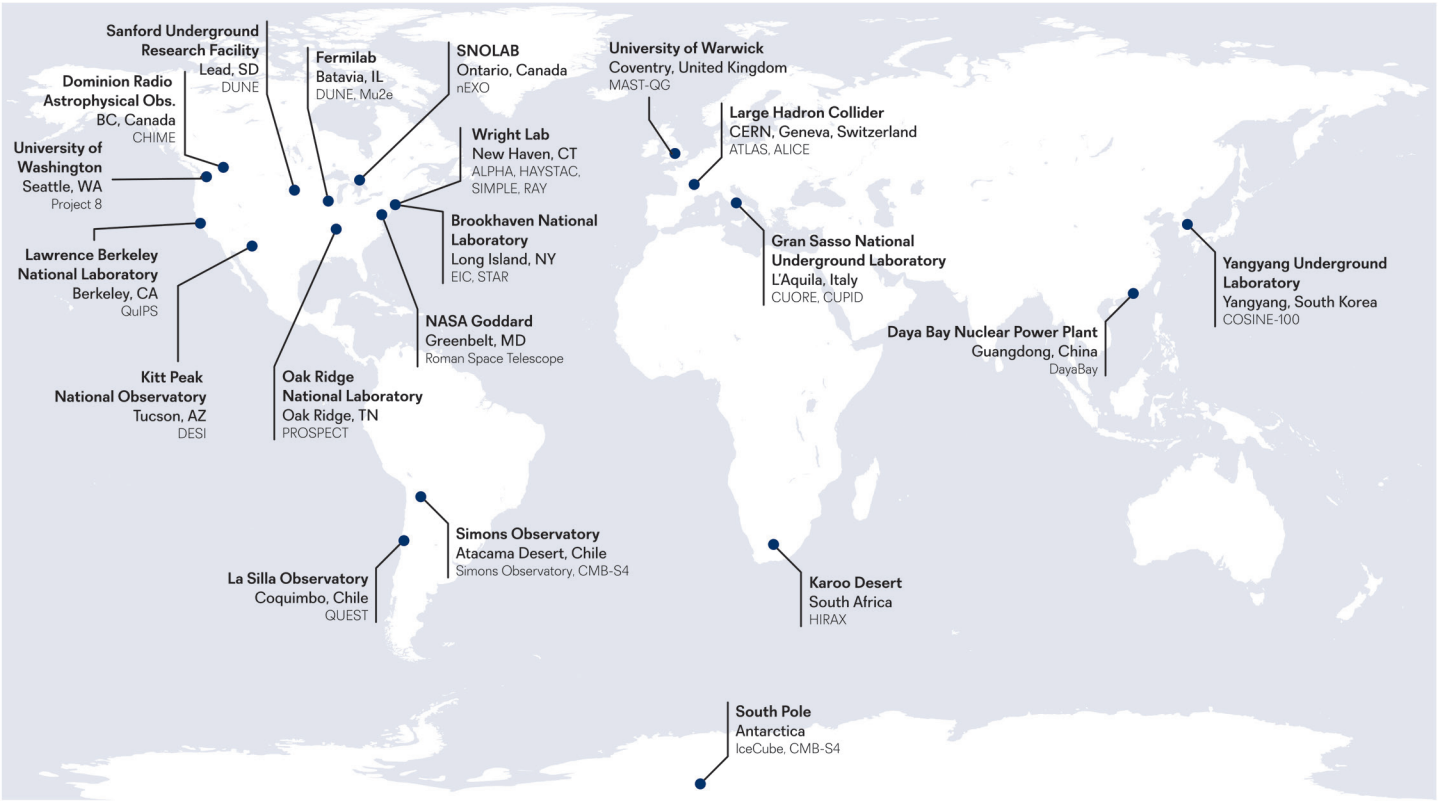
What is your favorite spot on the Yale campus?
Havener: I love the courtyard on Science Hill that is surrounded by the Yale Science Building and Kline Tower, where Steep café is. I love having lunch there in the summer. Another spot I like is a few steps off that courtyard, where you can look up and see East Rock in the distance.

This article is adapted from an interview by Jim Shelton, originally published in Yale News on January 3, 2024.

Collaborations

With its on-site facilities and research program, Wright Lab fosters cross-disciplinary research collaborations in nuclear, particle, and astrophysics; quantum science; and instrumentation development at Yale and worldwide.

Research Worldwide



Campus collaborations

- **Yale Center for Astronomy and Astrophysics (YCAA)** - working towards understanding dark matter in the Universe through scientific investigations
- **Yale Center for Research Computing (YCRC)** - developing novel solutions to the research computing challenges in nuclear, particle, and astrophysics
- **Yale Quantum Institute (YQI)** - jointly developing quantum sensors and techniques
- Wright Lab also has **strong interdisciplinary partnerships** with the Institute for the Preservation of Cultural Heritage (IPCH), the Yale Center for Collaborative Arts and Media (CCAM), the Yale Peabody Museum of Natural History, and Yale Pathways to Science.

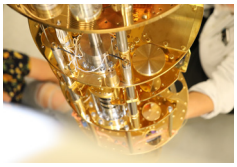
National laboratory partners

- Brookhaven National Laboratory, United States
- CERN, Switzerland
- Fermilab, United States
- Gran Sasso National Laboratory, Italy
- Oak Ridge National Laboratory, United States

Experiments

Dark Matter

While there is indirect evidence for dark matter based on the gravitational pull it exerts on visible matter, direct evidence remains elusive, as does exactly what dark matter is. Direct identification of dark matter would provide major insights for our understanding of a fundamental force of the unseen Universe.



HAYSTAC, ALPHA, RAY

Baker, Barrett, Brown, Heeger, Lamoreaux, Lehnert, Maruyama

Search for axion dark matter using quantum and microwave technologies.

Yale is responsible for systems engineering, cryogenics, and magnetics. Lamoreaux and Maruyama are PIs of HAYSTAC, Maruyama is deputy spokesperson of ALPHA and PI of RAY.

COSINE-100

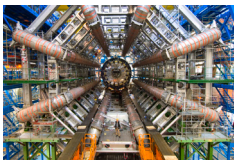
Maruyama

Search for direct detection of dark matter, probing for an annual modulation in the signal reported by the DAMA/LIBRA collaboration.

Maruyama is the PI and scientific co-spokesperson of COSINE-100.

Energy Frontier

Yale scientists question existing scientific models of the physical Universe and search for new understanding of how the Universe works, discovering and characterizing new particles and searching for other phenomenon beyond the Standard Model of physics.



ATLAS

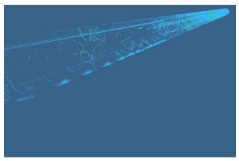
Baker, Demers, Tipton

Precision tests of the standard model and new physics searches; including characterizing the Higgs Boson and using it to probe for new physics.

The Yale team has critical responsibilities in the ATLAS collaboration for data quality and detector upgrades. Wright Lab has been the host of R&D and now construction of critical elements of the ATLAS tracker upgrade for the hl-LHC era.

Hot & Cold QCD

Yale scientists are recreating the conditions of the early Universe using high-energy particle colliders to study how nuclear matter behaves under extremes of temperature and density.



ALICE

Caines, Havener, Harris

Understand high energy density quantum chromodynamics (QCD) created in relativistic collisions of heavy nuclei.

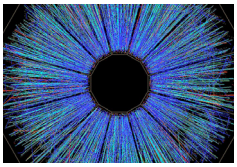
Havener is a co-convener for the Jets and Hard Photons Physics Working Group; Harris serves on the ALICE Management Board. Yale has contributed to various aspects of preparations and data-taking, including the construction of GEM readout chambers.

EIC/ePIC

Caines, Havener, Harris

Understand high energy density quantum chromodynamics (QCD) created in relativistic collisions of heavy nuclei.

Yale has multiple R&D projects, including particle identification detectors. Testing & characterizing photosensors for the pfRICH detector will be done at Wright Lab. Yale is also involved in software development for PID reconstruction.



STAR

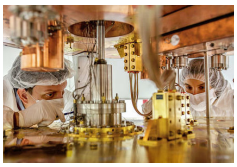
Caines, Havener, Harris

Understand the behavior of nuclear matter under extremes of temperature and density.

Yale plays a critical role in preparations and data-taking, including trigger coordination, shift leadership, on-call detector expertise, and a diverse range of analyses. Caines was co-spokesperson of STAR from 2017-2023.

Neutrinos & Fundamental Symmetries

Studying the properties of neutrinos and searching for rare event processes to investigate: What does the invisible Universe consist of? Why does the Universe have more matter than antimatter? What are the properties of neutrinos?

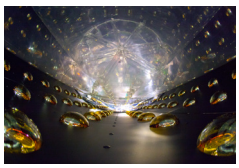


CUORE/CUPID

Heeger, Maruyama

Search for neutrinoless double beta decay, which could answer why we live in a Universe of matter, not antimatter.

Yale is responsible for detector calibration, the study of cosmogenic backgrounds, double beta decay analysis, & the search for solar axions. Heeger and Maruyama are CO-PIs of CUORE & CUPID.



Daya Bay

Heeger

Search for and measure the yet unknown neutrino mixing angle theta13.

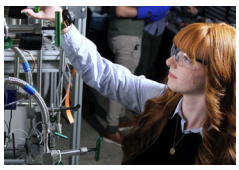
Yale has overall responsibility in the U.S. for the design and construction of the antineutrino detectors and is involved in data analysis and measurements.

DUNE

Heeger

Enable the study of parameters that determine the matter-antimatter imbalance in the Universe and the ordering of neutrino mass states.

Yale is responsible for the assembly of Charge Readout Planes at Wright Lab and studying the detector response.

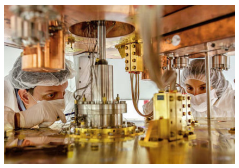


nEXO

Moore

Search for neutrinoless double beta decay, which could answer why we live in a Universe of matter, not antimatter.

Yale is leading efforts to build the photon detectors for nEXO. Moore serves as the sub-system scientist for the photon sensors. Moore is also collaborating with LLNL and SLAC to study ways to capture xenon directly from the atmosphere.



Project 8

Heeger

Utilize a novel technique (CRES) to perform a precision measurement of the yet unknown neutrino mass.

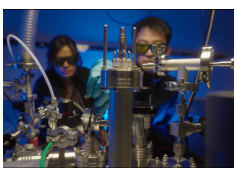
Yale performs R&D on antenna and cavity prototypes; develops algorithms for event reconstruction and analysis; and performs simulations to optimize the detector resolution.

PROSPECT

Heeger

Precision measurements of antineutrinos, search for sterile neutrinos, & develop technology for monitoring nuclear reactors for safeguard and non-proliferation.

PROSPECT was designed and built at Wright Lab in collaboration with national labs and other universities.



SIMPLE/QuIPS

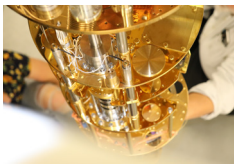
Moore

Study interactions involving neutrinos; to test gravity; & to search for dark matter, quantum phenomenon, sterile neutrinos, and new forces.

The Moore group has developed the world's most sensitive micron-sized force sensors. Both the SIMPLE and QuIPS experiments are located at Wright Lab.

Quantum Science & Sensing

Quantum science is one of five top priority areas identified by Yale University's Science Strategy. Yale's Wright Lab is exploring the applications of quantum science and sensing to tests of fundamental physics.

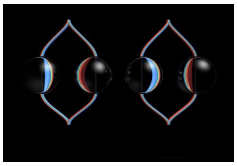


HAYSTAC, ALPHA, RAY

Baker, Barrett, Brown, Heeger, Lamoreaux, Lehnert, Maruyama

Searching for axion dark matter using quantum and microwave technologies.

Yale is responsible for systems engineering, cryogenics, and magnetics. Lamoreaux and Maruyama are PIs of HAYSTAC, Maruyama is deputy spokesperson of ALPHA and PI of RAY.

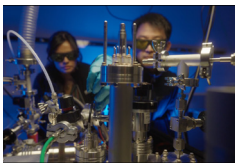


MAST-QG

Moore

Test whether gravity has a quantum nature by levitating tiny diamonds in a vacuum to see if they become entangled.

Yale is using their expertise in precisely trapping nanoparticles in a vacuum to study the electromagnetic interactions between nanodiamonds.



SIMPLE/QuIPS

Moore

Study interactions involving neutrinos; to test gravity; & to search for dark matter, quantum phenomenon, sterile neutrinos, and new forces.

The Moore group has developed the world's most sensitive micron-sized force sensors. Both the SIMPLE and QuIPS experiments are located at Wright Lab.

Harris Lab

Jack Harris

Explore the influence of quantum mechanics and topological effects upon the motion of macroscopic objects.

The group studies these phenomena in experiments that combine high-finesse optical cavities, ultrasensitive mechanical oscillators, and superfluid helium.

Baker Group

Baker

Study quantum information science in high energy physics, quantum entanglement, Bell's inequality, and entanglement entropy.

The group demonstrates applications of machine learning, quantum computing, and quantum algorithms in physics analyses at high energies to better understand certain anomalies in data from high energy particle physics experiments.

Newburgh Lab

Newburgh

Probe the Cosmic Microwave Background to learn more about the beginning of the Universe.

The Newburgh group is focused on software development for CMB-S4 and Simons Observatory, which are employing sensors that use superconducting quantum interference devices (SQUIDs).

Cosmology

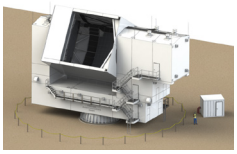
Yale scientists are investigating the beginning and the expansion of the Universe by studying the nature of dark energy—a mysterious component that makes up three quarters of our universe that we know essentially nothing about—and by measuring the Cosmic Microwave Background (CMB) and 21 cm hydrogen emission from faraway galaxies.

CHIME

Newburgh

Measure the expansion history of the Universe and discover insights about dark energy.

The Newburgh group uses a technique called holography to map the beam shape of CHIME to be able to identify and remove emission from unintended sources.

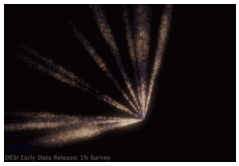


CMB-S4

Newburgh

Will make measurements of the Cosmic Microwave Background with an order of magnitude greater than any current experiment.

Newburgh leads the data acquisition and control group, mainly building software to control and acquire data from the telescopes.



DESI

Baltay

Measure the effects of dark energy on the expansion of the Universe

The Yale Fiberview Camera—designed, built, and installed by the Baltay group at Wright Lab—is an integral part of the efficiency and precision of DESI.

HIRAX

Newburgh

Study high-redshift large-scale structure for a constraint on dark energy and transient science to understand the nature of Fast Radio Bursts (FRBs).

The Newburgh group is leading the development of techniques, hardware, and analysis to measure and map the HIRAX beam shape with a quadcopter drone.

IceCube

Maruyama

Search for neutrinos by studying exploding stars, gamma-ray bursts, black holes, and neutron stars.

The Maruyama group studies how supernovae explode, as well as fundamental properties of neutrinos.

La Silla-QUEST

Baltay

Study the expansion of the Universe and dark energy.

The Baltay group's work has improved the precision of the Hubble constant measurement using supernovae and variable stars as calibration standards, such that it is now better than the unexplained discrepancies.

Roman Space Telescope

Baltay

Study the nature of the mysterious accelaration of the expansion of the Universe and dark energy.

Baltay and his collaborator Saul Perlmutter (U.C. Berkeley) have advised NASA for many years on the design and use of the Roman Space Telescope for a supernova survey. The telescope is expected to launch in 2026.

Simons Observatory

Newburgh

Probe the Cosmic Microwave Background to learn more about the beginning of the Universe.

The Newburgh group is part of the team commissioning SO. Newburgh leads the data acquisition and control group, mainly building software to control and acquire data.

Conferences, workshops, and collaboration meetings

In 2023-24, Wright Lab hosted 4 workshops and collaboration meetings. **Community members also attended a number of conferences, workshops, and collaboration meetings nationally and internationally.**

Quantum Sensing for High Energy Physics

April 27-29, 2023 at Yale University

42 scientists participated from 22 institutions across the nation, including 10 national labs and governmental agencies and 12 academic institutions. The workshop organizers were Reina Maruyama, professor of physics and a member of Yale's Wright Lab; Aaron Chou, a physicist at Fermilab; and Kent Irwin, professor of physics at Stanford.

ALPHA workshop & collaboration meeting

September 25-26, 2023 at Yale Wright Lab

Attended by 48 people from 17 institutions, this workshop was the official "kickoff" meeting of the experiment, and included two days of talks on current axion theory and experiments; results of ALPHA R&D efforts; data analysis techniques; plans for administration, organization and funding of the experiment; and preliminary plans for upgrades.

HAYSTAC collaboration meeting

September 27-28, 2023 at Yale Wright Lab

This meeting coordinated the current efforts on the HAYSTAC experiment. Two days of talks focused on the current status of the experiment; ongoing analysis efforts for the main axion search; ideas for alternative searches with HAYSTAC; and plans for future upgrades to the detector to further the search for axion dark matter in unexplored regions.

ALICE-USA meeting

May 29-31, 2024 at Yale Wright Lab

The meeting included presentations to highlight and facilitate the research work of junior and senior researchers working at the ALICE experiment's United States institutions. There were also overview talks of the ALICE status and plans, focusing on the efforts led by ALICE institutions in the U.S., and invited talks from other heavy-ion experiments. 46 participants from 17 institutions registered for the meeting.

Hard Probes 2023

March 26-31, 2023; Aschaffenburg, Germany

15 present and past members of Wright Lab's Relativistic Heavy Ion group joined more than 300 scientists in Aschaffenburg, Germany to attend and present at the 11th International Conference on Hard and Electromagnetic Probes of High-Energy Nuclear Collisions. Additionally, former associate research scientist Laura Havener (now assistant professor of physics at Yale) presented a conference summary.

Conferences, workshops, and collaboration meetings

Quark Matter 2023

Sept. 3-9, 2023; Houston, Texas

The Relativistic Heavy-Ion Group joined over 700 scientists for the 30th International Conference on Ultra-relativistic Nucleus-Nucleus Collisions. 10 members of RHIG presented talks and posters, and professor Helen Caines delivered the conference summary talk—the first time in the conference's 30-year history that a woman gave this important talk.

DNP annual meetings in 2023 and 2024

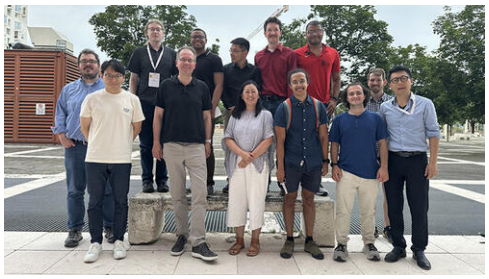
November 26-December 1, 2023; Hawaii
October 7-10, 2024; Boston

Wright Lab faculty, postdocs, graduate students, and undergraduates attended and presented their research at the fall meetings of the Division of Nuclear Physics (DNP) of the American Physical Society (APS).

Asian Americans and STEM Conference

May 10, 2024; New Haven

The interdisciplinary conference was held at Yale with over 60 attendees from 18 institutions, including leadership and support from Wright Lab. The attendees were scholars from the humanities and STEM fields who are actively engaged in exploring the history of race and racialization in their respective fields.



Neutrino 2024

June 16-22, 2024; Italy

Wright Lab research was well represented at the 31st International Conference on Neutrino Physics and Astrophysics (Neutrino 2024). The conference featured talks and results from neutrino experiments that involve contributions and leadership from Wright Lab scientists. See wlab.yale.edu/neutrino-experiments for more information.

CPAD 2024

November 18-22, 2024; University of Tennesee, Knoxville

Three members of the Wright Lab community attended and presented at the 2024 Coordinating Panel for Advanced Detectors (CPAD) Workshop. Fernando Flor, NSF MPS-Ascend postdoctoral fellow, and Prakhar Garg, research scientist presented on their work for the EIC. Graduate student Sierra Wiled presented on her work for nEXO.

Graduate Recruiting at Conferences

Wright Lab members also traveled to conferences for graduate recruiting: Conference for Undergraduate Women in Physics, SACNAS National Diversity in STEM Conference, National Society for Hispanic Physicists Día De la Física (2023), National Society of Black Physicists (NSBP) and National Society for Hispanic Physicists (NSHP) Conference, and the APS Division of Nuclear Physics (DNP) annual meetings.

Seminars

The intellectual and scientific vibrancy of the Wright Lab research program builds on number of programs including several seminar series. Discover more at: wlab.yale.edu/seminars. For a complete listing of all events including event materials (poster, flyer, slides, recording, etc.) please see indico.wlab.yale.edu.

2022-23 Academic Year Seminars

Wright Lab hosted 94 seminars and Journal Clubs:

- NPA Seminar 33
- WIDG Seminar 11
- YPPDO Seminar 1
- Elusives Journal Club 26
- Wright Lab All Hands Meeting 23

2023-24 Academic Year Seminars

Wright Lab hosted 86 seminars and Journal Clubs:

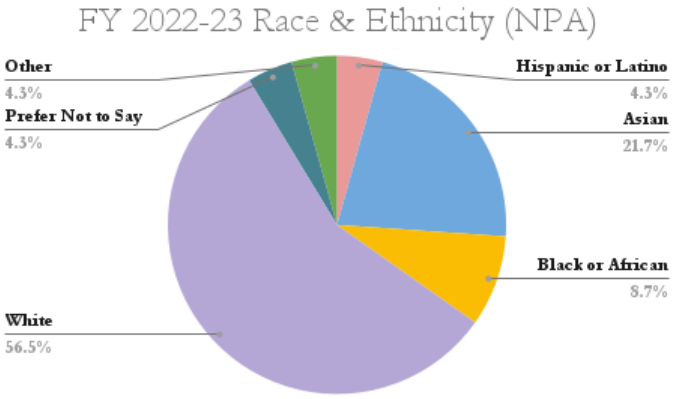
- NPA Seminar 34
- WIDG Seminar 11
- YPPDO Seminar 4
- Elusives Journal Club 15
- Wright Lab All Hands Meeting 22

Professional Development

The **Yale Physics Professional Development Organization (YPPDO)**, founded in 2017 by two Wright Lab graduate students, is focused on providing physical science Ph.D.s and postdocs with information, contacts, and resources on a range of career opportunities, especially outside academia. YPPDO talks are supported by the Yale Physics Department and Wright Lab.

Diversity and Inclusion

The seminar organizers for Wright Lab have always made an effort to invite and host a diverse set of speakers, including representation from underrepresented groups as well as diversity in scientific subfields and experience. We note that the NPA seminars achieved a gender balance amongst the speakers in 2022-2023.



Early Career Opportunities

The **Early Career Scientist Seminar** is a seminar series that was started in Fall of 2024 as an evolution of the WIDG seminar. The series is held at Wright Lab, with talks generally given by Yale Physics graduate students and postdocs on a variety of topics. The seminar is open to all members of the Yale Physics community. Talks are supported by Wright Lab, the Yale Physics Department and Yale University.

Wright Lab and National Priorities—A New Era of Discovery

Wright Lab plays a role in several initiatives highlighted both in the Nuclear Science Advisory Committee (NSAC) and the High Energy Physics Advisory Panel (HEPAP)'s long-range plans for nuclear physics research.

The federal government's **Nuclear Science Advisory Committee (NSAC)**, which provides official advice to the U.S. Department of Energy and the National Science Foundation, has approved a long-range plan for nuclear physics research in the next decade — and it includes key contributions from Yale.

"A New Era of Discovery: The 2023 Long Range Plan for Nuclear Science" is the eighth plan approved by NSAC since 1979. The 103-page report highlights scientific opportunities in nuclear physics that will enable the U.S. to maintain world leadership in nuclear physics. The report makes four overall recommendations:

- Capitalize on U.S. investments in scientific discovery by increasing funding for research; continuing the effective operation of national research facilities; expanding opportunities in science by raising compensation of graduate students; and expanding policy and resources to ensure a safe and respectful environment.
- Lead an international consortium to investigate the existence of neutrinoless double beta decay — a process that would show that neutrinos are their own antiparticles and could help explain the dominance of matter over antimatter in the universe.
- Complete the construction of the Electron-Ion Collider (EIC) at Brookhaven National Laboratory in Long Island, New York — a unique, high-luminosity electron-hadron collider capable of colliding high-energy beams of polarized electrons with heavy ions, polarized protons, and polarized light ions.
- Invest in additional, innovative projects in emerging technologies and discoveries, including detectors, quantum sensors, high-performance computing.

"It is great to see that much of the research being pursued at Wright Lab is highlighted as a top priority in the 2023 Long Range Plan for Nuclear Science," said Wright Lab Director Karsten Heeger, Eugene Higgins Professor and Chair of Physics at Yale. "Both the search for neutrinoless double beta decay and the EIC are recommended as highest priority for new projects with major discovery potential."

For example, associate professor David Moore's team is involved in the neutrinoless double beta decay experiment nEXO (Yale will build a photon detector for the experiment) and the quantum information and technology experiment QuIPS (it will apply quantum sensors to the search for nuclear decays).

Professor Reina Maruyama is co-spokesperson and Heeger is a principal investigator for the neutrino experiment CUORE. Heeger is also co-spokesperson for the ton-scale neutrinoless double beta decay experiment CUPID and a principal investigator for Project 8, a project to measure neutrino mass.

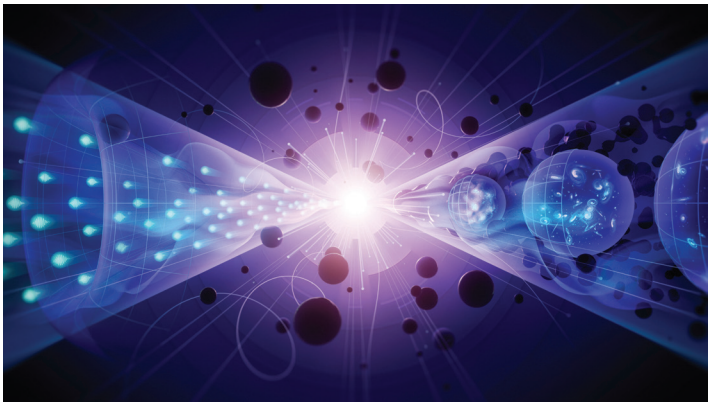
Professors Helen Caines and John Harris have had leadership roles in both the ALICE and STAR collaborations, which are based at the Relativistic Heavy-Ion Collider at Brookhaven and the Large Hadron Collider at CERN in Geneva, Switzerland. The collaborations explore the nature of quark-gluon matter. Newly hired assistant professor Laura Havener is a member of the ALICE collaboration. Caines and Havener are also active in detector research and development at Wright Lab for the ePic experiment to be installed at the EIC.

Faculty members also voiced strong support for national efforts to encourage a supportive research environment.

"We are very pleased to see the top recommendation highlighting the need to create a safe and supportive workplace environment for research to thrive," Caines said. "Wright Lab and the physics department highly value this important aspect of the workplace and developed a 'Statement of Principles' for our community four years ago."

This article is adapted from a Yale News article by Jim Shelton published on October 17, 2023.

Wright Lab and National Priorities—Exploring the Quantum Universe



On December 8, the **High Energy Physics Advisory Panel (HEPAP)**—a high-level advisory group to the U.S. Department of Energy (DOE) and the National Science Foundation (NSF)—approved a new set of strategic funding priorities related to particle physics research at an event in Washington, D.C. that included leading physicists from across the nation, including two from Yale's Wright Lab. Yale Physics' research and leadership in initiatives identified by the plan aligns strongly with the plan's goals.

The plan, titled "Exploring the Quantum Universe: Pathways to Innovation and Discovery in Particle Physics" was developed by the Particle Physics Project Prioritization Panel (P5), a subpanel of HEPAP that develops a long-term strategic plan every 8 to 10 years. Karsten Heeger, the Eugene Higgins Professor and Chair of Physics and director of Wright Lab, is deputy chair of the P5 panel; and Sarah Demers, professor of physics, is a P5 panel member.

Heeger said the P5 report is a 10-year strategic plan with a 20-year vision for U.S. particle physics research. "The panel thought about where the next big discoveries might lie and how we could maximize impact within budget, to support future discoveries and the next generation of researchers and technical workers who will be needed to achieve them," Heeger said.

The panel identified three main scientific themes in its report: decoding the quantum realm, revealing new knowledge about the hidden Universe at a cosmological level, and exploring new scientific paradigms emerging from the intersection of quantum and cosmological research.

Among the report's specific recommendations are the completion of construction projects and ongoing experiments that involve Wright Lab leadership and participation (*see pp. 28-32*), including: the ATLAS experiment at the Large Hadron Collider (LHC) at CERN in Switzerland (Baker, Demers, Tipton); the CMB-S4 network of ground-based telescopes observing the cosmic wave background (Newburgh); the Deep Underground Neutrino Experiment (DUNE (Heeger)); the muon-to-electron conversion experiment (Mu2e) at Fermilab in Illinois (Demers); and the expansion of the South Pole neutrino observatory IceCube-Gen2 (Maruyama).

Furthermore, the technical infrastructure and research facilities at Wright Lab have been key to the development of detector components and upgrades for both ATLAS and DUNE.

The report also encourages an enhanced connection between experimental and theoretical physics, stating, "Just as hints of new physics revealed by experiment drive new theoretical developments, theory guides experimental inquiries and enriches our understanding of fundamental principles."

Demers said, "We converged on a portfolio of projects that will let us investigate neutrinos, the Higgs boson, dark matter, the accelerating expansion of the universe, new accelerator and detector technologies, and more. . . We have deep involvement in a lot of this work at Yale, so it is going to be an exciting decade."

The P5 report also recommended that the U.S. invest in initiatives aimed at developing the skilled workforce that will be needed for new technologies that may emerge from the next generation of particle physics research. Discoveries in previous eras have led to manufacturing opportunities and new jobs in industries as varied as telecommunications, medical products, personal electronics, and the financial sector.

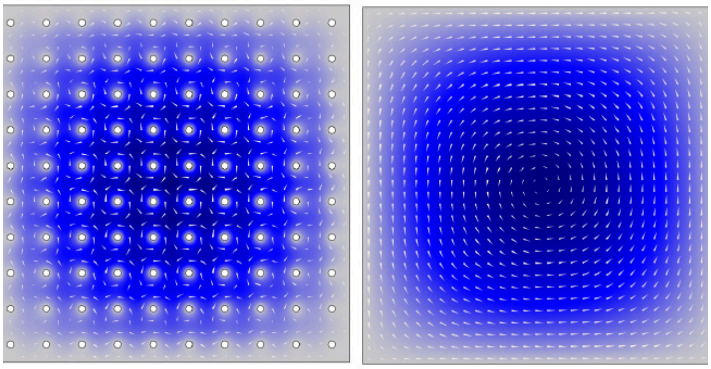
"In putting together our report, we thought about the science, of course, but also about the societal impact," Heeger said. "There are direct benefits to our society that come out of physics research, everything from gaining a deeper understanding of who we are in the context of the universe, to new technologies. And all of this provides a training ground for a highly skilled workforce going forward."

This article is adapted from a Yale News article by Jim Shelton published on December 11, 2023.

Wright Lab and Yale Science Priorities

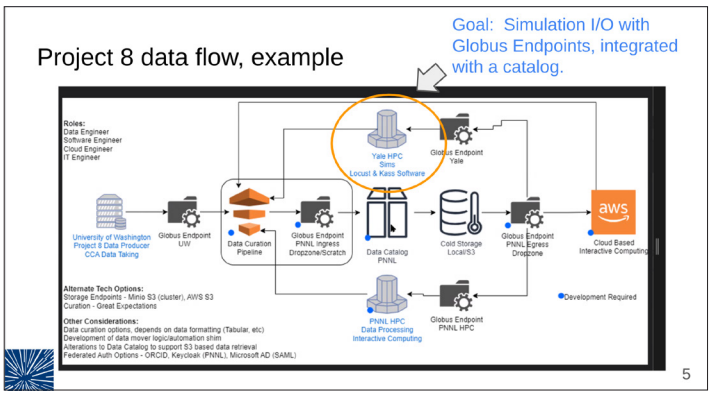
The Yale University Science Strategy Committee (USSC) was charged with identifying the most promising opportunities for investment across scientific disciplines and mechanisms for better coordinating science at Yale. In 2018, the USSC identified four cross-cutting investments and five ideas for top-priority investment. Wright Lab was specifically mentioned multiple times in the report, and continues to align with these strategic priorities.

Quantum sensors and measurement



Nine Wright Lab faculty members are engaged in a variety of experiments and efforts to develop quantum sensing tools and techniques for fundamental science. In 2023-24 several new experiments with Wright Lab leadership and involvement that involve quantum technologies came online, including ALPHA, RAY, CMB-S4, Simons Observatory, QuIPS, and MAST-QG. *See pp. 28-32 for more information*.

Data Science and Machine Learning



In October 2024, members of the Wright Lab community filled out a survey about their use of Artificial Intelligence (AI), Machine Learning (ML), and Data Science (DS). The survey found that Wright Lab members are engaged in a diverse spread of AI/ML/DS initiatives that enhance their research, teaching, and general productivity. Many indicated an interest in expanding their use of these tools and would like to learn more, presenting an opportunity for the WL community to share knowledge and resources.

Instrumentation Development

Wright Lab researchers continue to benefit from the facilities and infrastructure provided on-site by Wright Lab to develop cutting-edge instrumentation for current and future experiments. Please see our research pages (*pp. 4-26*), collaboration map (*p. 28*), and experiment table (*p. 29*) for more information on Wright Lab instrumentation efforts.

Core Facilities

Wright Lab hosts four University core facilities: the Advanced Prototyping Ceenter (*see p. 75*), the Research Support Shop, the Teaching Shop, and the J.W. Gibbs Professional Shop. For more information on these, please see wlab.yale.edu/facilities.

Starting May 2024, through August 2025, due to construction (*see p. 40*), the Gibbs shop has been temporarily relocated to the Sterling Chemistry Laboratory. There are some impacts to shop capabilities during this time period; for details, contact Vincent Bernardo.

Belonging & Diversity

The Wright Lab community was sent a survey in October 2024 to contribute to the Yale Physics Department self-study. The feedback was very positive, highlighting the supportive, inclusive community and productive environment at Wright Lab. *See more on pp. 58-67.*

Graduate Student Support

Wright Lab supports the training, mentorship, and research of a number of graduate students in physics and related departments. Wright Lab students excel in their fields and often are awarded competitive external, Yale, and departmental fellowships (*see p. 62*).

Ongoing Collaborations between BNL and Yale Wright Lab

Maintaining the strong, ongoing legacy of collaboration and substantial partnership between Brookhaven National Laboratory (BNL) and Yale in research and instrumentation initiatives aligns with the University's science priorities. Increasing connections with BNL was one of ten "Recommended Changes to the Organizational Structures that Support Science" in the 2018 Yale University Science Strategy Committee (USSC) report.

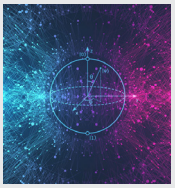
ATLAS
Elementary Particles
K. Baker, S. Demers, P. Tipton

DUNE
Neutrinos & Fundamental Symmetries
K. Heeger

Electron Ion Collider
Relativistic Heavy Ions
H. Caines, J. W. Harris, L. Havener

nEXO
Neutrinos & Fundamental Symmetries
D. Moore

PROSPECT
Neutrinos & Fundamental Symmetries
K. Heeger



Quantum Science
Quantum Science & Sensing
K. Baker, S. Lamoreaux,
R. Maruyama, D. Moore,
J. Harris, L. Newburgh, C^{2}QA

sPHENIX
Relativistic Heavy Ions
H. Caines, J. W. Harris, L. Havener

STAR
Relativistic Heavy Ions
H. Caines, J. W. Harris, L. Havener

21cm cosmology
Astrophysics & Cosmology
L. Newburgh

Groundbreaking for innovation on Upper Science Hill

On September 30, 2024, Yale leaders and state and local officials commemorated the groundbreaking for Yale's Upper Science Hill Building Complex.

The Upper Science Hill Development program includes an addition to Wright Lab (WLA), a new Advanced Instrumentation Development Center (AIDC) connecting research instrumentation efforts across the University, and a new, 320,000-square-foot Physical Sciences and Engineering Building (PSEB). The complex has a footprint bordered on three sides by Edwards Street, Prospect Street, and Whitney Avenue. Construction began in June 2024 and is expected to be completed in 2030.

Dignitaries attending the groundbreaking included Connecticut Governor Ned Lamont, New Haven Mayor Justin Elicker, University of Connecticut (UConn) President Radenka Marić, Yale University President Maurie McInnis, Yale Provost Scott Strobel, and Yale's vice provost for research Michael Crair. Wright Lab director Karsten Heeger, who co-chaired the faculty committee for the project, along with Sohrab Ismail-Beigi, was also in attendance and named as a contributor during the presentations.

The complex is a major effort to realize the strategic scientific priorities identified by the University (*see p. 38*), in particular, the facilities' focus on both quantum science and instrumentation development.

Quoted in a Yale News article about the groundbreaking, Heeger said, "This will be a transformational project that brings together departments and crosses boundaries... It is vitally important to fundamental science in both the Faculty of Arts and Sciences and Yale Engineering, as we become one of the premiere locations for quantum science and engineering."

The Wright Lab addition will provide new research laboratories, office areas, and interaction spaces for Wright Lab's program in experimental nuclear, particle, and astrophysics. Research group offices and labs that are currently housed in Wright Lab West (WLW) will move to the new addition, in preparation for the demolition of WLW to make way for the PSEB. The addition will also create a central interaction space adjacent to the new Advanced Instrumentation Development Center (AIDC).

The AIDC builds upon the success of Wright Lab's instrumentation efforts, including those coordinated through the Advanced Prototyping Center.

Quoted in a recent article in the Yale Alumni Magazine, "Big plans for Science Hill," Sheri Miller, Yale's senior director of sciences campus development said, "People from all over campus, whether they're in a science discipline or not, can come to this facility and work with the scientists here... [Due, in part, to the glass facade of the building,] It'll be a transparent and welcoming beacon to the science that's going on inside the [AIDC] building."

Wright Lab Construction Updates

Construction activities for the Wright Lab Addition (WLA) and Phase I of the Physical Sciences and Engineering Building (PSEB) project began in June 2024 (*see p. 40*). Below are a few highlights; please also see our Flickr album for additional construction photos, updated regularly at flic.kr/s/aHBqjBv7yX








Wright Lab Portal move 2024

The Portal sculpture outside of Wright Lab was transferred to a temporary home in Yale's West Campus; keeping it safe during the construction period. The portal originally came from Yale's Extended Stretched TransUranium (ESTU) tandem accelerator, which was formerly housed in the building and contributed to Wright Lab's legacy and continuing leadership in the fields of nuclear, particle, and astrophysics. See a time-lapse video at: www.youtube.com/watch?v=4gMZQtBifF4

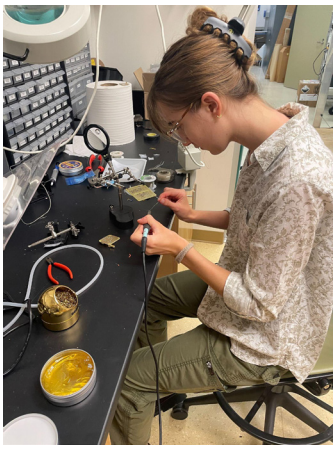
Preparing future scientists

As part of the Yale Department of Physics, education is a core pillar of Wright Lab's mission. We educate and train a diverse community of scientists and future leaders through mentoring, hands-on research experience, career development, and outreach.

Wright Lab is a place where Yale students and postdoctoral researchers become well-rounded experimental physicists. They are empowered to design and build their own research experiments and instrumentation, analyze data, publish results that contribute to answering the most challenging questions in the field of physics today, and develop project management skills. Students and postdocs are central to all stages of research at Wright Lab.

Wright Lab hosts weekly scientific seminars with external speakers who are doing cutting-edge research in the fields of nuclear, particle, and astrophysics; a seminar series for advanced graduate students and early-career postdocs; regular training workshops and orientations for theAPC, machine shop, and computing facilities; and professional development opportunities. Wright Lab has also hosted a summer school, two formal externally funded research programs, and, since 2018, a thriving annual summer research program for undergraduates, postgraduates, and high school students, co-sponsored by Yale Physics Department, Yale Astronomy Department, and Yale Quantum Institute.

As Wright Lab is an entity that is closely related to, yet separate from an academic department, we have a holistic, interdisciplinary approach to education and training; serving graduate, postgraduate, and undergraduate students, postdoctoral associates across Yale's "Science Hill" and beyond, and the greater community-at-large.



Wright Lab promotes the value of science in society and develops science communication skills for its researchers via regular outreach programs led by Wright Lab community members, including through partnerships with Yale Pathways to Science and the Yale Peabody Museum. Wright Lab members also communicate science to the public through appearances in the media and special events. Wright Lab has a legacy of connecting art and science through exhibits and programming to educate, inspire, entertain, and engage people of varied ages and backgrounds.

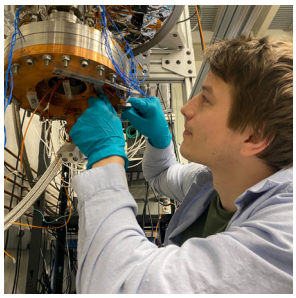
Postdoctoral training

Wright Lab mentored fourteen postdoctoral associates and fellows in 2023 and 2024.

Eun-Joo Ahn

Postdoctoral Associate, Yale Center for the Study of Race, Indigeneity, and Transnational Migration (2023-24); lecturer in Physics (2024-25)

Read more about Eun-Joo Ahn on p. 73.



Lucas Darroch

Postdoctoral Associate (Moore group)

I work on measuring nuclear decays that are loaded inside of an optically levitated silica sphere. Additionally, I do instrumentation for liquid xenon detectors, which are used for rare event searches.

Fernando Antonio Flor

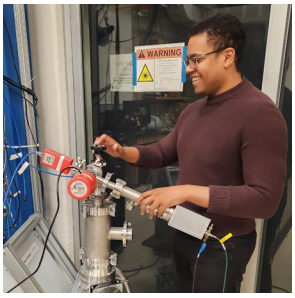
NSF-MPS Ascend Postdoctoral Research Fellow (Relativistic Heavy Ion Group)

My research involves investigating the strong nuclear interaction responsible for binding most of the visible matter in the observable Universe. I am in charge of developing phenomenological models for elucidating particle production in high energy particle physics experiments at Brookhaven National Laboratory and CERN. I am also involved in subdetector R&D activities for the construction of the ePIC detector.

Elise Le Boulicaut Ennis

Postdoctoral Associate (Demers and Tipton groups)

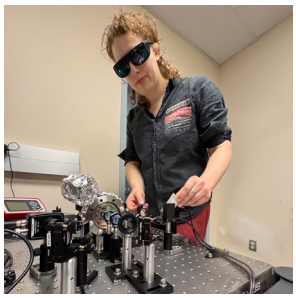
I work on ATLAS, focusing on the Higgs boson and the tau lepton. I co-lead an analysis team to study the charge-parity properties of the Higgs boson using data collected by ATLAS from 2022-24. I am also involved in testing hardware components for the ATLAS Inner Tracker upgrade. I am an active member of the ATLAS Outreach and Education Team, and coordinate the activities related to printable material.



Tyler Johnson

Postdoctoral Associate (Maruyama group)

I work on the RAY experiment, developing quantum sensors out of Rydberg atoms to detect axion dark matter. Rydberg atoms have electrons in an orbit far from the nucleus, where incredibly small perturbations can lead to overt and trackable observations making them a very sensitive, tunable sensor. This sensor can allow us to go beyond the "standard quantum limit," constraining other state-of-the-art axion searches.



Aaron Markowitz

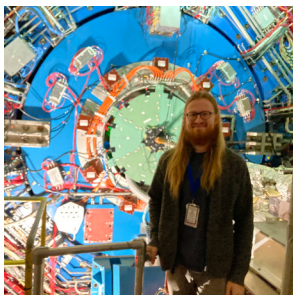
Postdoctoral Associate (Moore group)

I magnetically levitate microscopic diamonds to completely isolate them from the environment. I use a combination of lasers and electric fields to precisely sense and control the diamond's motion. My measurements inform the MAST-QG collaboration's effort to reveal the quantum nature of spacetime by transmitting quantum information through the diamonds' gravitational interaction.

Michael McCrackan

Postdoctoral Associate (Newburgh group)

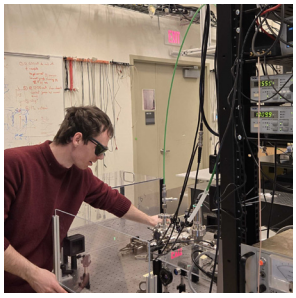
My work focuses on developing and optimizing the time-ordered data reduction pipeline for the Simons Observatory (SO), which transforms raw data into a form suitable for generating on-sky maps for the SO telescopes. I also contribute to developing software to generate telescope operation schedules to ensure high observing efficiency and good coverage of the target fields.



Isaac Mooney

Postdoctoral Associate (Relativistic Heavy Ion Group)

I work on STAR, which measures the products of ion collisions of ultrarelativistic speeds at the Relativistic Heavy-Ion Collider. Each collision may generate a quark-gluon plasma (QGP), which allows for study of the strong force under extreme conditions. To obtain information about the QGP, I use an internally generated tomographic probe called jets. The modification of these jets upon interaction with the QGP allows us to infer its properties. Recent focuses for my work have been determining whether the QGP is formed and modifies jets in collisions of light ions which produce less energy density; the dependence of jet energy loss on the length of time spent in the QGP, which would illuminate the plasma's microscopic properties; and the possible effect that the QGP has on the way that the fundamental particles within jets reform into the measured particles."



Thomas Penny

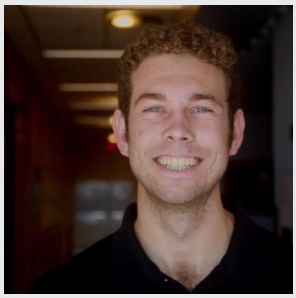
Postdoctoral Associate (Moore group)

I search for new fundamental particles using light to levitate small glass spheres with SIMPLE and QuIPS. Recently, we levitated radioactively doped spheres for the first time. We demonstrated the reconstruction of individual alpha decays occurring within a levitated sphere. I am currently developing this technique further to attempt to see neutrinos being emitted during beta decays. We are also conducting a search for Dark Matter directly interacting with our levitated spheres.

Pranav Sanghavi

Postdoctoral Associate (Newburgh group)

My work is focused on understanding the instrumental systemics of the Canadian Hydrogen Instrument Mapping Experiment (CHIME) telescope. Understanding these systematics are crucial towards a detection of the neutral hydrogen signal, which we shall use to map the large scale structure of our Universe and help constrain the nature of dark energy.



Max Silva-Feaver

Mossman Fellow

Max Silva-Feaver is the 2023 Yale Mossman Postdctoral Fellow, working with both the Reina Maruyama and Laura Newburgh groups at Wright Lab. The Mossman Fellowship is a 3-year appointment, intended to support promising physicists in the early stages of their careers.

Silva-Feaver received his Ph.D. in 2023 from the University of California, San Diego. He has been working on deploying the Simons Observatory telescopes, and is currently focusing on the data reduction and analysis pipeline. He also has joined the HAYSTAC and ALPHA axion dark matter detection experiments, located at Wright Lab. He is upgrading HAYSTAC to extend its sensitivity to a 30-35 micro-electronvolt mass range and he is designing and testing the ALPHA microwave receiver system and integrating the ALPHA haloscope at Yale.

Jorge Torres

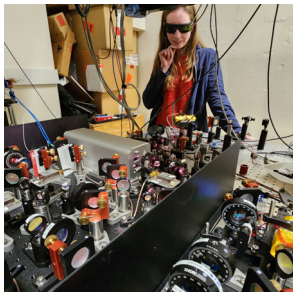
Postdoctoral Associate (Maruyama group)

My research tries to answer the question of why there's more matter than antimatter in the universe with CUORE/CUPID. We are looking for a very rare, theorized process called neutrinoless double beta decay, a nuclear decay that has a clear signature but that can be mimicked by background events. Besides data analysis for the experiment, Yale is in charge of designing a system to mitigate one of these backgrounds: muons. We are building a system that would tag muons and exclude muon-associated events.

Zoltán Varga

Postdoctoral Associate (Relativistic Heavy Ion Group)

Jets are collimated showers of particles that are produced in high-energy collisions of hadrons. As a member of the ALICE experiment at CERN, I have been studying whether the particle content of these jets scale with their momentum according to certain rules. The limited statistics and the effect of the background makes it a challenging measurement, but the confirmation of the scaling would be an important step to better understand the jet evolution.



Sabrina Zacarias

Postdoctoral Associate (Maruyama group)

I work on the RAY experiment, which is dedicated to the detection of dark matter particles, specifically axions, through the approach of single-photon detection with Rydberg atoms. My primary focus involves the design and testing of atomic Rydberg states using selective field ionization techniques.

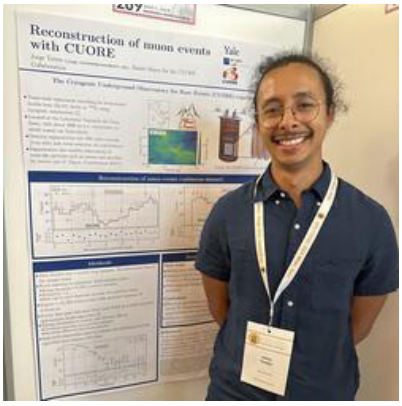
Postdocs in the community

Left to right: Jorge Torres (WL), Isabella Graf, Farnik Nikakhtar, and Yogesh Patil (WL)

Yale Physics Postdoctoral Advisory Committee

PDAC serves as a point of communication between postdocs and junior research scientists and the administration of the department. The committee advises the chair, the director of postdoctoral affairs, and other faculty on matters related to postdocs and the postdoc program, including (but not limited to) helping plan and organize annually scheduled departmental events. The committee also advocates on behalf of postdocs with the chair and the director of postdoctoral affairs. The composition of the committee includes postdocs and associate research scientists who represent inclusive and diverse sets of interests.

Presenting results at Neutrino 2024 conference



Yale Wright Lab research was well represented at the 31st International Conference on Neutrino Physics and Astrophysics (Neutrino 2024), held in Italy from June 16 to 22, 2024. This biennial conference focuses on the status of neutrino physics, its interplay with astronomy and cosmology, and the prospects of these fields. The conference was jointly organized by the University of Milano-Bicocca, the University of Milano, and the Istituto Nazionale di Fisica Nucleare (INFN).

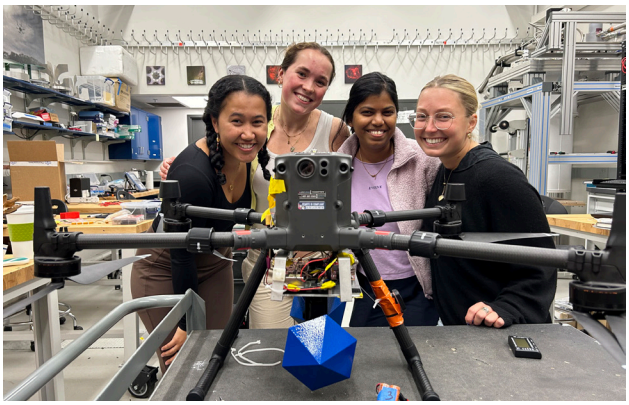
Among other Wright Lab participants, Wright lab postdoctoral associate Jorge Torres presented the poster "Reconstruction of muon events with the CUORE experiment".

Torres said, "Several people stopped by my poster and asked questions about my project, and other more general questions regarding CUORE. Because of the large size of the conference, it was likely to find people who were trying to answer similar questions as yours, but with different experiments, which made it a favorable environment for the exchange of ideas."

Postgraduate training

Postgraduate Associate positions are short term training positions for recent college graduates who seek research experience prior to graduate school. Wright Lab offers hands-on summer and academic year research opportunities in experimental nuclear, particle, and astrophysics; quantum science; and instrumentation for postgraduates, both from Yale and from other institutions. These positions are available in Wright Lab research groups, including through selection for the Wright Lab DOE Research Traineeship for Diversity in Nuclear Physics (*see p. 47*).

See: wlab.yale.edu/research/postgraduate-researchers



Postgraduate associate Mallory Helfenbein (on right) and fellow Newburgh group drone team members pause work in the lab for a photo op.

Wright Lab DOE Research Traineeship for Diversity in Nuclear Physics

The U.S. Department of Energy (DOE) awarded support for a pilot Research Traineeship for Diversity in Nuclear Physics program at Wright Lab for undergraduates and recent college graduates to gain hands-on research experience before graduate school. The traineeship is aimed at training and retaining a diverse cohort of next-generation scientists as future nuclear physicists and leaders in science. Celín Hidalgo and Sergio Oscar Nuñez Silva were the Wright Lab DOE Research Trainees for Diversity in Nuclear Physics for 2023-24.

Celín Hidalgo

Born and raised in Cuba, Hidalgo recently graduated from Rutgers University with degrees in astrophysics and art history. At Wright Lab, under the mentorship of Dr. Karsten Heeger, she collaborated in Project 8, a next-generation experiment to measure neutrino mass. In addition to working at Yale, Celín also worked as a science communicator for NASA Goddard Space Flight Center.

Hidalgo said, "I enjoyed getting a lot of hands-on experience at the lab and collaborating closely in the experiment." Hidalgo continued, "The neutrino, even when small, can change our perspective about the Universe. It is exciting to work on trying to understand how small particles can change our understanding from the Big Bang until now."

Hidalgo was also excited to join the Women+ in Physics group at Yale. Hidalgo said, "it's a great way to connect and meet new physicists of similar backgrounds."

Sergio Oscar Nuñez Silva

Nuñez was born and raised in Peru, where he obtained his bachelor's degree in Physics from Universidad Nacional de Ingeniería in Lima. During his third year, as part of the Research Experience for Peruvian Undergraduates (REPU) program, he came to Wright Lab to conduct an internship in the PROSPECT experiment, under the supervision of Karsten Heeger and Pranava Teja Surukuchi.

Nuñez then went to Colorado School of Mines to work in the BeEST experiment (which searches for sterile neutrinos in the keV scale) and to take some graduate classes. After a year working as a data scientist in a consulting firm in Peru, Nuñez returned to Yale and Wright Lab.

Nuñez worked on Project 8, part of the time in simulation and part in developing instrumentation for the Large UHF Cavity CRES Krypton Experiment at Yale (LUCKEY) prototype.

Nuñez said, "I was really happy to be back into scientific research and to meet so many outstanding people! I looked forward to getting the expertise to contribute to Project 8 research, and I hope to extend this experience into my Ph.D. research."

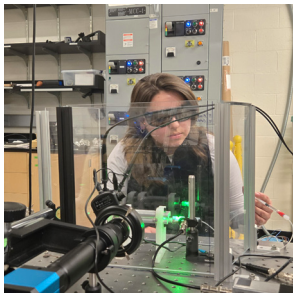
Nuñez added that he was especially excited for the opportunity "to find physics that no one saw, measured, or thought before".

Nuñez enjoys science communication, in particular, in Spanish, and has created an Instagram page called "Física para gente con prisa" (Physics for People in a Hurry). In his free time, Nuñez likes to read and discuss many topics, in particular science policy, philosophy, and classical novels. He is a big fan of Star Wars, loves soccer and Latin dance, and plays the saxophone.

Discover more about Wright Lab postgraduates at wlab.yale.edu/research/postgraduate-researchers

Graduate student training

Wright Lab trained 69 graduate students in 2023-24. Most Wright Lab students are formally affiliated with the Yale Physics Department, while some are formally affiliated with related departments, such as Applied Physics or Astronomy. Wright Lab alumni have gone on to positions in academia, national laboratories, government, industry, and science communication. Discover more at wlab.yale.edu/people/alumni. A few highlights of what some of our students are currently working on are below.



Jackie Baeza-Rubio

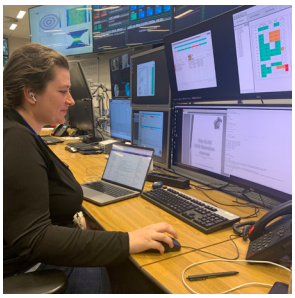
Advisor: David Moore

I am searching for sterile neutrinos, a hypothetical fourth flavor of neutrino that may explain the nature of massive neutrinos, by using a tabletop radioactive nanosphere levitation experiment. Currently, I am building a radiofrequency Paul trap to safely and precisely transport radioactive nanospheres into an optical trap. In this set up, the momentum of an emitted antineutrino will be determined by measuring the momentum of a recoiling daughter nucleus using a levitated radioactive nanosphere. Furthermore, by looking for any deviations in the measured momentum relative to the expected momentum of a Standard Model neutrino, one can detect even a small fraction of heavy sterile neutrinos being emitted during the decay if they exist.

Eunice Beato

Advisor: Reina Maruyama

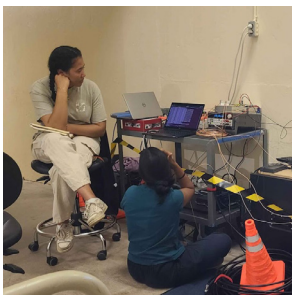
I have spent the summer and last couple of months working on the data acquisition system for the new ALPHA experiments. This includes programming the devices we will use in the experiments and making sure that the devices can communicate with each other and the main computer. I have also been developing cavity design simulations for the RAY experiment that will be used for single photon detection.



Sierra Cantway

Advisor: Helen Caines

I work on the ALICE experiment at the Large Hadron Collider in Geneva, Switzerland. I study collisions of heavy ions that create a hot, short-lived, novel state of matter called the Quark Gluon Plasma (QGP) to test the theory of the strong force at extremely high energy densities. My tool of choice to investigate the QGP is jets: high-momentum collimated sprays of particles that evolve with the QGP. I am particularly interested in how the types of particles in jets are modified compared to those in jets in a vacuum.



Morgan Cole

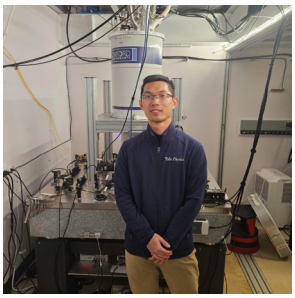
Advisor: Laura Newburgh

I work on various radio telescope experiments, specifically on calibrating them. I work to refine and implement a relatively new method of telescope calibration that involves flying drones! My work combines aspects of astrophysics instrumentation, engineering, and data analysis.

Ryan Hamilton

Advisor: Helen Caines

I study Quark Gluon Plasma (QGP): a hot soup of deconfined quarks that is formed in high energy collisions of large nuclei at particle accelerators. My work is focused on phenomenological analysis of QGP, which is a complicated way of saying that I design simple models to try and describe phenomena we see in the collisions. For one example, we often use fluid dynamics to model the evolution of QGP, which works surprisingly well. I study smaller parts of that fluid dynamical model to try and understand why they work in the context of QCD/how we understand the strong force fundamentally.



Yinchin Hao

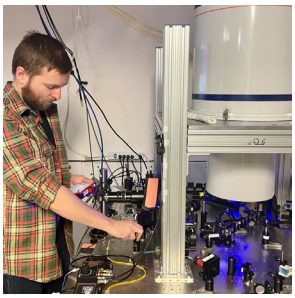
Advisor: Jack Harris

I work with a team of students and scientists on the Helium drop project in the Jack Harris lab. We form superfluid liquid Helium drops in vacuum and use lasers to detect their mechanical motions and optical modes. I developed the full model to characterize the Whispering-Gallery-Modes optical cavities formed by our drops. We showed potential to use the drop as a record-breaking optomechanical system.

Sophia Hollick

Advisor: Reina Maruyama

I work on COSINE-100. I am currently located in Zaragoza, Spain, where I am working directly with colleagues on ANAIS-112, a sister experiment of COSINE-100, to perform a combined dark matter search with data from both experiments. Individually, the two collaborations have been in operation for 6 years, each with 3-year search results published. Through the combined analysis, sensitivity is expected to sufficiently increase to test the DAMA/LIBRA result, which claimed to have found dark matter. Results for this combined search were recently completed and a publication is expected in the coming months. (Wright Lab is excited to welcome Sophia back later this spring for her thesis defense!)



Theophilus Human

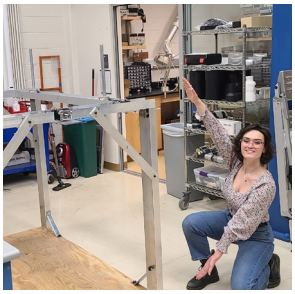
Advisor: Jack Harris

I work on the Helium Drop project, where we use a strong magnet to levitate a single droplet of superfluid helium in high vacuum. These drops serve multiple purposes, including enabling high-precision measurements and studying the unique properties of superfluids. Over the past year, significant upgrades have been made to the experimental setup to improve control over liquid helium drops. These enhancements include better regulation of drop size, extended drop lifetimes, and reduced center-of-mass motion, allowing for more precise studies of the drops' properties. We have measured surface mode frequencies (the ripples on the surface of the drop) with exceptional precision, agreeing with theoretical predictions to about one part in a million. Optical whispering-gallery modes (the confinement of light along the drop's circumference) were also characterized, and we resolved the most radial whispering gallery mode (q=1) for the first time. Additionally, evaporation rates were measured with sub-picometer-per-second precision and are now highly controllable. Currently, we are exploring exciting physics avenues, including measurements of the circulating light on the surface shape (optical spring and optical damping), and the emergence of multimodal surface waves.

Morgan Knuesel

Advisor: Helen Caines

When heavy ions are accelerated to nearly the speed of light and collide, the quarks and gluons that make up ordinary matter are momentarily deconfined. When two high-energy particles collide within this quark-gluon plasma, a collimated radiative spray of particles may be created, which can act as a probe of the plasma droplet. Using proton-proton and Pb–Pb collision data from the ALICE Collaboration at the Large Hadron Collider, I seek to understand how energy disperses within these collimated sprays of particles as a function of time. By examining how the quark-gluon plasma modified the evolution of these particles, we can gain better insight into the properties of the plasma!



Claire Laffan

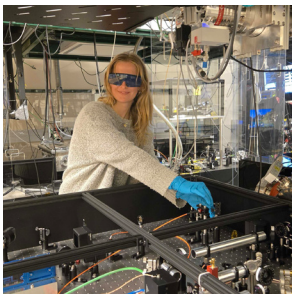
Advisor: Reina Maruyama

I work on two dark matter experiments at Wright Lab: Haloscope At Yale Sensitive To Axion CDM (HAYSTAC) and Axion Longitudinal Plasma HAloscope (ALPHA). HAYSTAC has been running for over a decade, while ALPHA is a new experiment currently under construction at WL. My work this year has been preparing for ALPHA's commissioning by helping design its electronics system as well as aiding in the design, purchase, and integration of ALPHA's 9T superconducting magnet. Additionally, I am integrating an RF veto system into HAYSTAC's data acquisition routine and designing a new lifting structure to move the HAYSTAC experiment during routine maintenance.

Ridge Liu

Advisor: Reina Maruyama

I work on CUORE, studying neutrino and nuclear physics. We have a large mass of tellurium dioxide which we use to look for rare nuclear decays, which can give us critical information about how neutrinos, a type of fundamental particle, interact with other neutrinos and with matter.



Cecily Lowe

Advisor: David Moore

I am developing a novel method to directly detect dark matter using an array of levitated optomechanical sensors. These sensors are sensitive to small momentum transfers from scattering dark matter particles, allowing us to probe mechanisms for dark matter interaction with normal matter in regions of the mass parameter space unexplored by traditional detector technologies. An array of these sensors enables rejection of correlated noise sources and increases sensitivity to interactions that may be too rare to detect with a single sensor. My current work focuses on achieving electrical and thermal isolation to enhance the sensitivity required for a dark matter search.

Siddhant Mehrotra

Advisor: David Moore

I am working on designing a setup in the Moore lab that will implement optically levitated Xenon spheres as high sensitivity detectors for rare physics searches. Over the fall semester, I investigated levitated methanol spheres as a testbed setup for optically trapping liquids. This work will aid in the general group's goal in answering outstanding questions in nuclear and particle physics.

Emily Pottebaum

Advisors: Helen Caines, Laura Havener

I work in the Relativistic Heavy Ion Group. Currently I am writing simulations of Au+Au collisions to compare results from "collider mode" (collision between two gold beams) and "fixed-target mode" (collision between a gold beam and stationary gold foil target). My goal with this project is to investigate the feasibility of a fixed-target program at the upcoming Electron-Proton/Ion Collider (ePIC) experiment.

Ananya Rai

Advisor: Helen Caines

My work involves studying the Quark Gluon Plasma—a hot dense state of nuclear matter produced when two ultrarelativistic heavy nuclei collide—with the ALICE experiment. I use probes called jets to study the microscopic structure of this state of matter where quarks and gluons are deconfined.

Benjamin Siegel

Advisor: David Moore

I work on table top experiments for particle physics. To search for dark matter and new forces I use microscopic glass spheres levitated solely by light. By watching how these spheres dance, we can measure incredibly small forces comparable to the weight of a single virus. My project has been orchestrating a ballet of these sensors, levitating up to 100 at once to improve our sensitivity in searches for new physics.

Andrew Tamis

Advisor: Helen Caines

I work with data from the STAR (Solenoidal Tracker at RHIC) experiment of the Relativistic Heavy Ion Collider (RHIC) at Brookhaven National Lab. This collider accelerates protons and heavy ions to near-speed-of-light velocities, with collisions of heavy ions resulting in the generation of Quark-Gluon Plasma (QGP), where the partons that comprise protons and neutrons are de-confined into a strongly interacting "soup" of particles. The behavior of strongly scattered quarks and gluons flying out of the collision, and their resulting interactions with the QGP provide fundamental information about the strong force. I also perform testing for detectors going into the proximity-focusing ring imaging cherenkov detector (pfRICH) at the future electron-ion collider that will be build using the infrastructure from RHIC.

Mira Varma

Advisor: Keith Baker

I explore the quantum nature of particle physics within the ATLAS experiment at CERN's Large Hadron Collider. My research applies quantum information techniques to study Higgs boson decays, investigating how quantum entanglement manifests in these fundamental interactions. As part of my work with ATLAS, I also contribute to improving our understanding of background processes in particle collisions by validating and optimizing simulation tools essential for the experiment's current data-taking period.

Jiaxiang Wang

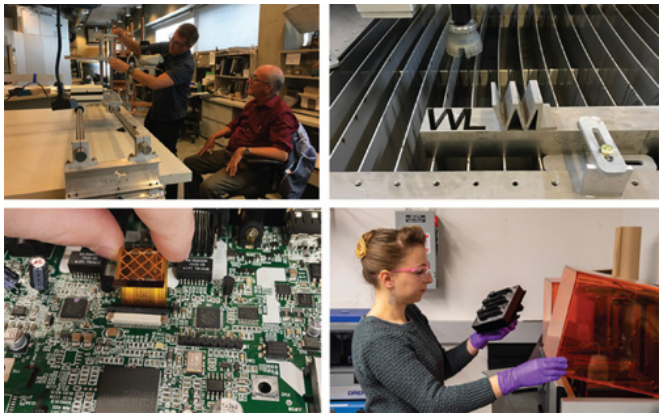
Advisor: David Moore

I work on ultra-sensitive quantum measurements using optically levitated dielectric spheres in high vacuum. This approach allows for the mechanical detection of particle recoils from radioactive decays, providing a powerful tool for exploring weakly interacting physics and detecting particles that may evade traditional particle detectors.

Grad students by the numbers

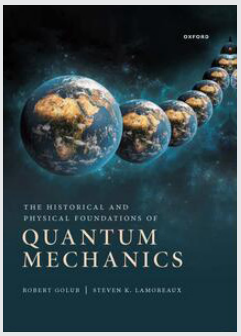
2023-24 students (all classes)	69
2023-24 grad alumni	19
Alumni in academia	8
Alumni at national labs	2
Alumni in industry - technical/science	2
Alumni in industry - other fields	3
Alumni in Law	1
Alumni in Medicine	1
Other/Unknown	2

New course on research instrumentation development

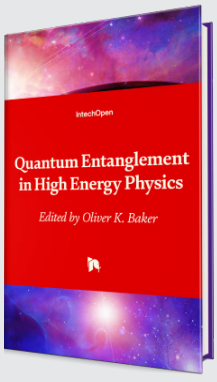


Yale Physics is offering a new graduate-level course called "PHYS 765: Advanced Scientific Instrumentation Development, Prototyping, and Fabrication". The course focuses on research instrumentation design and development using the Advanced Prototyping Center (APC), housed in Yale Wright Laboratory. Techniques include water-jet cutting, laser cutting, 3D printing, and CNC (Computer Numerical Control) machining. Training with Computer-Aided Design (CAD) and Computer-Aided Manufacturing (CAM) programs necessary for design and preparation of parts is provided.

Wright Lab Faculty Publications



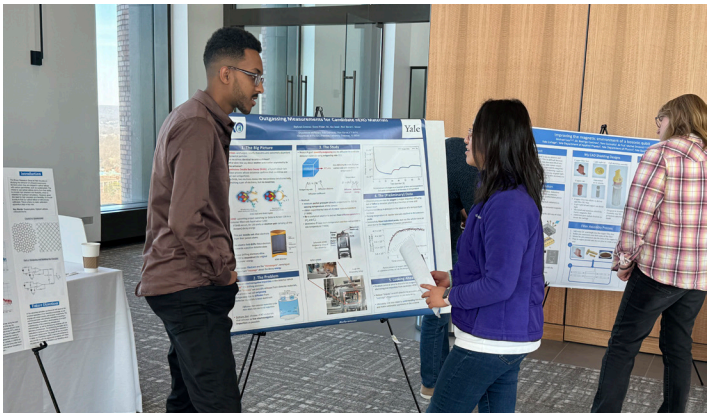
Professor **Steve Lamoreaux** has recently published; with co-author Robert Golub, professor of physics at North Carolina State University; *The Historical and Physical Foundations of Quantum Mechanics* (Oxford University Press, 2023). Wright lab hosted a book launch in May 2023.



Professor **Keith Baker** is the academic editor and co-author of the book *Quantum Entanglement in High Energy Physics*, published by IntechOpen. The book is an open access, peer-reviewed, edited volume, available for free online and also in print. Wright Lab hosted a book launch in August 2024.

Undergraduate research

Wright Lab undergraduates carry out research throughout their time at Yale and have a number of opportunities to present their research, including at Wright Lab's annual summer research symposium *(see p. 56)*, the Yale Physics Department's Fall and Spring semester final presentations, and at both national and international conferences, including regularly at the American Physical Society (APS) Division of Nuclear Physics' (DNP) Conference Experience for Undergraduates (CEU).



2023-24 Senior thesis projects

Audrey Cesene '24 (Laura Newburgh), "Noise Source Printed Circuit Board and Drone Payload Iterations: High Precision Drone Radio Telescope Calibration"
Kameron Duncan '24 (Jack Harris), "Measuring Femtometer Displacement in High-finesse Cavity Optomechanics"
Elsa Durcan '24 (Reina Maruyama), "Superconducting Nanowire Electron Detectors for the RAY Experiment"
Michael Lin '24 (Reina Maruyama), "Synthetic Signal Injection Routines for the Haloscope At Yale Sensitive to Axion Cold Dark Matter (HAYSTAC)"
Luke Mozarsky '24 (Helen Caines), "Tuning the Herwig 7.2 Monte Carlo Event Generator using Professor 2.0"
Rose Powers '24 (Sarah Demers), "Photon Energy Resolution Studies for a 10TeV Muon Collider"
Juan Recoaro '24 (Jack Harris), "Probing Supercooled Water with a Magnetic Levitation Platform"
Jack Roche '24 (Helen Caines), "Establishing a Methodology for Scintillating Tile Characterization"
Barkotel Zemenu '24 (David Moore), "Characterizing the Outgassing of Electronegative Impurities in nEXO"
Tausif Hossain '23 (Sarah Demers), "The Mu2e Trigger Rates Analysis and Data Quality Monitor Development"
Matthew Robert Murphy '23 (Sarah Demers)
Kohsuke Sato '23 (Charles Baltay)
Yu Jun Shen '23 (Sarah Demers), "Investigation of Variational Quantum Eigensolver techniques in Qiskit"
Shayaan Subzwari '23 (Karsten Heeger), "The LUCKEY Magnet"
Dawson Thomas '23 (Sarah Demers), "Topological Machine Learning for Jet Physics"
Giovanna Truong '23 (Jack Harris), "Studying supercooled water using diamagnetic levitation"

One Yale student's love languages: Mandarin, Greek, and particle physics

In his time at Yale, senior Barkotel Zemenu has embraced profound questions about the universe and personal bonds at the heart of one-on-one conversation.

The imperceptible forces that push, pull, and pass through the universe have clearly tugged at Barkotel Zemenu a time or two. Or 10.

Four years ago, Zemenu entered the vortex of Yale undergraduate life with a passion to study history. Perhaps he might teach it someday, he thought. Instead, he emerges this spring as a promising particle physicist who has already contributed to cutting-edge research and interned at an international physics project in Germany and at a premiere astrophysics institute in Israel.

Zemenu has gone from crabbing about the undergraduate foreign language requirement to enthusiastically developing a knowledge of Hebrew, Arabic, Mandarin, and Greek, in addition to English and Amharic, his native language; he's traveled across the United States to academic conferences, giving high-level physics presentations on neutrinoless beta double decay; he's even found the time to co-teach a class for middle schoolers on the meaning of life.

Not bad for a guy who spent his first year as a Yalie doing middle-of-the-night Zoom classes from a hotel lobby — where the wifi was stronger than at his parents' house — in Addis Ababa, Ethiopia.

"So many of these things were unexpected, but I'm grateful for all the pivots," he said, basking in the afternoon sun from a bench outside Pauli Murray College, a frequent stopping place between his physics home base at Wright Lab and his dorm room at Hopper College. "I had not expected college to be a place where I pivoted so much."

Zemenu picked Yale after participating in Yale Young Global Scholars, a summer program that brings American and international high school students together and introduces them to the Yale campus. But then came Zemenu's first pivot.

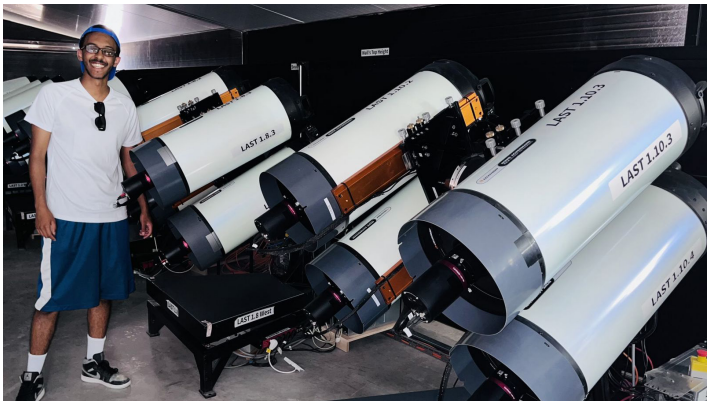
He spent his first year of college living in Ethiopia with his parents, after the COVID-19 pandemic led Yale to make all classes remote as a public safety measure. In those early days, Zemenu would set an alarm for the middle of the night, take a cab to a nearby hotel with a strong wifi connection, and dial into his online classes from the hotel lobby. He became such a frequent visitor that the hotel's employees would recognize him and leave him alone to work undisturbed.

"It was just business as usual," he said. "Now, any time I find myself complaining about the walk up Science Hill, I remind myself what a luxury it is to be here, in person."

Once Zemenu got to New Haven, the pivots began to pile up. He leaned into physics, particularly the unseen world of dark matter and neutrinoless double beta decay — a theoretical nuclear process that, if proven, could shake up the Standard Model of Physics.

He also delved into the writings of revered 20th century physicist Richard Feynman, and a biography of 19th century Scottish physicist James Clerk Maxwell. Zemenu came to the notion that it would be valuable to have one area of deep expertise that is informed by a broad range of studies. He chose physics as his deep dive.

"We've been lucky to have Barkotel as a member of our research group over the past three years, where he's been studying detector technologies aimed at figuring out why there is matter, rather than antimatter, in the universe," said David Moore, an associate professor of physics in Yale's Faculty of Arts and Sciences. "In addition to his packed academic schedule and leadership activities in the department, Barkotel has been a key contributor to our research."



"While we are sad to see him go, we look forward to seeing his many accomplishments in the future."

Zemenu spent part of a summer at the Weizmann Institute of Science, near Tel Aviv, where he wrote a 20-page white paper on his research developing a novel program to automate the identification of variable stars from a telescope image. He spent part of another summer in Germany, at the Munich Center for Quantum Science and Technology, where he studied quantum gravity. He's also attended science conferences in New Orleans, Honolulu, Washington, D.C., and Minneapolis.

Meanwhile, his list of honors grew along with his frequent flier miles: the Jocelyn Bell Outstanding Leadership Scholarship, the Sigma Pi Sigma Leadership Scholarship, a Rosenfeld Science Scholar award, an American Physical Society Top Presenter award.

"I remain extremely interested in this idea of dark matter and dark energy," he said. "We don't know what the majority of the matter in the universe is actually made of. We've quantified it, but we don't know what it is. That's a question I'd like to see answered in our lifetime."

While open to pivoting yet again, Zemenu intends to pursue that question after leaving Yale and entering graduate school at Stanford. He'll also pursue a more recent passion: accessing the deeper, more meaningful interactions that emerge when you communicate with people in their native language.

Much to his surprise, he discovered at Yale that he has a great facility for reading, writing, and speaking other languages. He's written poetry in Hebrew, for instance, and shared a laugh with a family member of a friend by explaining, in Chinese, that his preferred level of spice is "scared of not-spicy food."

"Speaking to someone in their own language opens a different door to aspects of themselves that you won't learn about otherwise," Zemenu said. "That was the part about languages I hadn't realized. It isn't purely academic. It's about relationships."

That may be his biggest pivot of all, he said.

This story is by Jim Shelton and was originally published in Yale News on April 30, 2024.

Zemenu's awards & honors

Named the 2023 recipient of the **Jocelyn Bell Burnell Outstanding Leadership Scholarship**. This award, annually given to one student in the nation for demonstrating academic excellence and leadership, is the highest honor in the scholarship program administered by SPS, an organization of the American Institute of Physics (AIP).

Selected as a **2024 Lindau Young Scientist** and invited to the 73rd Lindau Nobel Laureate Meeting (Physics) to join over thirty Nobel Laureates to exchange ideas on the foundations and future of physics.

Selected as a **Knight-Hennessy Scholar** at Stanford University in 2024.

One of the recipients of the **Yale Science and Engineering Association's Seniors of Distinction award** for 2023-24.

Top presenter award for presenting research at the 2023 American Physical Society (APS) April Meeting on "Characterizing the Outgassing of Electronegative Impurities in nEXO".

Fall 2023 recipient of the **Sigma Pi Sigma Leadership Scholarship**. Sigma Pi Sigma is the oldest and only American honor society for physics and astronomy.

Summer Student Research Program at Wright Lab

The Summer Student Research Program at Wright Lab is an annual program for students working on research at Wright Lab, the Yale Physics Department, the Yale Astronomy Department, and the Yale Quantum Institute (YQI). In 2024, those in certain associated programs at Hopkins Authentic Research Program in Science (HARPS), NCA&T (QISE Scholars/ASCEND Initiative), SCSU (Werth IAF/Quantum Pie), and QuantumCT were invited to join the program. In 2023, the Wright Lab program supported the mentorship and enrichment of 40 undergraduate and 4 high school student researchers; and, in 2024, the program supported 66 participants.

Research experiences

Participating students did research during the 8-week summer program. At the conclusion of the program, they presented their work in a 10-minute scientific talk to their peers, mentors, and the research communities represented by the program at either the Yale Astronomy Symposium or the Wright Lab summer student research symposium.

Training workshops

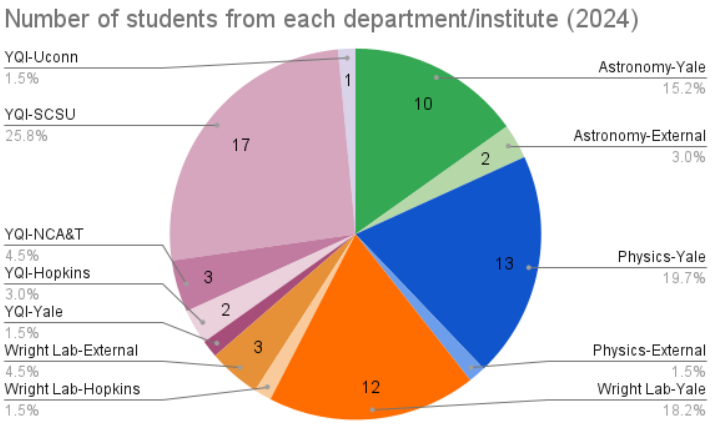
Participants were invited to a number of technical and professional development workshops, including shop trainings; hands-on research computing and quantum computing; applying to graduate schools; resumes and websites; and communicating research results.

Enrichment activities

Students were also invited to various enrichment activities throughout the summer, including lab and camupus tours; an evening at Yale's Leitner Family Observatory and Planetarium; scientific talks; a special viewing of historical scientific books at the Yale Library; the opportunity to lead outreach with Yale Pathways to Science; YQI installations at the New Haven Arts and Ideas Festival; and community-building events.

2023-24 Summer research projects (Wright Lab & YQI presentations)

Vedant Aryan & Swarna Navaratnam-Tomayko (Reina Maruyama and Mike Jewell), "Assessing the Filtering Technique in the HAYSTAC Analysis Procedure Through Simulations"
Eli Bader & Jordan Davidson (Laura Newburgh), "Radio Telescope Calibration with UAV"
Karl Bilston (Steven Girvin, Daniel Weiss), "Quantum Circuits"
Aaron Chizhik (Karsten Heeger), "Testing of Scintillator Panels for CUORE Muon-Veto Deployment" (2023); "Light Detector R&D for CUORE/CUPID" (2024)
Max Colomer & Silvia Wang (Paul Tipton), "Testing Procedures for ATLAS ITk Stave Cores"
Kelly Dai (Reina Maruyama), "ALPHA-DAQ: Data Acquisition System for the Axion Longitudinal Plasma HAloscope"
Éle Donegan (Laura Newburgh), "Upgrading the Receiver System and Amplifiers of the Drone and Transmitter System"
Katie Driscoll (Prakhar Garg), "Design and Assembly of a Faraday Dark Box for the Characterization of Scintillating Tiles"
Reagen Garcia (Karsten Heeger), "Muon Veto Panel Uniformity Tests for CUORE and CUPID"
Xavier Gilbert (Nishaad Khedkar)," Creating an Interface for Quantum Measurements"
Iris Henry (Ian Moult), "Using Energy-Energy Correlators to Explore QCD Strings"
Forrest Hutchison (Charlie Baltay), "Magnitude Calibration of Supernovae from the LSQ/LCO Collaboration"
Jacky Hua (Karsten Heeger), "LED Pulser Calibration of Plastic Scintillator Panels in CUORE"
Joshua Kerner & Mary Zhang (Helen Caines), "ePIC LFHCal R&D"
Andrew Kim (Steve Lamoreaux), "Inductance of a Single Loop of Wire using Laplace EQ & Numerical Methods"
Elisa Kim (Helen Caines), "Image Analysis and Segmentation with Scintillating Tiles of the LFHCal"
Seojun Lee (Keith Baker), "Quantum Entanglement in H->ZZ*"
Selma Mazioud (Helen Caines), "Statistical Hadronization Model Calculations of Charm Hadron Production in Relativistic Heavy Ion Collisions at the LHC"
Florence Polak (David Rabinowitz), "Coadding QUEST Data in Search of Treasure in the Sky"
Michael Mann (Benjamin Brock), "Modeling Measurement and Errors on GKP States"
Nikita Mazotov (Paul Tipton/Jeff Ashenfelter), "Metrology of CERN ATLAS Phase II ItK"
Daequan Peele (Qile Su), "Twirling Coherent Errors via Non-ideal Teleportation"
Austin Rosypal (Helen Caines), "Investigating the Path-Length Dependence of Jet Energy Loss in the Quark-Gluon Plasma"
Lily Shukla (Prakhar Garg), "Automation of Tile Scanning and Silicon Photomultiplier Characterization Set-Up"
Andrew Tejada-Vega (Laura Newburgh), "Lasers and Drones"
Ronald Thorpe (David Moore), "Outgassing of Electronegative Impurities within Materials Used in the nEXO Neutrinoless Double Beta Decay Detector"
Din-Ammar Tolj (Reina Maruyama), "Using Monte Carlo Simulations to Model Scintillator Panel Resolution"
Daniel Zhang (Laura Havener), "Implementation of a testing station to characterize photosensors for the proximity focusing Ring Imaging Cherenkov Detector (pfRICH) for the Electron-Proton/Ion Collider (ePIC) Collaboration"



Discover more: wlab.yale.edu/events/summer-programs

Advocacy

Wright Lab community members are frequently recognized for their advocacy and efforts pertaining to belonging, diversity, equity, and inclusion. A few highlights are below. **Discover more**: wlab.yale.edu/news

Asian Americans and STEM at Yale

Asian Americans and STEM is dedicated to promoting research, education, and wider scholarly and public communication at the intersection of humanities and STEM. Wright Lab's professor Reina Maruyama and postdoctoral fellow Eun-Joo Ahn (*see also p. 73*) co-lead the effort, along with professors Mary Lui (American Studies) and Theodore Kim (Computer Science); lecturer Rona Ramos (Physics), and postdoctoral associate Yoehan Oh (Computer Science). *See p. 34 for information about a related conference in 2024.*

Relativistic Heavy Ion Group (RHIG) plays leading roles in historic Quark Matter 2023

In September 2023, Wright Lab's RHIG attended the Quark Matter 2023 conference in Houston. This 30th-anniversary conference was a significant milestone for the heavy ion community, not only in terms of physics results but also for diversity and inclusion. The conference achieved a record-breaking representation of gender minority speakers at 25%. Additionally, the organizers (including Wright Lab's Helen Caines, professor of physics, and John Harris, D. Allan Bromley Professor *Emeritus* of Physics) made a dedicated effort to have 100% female session chairs for the plenary sessions, and 35% of plenary speakers were women or non-binary (including new Wright Lab faculty member Laura Havener, asisstant professor of physics). The conference also provided free childcare onsite for participants, an enforceable code of conduct, a Diversity and Inclusion Committee, and a pre-conference Student Day Lecture series. Finally, Caines delivered the conference summary talk at the end of the seven-day event—the first time in 30 Quark Matters that a woman gave this important talk.

Rai elected to Diversity Office for ALICE

Wright Lab graduate student Ananya Rai was elected the junior representative to the Diversity Office of the ALICE Collaboration at the Large Hadron Collider (LHC).

The Diversity Office advises members of ALICE on diversity issues and promotes diversity initiatives within the collaboration and the broader CERN community. In her role as junior representative, Rai will represent the ~750 juniors in the ALICE collaboration.

Yale Physics Graduate Diversity Fellowship at Wright Lab

Yale Physics initiated a Graduate Diversity Fellowship for graduate students, working with a faculty mentor, to promote student efforts in Diversity, Equity, Inclusion and Belonging (DEIB) in the Physics Department, and is awarded on a competitive basis following an application process and committee review. Wright Lab's Sanah Bhimani was the fellow for 2022-23 (mentor: Laura Newburgh). She focused on creating a departmental climate survey, including a review of past surveys and initiating new survey with a professional, external survey entity.

Advocacy

Yale Women in Physics+ organizes first CUWiP-Y

In February 2024, the undergraduate Yale Women in Physics+ (WiP+) held its first Conference for Undergraduate Women and Gender Minorities in Physics - Yale Edition (CUWiP-Y) in the third floor lounge of Sloane Physics Lab.

The event was held for those who were not able to attend the American Physical Society's Conference for Undergraduate Women in Physics, as well as for those who did attend but wanted to share their experience with others. The students heard from a panel of women professors here at Yale about their career journeys and had an opportunity to ask questions. The panel included Wright Lab's Sarah Demers and Reina Maruyama, as well as Alison Sweeney and Meg Urry. The event concluded with a lunch that was also attended by members of the graduate student Gender Representation in Physics (GRiP).

Yale Physics celebrates International Day of Women and Girls in Science

On February 11 of each year, Yale Physics celebrates the International Day of Women and Girls in Science. This annual celebration, initiated by a resolution of the United Nations in 2015, recognizes the critical role that women and girls play in science and technology. For a few spotlights on some of our advocates, see wlab.yale.edu/idwgs24.

At a related event, members of the graduate student Gender Representation in Physics (GRiP) gathered for a unique Valentine's Day event to craft odes to the female mathematicians and scientists who've paved the way in their fields.

History and Foundations of Physics group (HoFoP) explores representation of physics in museums

In May 2024, HoFoP held a discussion called, "How Does Physics Make it to the Museum," along with a visit to the history of science and technology exhibit in the newly reopened Peabody Museum, facilitated by Professor Paola Bertucci, who is the curator of the Peabody's History of Science and Technology Division.

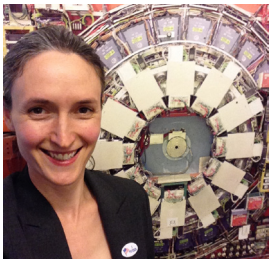
The discussion focused mainly on how to humanize the scientific experience in museum exhibits and how the people who contribute to the scientific process can best be represented. Additional discussion points included how to engage audiences of all ages and how to incorporate current, ongoing research along with the historical objects and more finalized scientific results.

Awards & Honors

Faculty

Charles Brown has won a National Science Foundation (NSF) Faculty Early Career Development (CAREER) Program award, a 2024 Young Investigator Program (YIP) award from the Air Force Office of Scientific Research (AFOSR), and was named an at-large director for the American Institute of Physics (AIP). Brown has also been awarded the Joseph A. Johnson Award for Excellence by the AIP and the National Society of Black Physicists (NSBP), recognizing both his pioneering experimental research and his dilligence supporting the needs of the larger Black physics community and intergenerationally connecting Black physicists across the globe.

Helen Caines was appointed the Horace D. Taft Professor of Physics



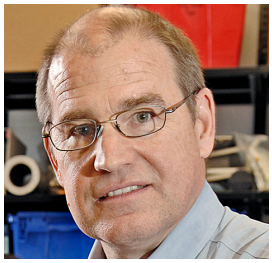
Sarah Demers has been elected as a Fellow of the American Physical Society (APS) "for important contributions to tau lepton triggering and identification and using the tau signature in the study of Higgs production and decay, and for important leadership both within the ATLAS collaboration and the broader physics community." Demers was also awarded the Yale College Dylan Hixon '88 Prize for Teaching Excellence in the Natural Sciences.

Karsten Heeger has been appointed the Eugene Higgins Professor of Physics at Yale. Heeger and his collaborators in the Daya Bay collaboration have been awarded the 2023 European Physical Society (EPS) High Energy Particle Physics (HEPP) prize for an outstanding contribution to high energy physics in an experimental, theoretical or technological area.

John Harris is the 2024 recipient of the American Physical Society Division of Nuclear Physics Mentoring Award.

Konrad Lehnert was appointed Eugene Higgins Professor of Physics.

Steven Lamoreaux was appointed Eugene Higgins Professor of Physics

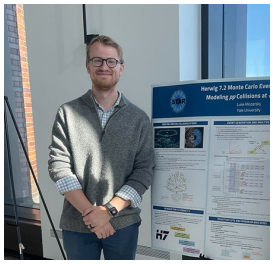


Samuel Moseley was elected to the prestigious National Academy of Sciences—one of the highest honors bestowed on a U.S. scientist or engineer—in recognition of distinguished and continuing achievements in original research.

Research undertaken by **David Moore**'s group was selected by *Physics World* as one of the Top 10 Breakthroughs of the Year for 2024 and by *Physics Magazine* as one of the "Highlights of the Year" for 2024. The Moore group's breakthrough is described in a paper that was published in "Physical Review Letters" called "Mechanical Detection of Nuclear Decays," led by Jiaxiang Wang, graduate student in applied physics and a member of the Moore group.

Ian Moult has won the Wu-Ki Tung Award for Early-Career Research on Quantum Chromodynamics (QCD) for his "pioneering work on QCD energy correlators, including their all-orders factorization, multi-loop structure, phenomenological applications, and connections to conformal field theory". Moult was also awarded the 2024 Early Career Scientist Prize in Particle Physics from the International Union of Pure and Applied Physics and received recognition from U.S. Department of Energy's Early Career Research Program.

Postdoctoral Associate Award

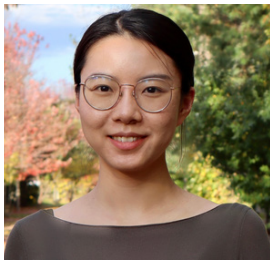


Isaac Mooney was one of four postdocs to receive the 2024 Office of the Provost and Yale Postdoctoral Association's Yale Mentoring Award for postdoctoral scholars. This award recognizes postdoctoral scholars who exemplify the role of a mentor to their undergraduate students or postgraduates. The winner of the prize is chosen based on recommendations from mentees.

Recognizing long-service

Wright Lab recognizes the long service of **Jeff Ashenfelter**, Associate Director for Operations, and **Frank Lopez**, Research and Development Technician, who celebrated 35 and 20 years, respectively, of working at Yale's Wright Lab. We also celebrate **Hannah Carroll**, Lead Administrator in Astronomy and Physics, who retired in 2023 after 32 years of service at Yale, including 22 years in Yale Physics; and **Satish Dhawan**, senior research scientist in physics, who is one of the longest-serving members of the Yale Physics Department, with more than 55 years of service to Yale.

Graduate Student Fellowships & Awards



Xiran Bai has received a Yale Dean's Emerging Scholar Award for 2023.

Jackie Baeza-Rubio has received a Yale Dean's Emerging Scholar Award for 2024.

Nathan Borak has been awarded a Department of Energy (DOE) Office of Science Graduate Student Research program (SCGSR) grant.

Hannah Bossi was awarded the 2023 D. Allan Bromley Fellowship from Yale. Within ALICE, Bossi was co-coordinator for the Machine Learning Working Group; Junior Representative; and Junior Ambassador.

Eleanor Graham received an honorable mention for the 2023 NSF Graduate Research Fellowship (NSF GRFP).

Matt King's outstanding performance and promise as a teacher has been recognized by being named a Yale Graduate School of Arts and Sciences (GSAS) Prize Teaching Fellow for 2022-23.

Emily Pottebaum received an honorable mention for the 2024 NSF Graduate Research Fellowship (NSF GRFP).

Ananya Rai was elected as the junior representative to the Diversity Office of the ALICE Collaboration at the Large Hadron Collider (LHC).

Glenn Richardson has been awarded a Department of Energy (DOE) Office of Science Graduate Student Research program (SCGSR) grant.

Lauren Saunders was a co-recipient of Yale Physics Department's Leigh Page Award for Excellence in Graduate Student Teaching.

Yu-Han Tseng was awarded the Graduate Instrumentation Research Award (GIRA) for his project "Development of Quantum Optomechanical Sensors for Dark Matter and Sterile Neutrino Searches".

Molly Watts was awarded a 2023 NSF Graduate Research Fellowship (NSF GRFP). Watts is currently working with associate professor David Moore on the nEXO experiment.

Talia Weiss was awarded the D. Allan Bromley Fellowship from Yale University in 2023. Weiss also has been chosen as a 2023 Next-Generation Fellow of the Physicists Coalition for Nuclear Threat Reduction.

Wright Laboratory

Undergraduate Student Fellowships & Awards

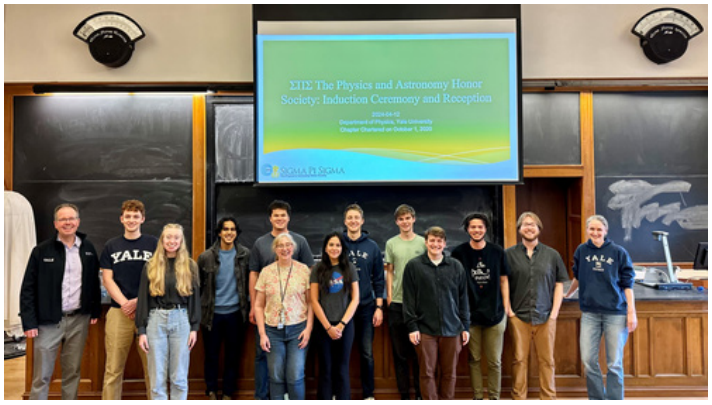
Aaron Chizhik was awarded the Joseph Lentilhon Selden Memorial Award, which is "given each year to a member of the junior class of Yale College whose verve, idealism, and constructive interest in music and the humanities exemplify those qualities for which Selden is remembered. In recent years this award has gone to students especially notable for their contribution in the field of music."

Rose Powers was awarded a 2024 National Science Foundation Graduate Research Fellowship (NSF GRFP). We also congratulate undergraduate **Dawson Thomas** and alum **Laura Zhou** '22 for receiving honorable mentions for the 2023 NSF GRFP.

Powers was also one of the recipients of the Yale Science and Engineering Association's Seniors of Distinction award for 2023-24.

Barkotel Zemenu was named the 2023 recipient of the Jocelyn Bell Burnell Outstanding Leadership Scholarship, selected as a 2024 Lindau Young Scientist, and selected as a 2024 Knight-Hennessy Scholar at Stanford. Zemenu was awarded a top presenter award at the 2023 American Physical Society April Meeting and was the Fall 2023 recipient of the Sigma Pi Sigma Leadership Scholarship. Zemenu was also one of the recipients of the Yale Science and Engineering Association's Seniors of Distinction award for 2023-24. *See pp. 54-55 for more information.*

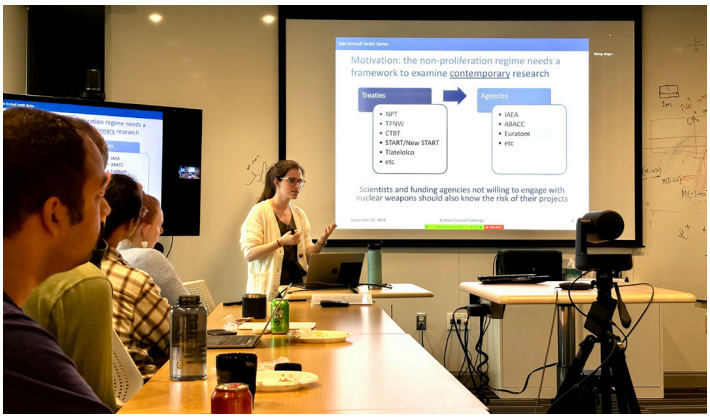
Congratulations to Wright Lab undergraduates **Tausif Hossain, Shayaan Subzwari**, **Dawson Thomas**, and **Giovanna Truong**, who, along with six other Yale Physics students, were awarded the 2023 Howard L. Schultz, Sr. Prize. Congratulations also to Wright Lab undergraduates **Elsa Durcan**, **Luke Mozarsky**, **Rose Powers**, and **Barkotel Zemenu;** as well as former Wright Lab students **Sophia Getz** and **Argyris Giannisis Manes**; for being awarded the 2024 prize, along with Jessie Chen. The Schultz Prize is in honor of Howard L. Schultz, Ph.D. 1937, and is awarded annually to outstanding seniors in the Yale Physics department.



Congratulations also to the following Wright Lab undergraduates who were inducted to Sigma Pi Sigma, the official honor society of the physics profession, in 2024: **Aaron Chizhik**, **Sophia Getz**, **Quazi Rumman Rahman**, and **Din-Ammar Tolj**. Sigma Pi Sigma is an organization of the American Institute of Physics and a member of the Association of College Honor Societies whose mission is to honor outstanding scholarship in physics and astronomy, to encourage interest in physics and astronomy among students at all levels, to promote an attitude of service, and to provide a fellowship of persons who have excelled in physics and astronomy.

Student Organizations

Kimball Smith Series



The Kimball Smith Series is an event series that tackles issues at the intersection of science, technology, ethics, and global affairs; ranging from nuclear weapons risks to artificial intelligence policy. The series was co-founded by Talia Weiss, graduate student in physics and member of Yale's Wright Lab; Ellie Singer, undergraduate student in political science; and Lucas Arthur, who studied at MIT and is now a Technical Associate in the MIT Laboratory for Nuclear Security and Policy.

Kimball Smith events promote cross-disciplinary conversations and connections. Core events feature: speaker panels, with experts in scientific and political aspects of the event topic and multidisciplinary, small-group discussions among attendees. Beyond these core events, Kimball Smith facilitates and hosts policy-focused talks at STEM seminars and events, and vice-versa—in partnership with other Yale programs and departments.

The Series honors Alice Kimball Smith, PhD '36, a historian who analyzed scientists' efforts to shape nuclear politics early in the atomic age.

The Kimball Smith Series is sponsored by the Yale Physics Department, Wright Lab, International Security Studies Center for Industrial Ecology at the Yale School of the Environment, and the Astronomy Department. The series also partners with the Jackson Institute's Maurice R. Greenberg World Fellows Program, the Political Science Department, and Tech and Society at the School of Management.

Events in 2023-2024 hosted by or co-sponsored by Kimball Smith included:

- Science, Tech & World Affairs: A Book Talk and Q&A with Charles Weiss
- Material Energy Nexus (hosted by Yale School of the Environment) and lunch discussion
- International Security in Orbit and Beyond (hosted by the Yale Schmidt Program)
- Arms Races in Outer Space: Physics and Politics
- Walking the World Back from the Nuclear Brink: What Can Scientists Do? (Joint with Wright Lab NPA Seminar)
- Yale Film Archive Screening: Dr. Strangelove
- The Science and Ethics of Autonomous Warfare
- Possibilities for Neutrinos in Nuclear Security
- AI and the Future of Space Conflict
- Beyond Bits: Global Effects of Quantum Technology
- Let's stick together: Sustaining the scientific record and scientific community during chaos
- The Rise of Malignant Deterrence
- Flagging Dual-Purpose Research in the Physical Sciences
- Small Reactors, Big Impact: Policy, Technology, and the Future of Nuclear

Learn more at: kimballsmithseries.yale.edu

Student Organizations

Yale Society of Physics Students (SPS)

The Society of Physics Students (SPS) at Yale is a registered undergraduate organization dedicated to serving the physics community. Yale SPS is a chapter of the national Society of Physics Students, as well as a member organization of the American Institute of Physics (AIP) since 1998.

Yale SPS has benefited from Wright Lab leadership in 2023-24. The following Wright Lab undergraduates served as co-presidents during this time: Barkotel Zemenu, 22 (co-president with Maddie Butchko, '23); and Aaron Chizhik and Nikita Mazotov (co-presidents together). Other Wright Lab undergraduate members have served on the Board during this time, including Henry Kaplan, Max Watzky, Maddi Brown, and Diya Naik.

Yale SPS hosted their first day-long regional meeting for New England (SPS Zone 1) on April 13, 2024. Twenty students participated from six institutions across the region, including Providence College, Saint Anselm College, Southern Connecticut State University, Tufts, University of Massachusetts Dartmouth, and Yale.

The national SPS website explains, "Zone meetings bring together students from SPS chapters within geographical zones. They are a fun and effective way for undergraduates to meet other students, present their research, and interact with practicing scientists."

The meeting gave students the chance to network and present their own research, as well as hear keynote talks from professors Timothy Atherton (Tufts University), Elliot Horch (Southern Connecticut State University) and Sarah Demers (Yale University). Participants also attended a panel led by graduate students from a diversity of institutions, including Florida State, Iowa State, and Tufts.

Demers, who is director of undergraduate studies, a member of Wright Lab, and the advisor of Yale's SPS said, "The graduate panel was phenomenal! The students were honest, thoughtful, and gave some actionable great advice about how to advocate for yourself and how to build community, while talking about the fun and challenges of grad school. There were also three undergraduate seniors who were in the midst of making their decision about where to go who gave fantastic advice."

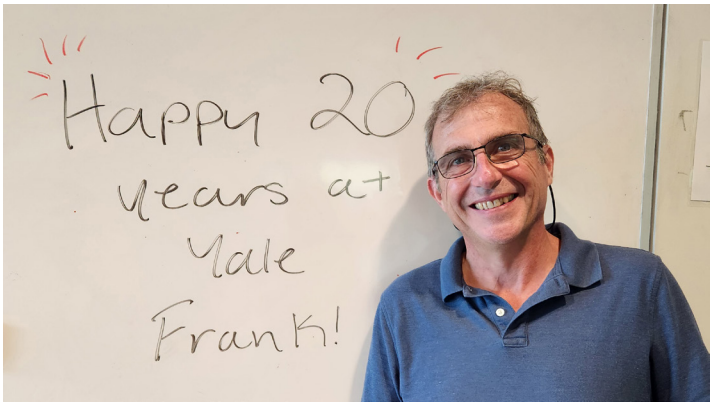
Optional activities for the participants included a tour of Wright Lab, a science trivia quiz, and a physics movie night.

Demers said, "The event was a smashing success. From hosting visiting students overnight to the campus tour to a smooth registration with tons of SPS and Yale Physics swag; through snacks, meals, etc., I think we provided a welcoming and fun physics environment for the visiting students."

Chizhik, Mazotov, and Andrew Nupp coordinated the event on behalf of SPS. Yale Physics administrative staff members Daphne Klemme, Layla Nayar, Jennifer Ongley, and Elena Siuzdak all contributed to the logistical coordination of the event.

Celebrating our community

Yale Physics Prospective Student Tour - Mar. 31, 2023



Frank Lopez 20th Anniversary at WL - Jun. 26, 2023

Wright Lab Summer Students - Jul. 30, 2023

Historical Scientific Books at YUL - Jul. 5, 2023

Hannah Carroll Retirement - Sep. 9, 2023

WL Ice Cream Social - Aug. 28, 2023

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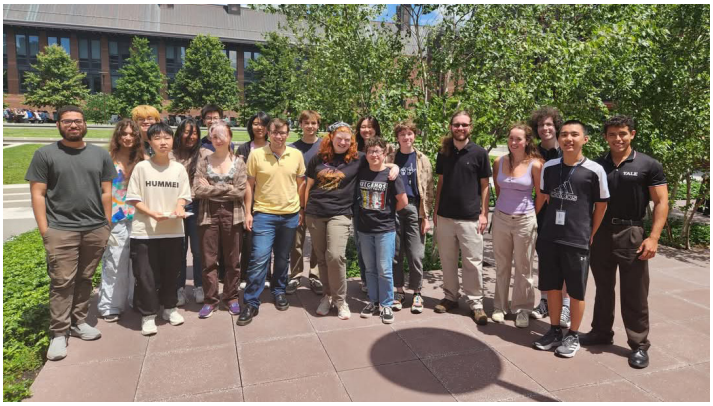
Events Mailing List: Subscribe to "Wright Lab Events" on the Yale E-mail Subscription service (subscribe.yale.edu) to receive regular updates on Wright Lab events and news. Subscribers receive 1-5 notifications per week, including our weekly E-mail newsletter.

Alumni Mailing List: Subscribe to "Wright Lab News" on the Yale E-mail subscription service (subscribe.yale.edu) if you want to receive publications like our annual report and less-frequent communications (e.g., quarterly, monthly). Subscribers will receive no more than 20 communications per year.

International Women's Day - Mar. 8, 2024

2024 Solar Eclipse at Wright Lab - Apr. 8, 2024

Yale Physics Prospective Student Tour - Apr. 5, 2024



WL Summer Program Pizza Lunch - Jul. 1, 2024

Baker Book Launch- Aug. 19, 2024

WL Winter Celebration - Dec. 18, 2024

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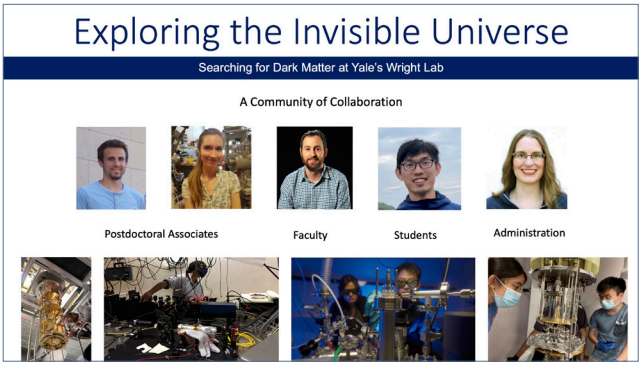
flickr.com/photos/yalewlab/collections

Communicating science and inspiring future scientists

Wright Lab promotes the value of science in society and develops science communication skills for Wright Lab researchers through regular outreach programs led by Wright Lab community members, including:

Yale Pathways to Science Summer Scholars

In the summers of 2023 and 2024, members of the Yale Physics community, including many members of the Wright Lab community, taught three week-long workshops per year and a total of six enrichment sessions for the Pathways Summer Scholars—a free two-week summer science program exclusively for over 100 high school students from the Yale Pathways to Science program.



Celebrating Dark Matter Day with local schools

Wright Lab celebrated Dark Matter Day 2023 by hosting an online event at the lab for local schools, in partnership with Yale Pathways to Science. Seventy-one students from grades 9-12 and four teachers registered to attend the program. The participating schools were Engineering and Science University Magnet School in West Haven, Wilbur Cross High School in New Haven, and Xavier High School in Middletown.

Upward Bound Math Science students explore physics at Wright Lab

On May 4, 2023, fourteen students from Waterbury's Upward Bound Math Science program came to Wright Lab for a half-day's worth of activities that included a facility tour, two scientific demonstrations, a panel discussion, and a meet and greet with representatives from various student organizations in Yale Physics and the researchers who had led tours earlier.

Wright Lab in Yale Physics outreach

Members of Wright Lab lead and participate in many of the outreach endeavors of the Yale Physics Department. In 2023-24, this included Girls' Science Investigations events on the World of Light (2023) and the World of Sound (2024), the annual Yale Physics Olympics, the annual Halloween Spooky Demo Show, and attendance at annual outreach conferences. Wright Lab members also participate in a variety of outreach organizations sponsored by the University.

Discover more about Wright Lab outreach at wlab.yale.edu/events/outreach

Local students explore science, technology, and the natural world at Wright Lab

Wright Lab hosted a four-day program in August 2024 for eight middle school students—ranging from 6th through 8th grade—called "Summer Explorations in Science, Technology, and the Natural World". Participants learned about programming and robotics through hands-on projects and group-led exploration, attended lectures by Yale scientists, and engaged in guided tours of both Wright Lab and the Yale Peabody Museum.

Throughout the program, the students participated in hands-on robotics activities led by Lynn Connelly, a science teacher from Hopkins School who teaches physics and robotics and advises the Hopkins robotics team. Activities included assembling a robot from a kit and then programming the robot to play soccer, write using a pen, become a solar robot, change color, avoid obstacles on a course, and play songs. For a capstone project of the program, the students created a "smart" city and programmed the robots to drive safely around the city autonomously.

The students also interacted with Wright Lab graduate student volunteers, who assisted with the hands-on activities and led short lectures in topics of physics, such as the physics of light, color, sound, and acceleration. Volunteers included: Eunice Beato, Eleanor Graham, Claire Laffan, Cecily Lowe, Samantha Pagan, and Molly Watts.

Connelly said, "The kids were super excited about the combination of physics and robotics, and it made the camp really unique."

Each day, the students also experienced an enrichment activity. Theodore Kim, professor of Engineering & Applied Science and two-time Academy Award-winner gave a lecture on "Computer programming, art, and animations". Amaleah Hartman, lecturer in Molecular, Cellular, and Developmental Biology, gave a lecture on "Stem Cells". Participants also toured Wright Lab, led by Lowe and Pagan, and the Yale Peabody Museum, led by Alexi Baker, collections manager for the History of Science and Technology at the Peabody.

Beato said, "My favorite part about helping during the program was just seeing how excited and curious the kids were. I think getting excited about science and having people support that curiosity at a young age is very important in giving kids the confidence to continue in STEM! So I was glad to be a part of the process for the kids that were here this summer."

The program was conceived and coordinated by Karsten Heeger, Eugene Higgins Professor and Chair of Physics and Director of Wright Lab; and Reina Maruyama, professor of physics and astronomy and a member of Wright Lab. Paul Noel, Yale Physics technology services specialist and instructional tech served as technical advisor. Yale Physics senior administrative assistants Jenn Arnone and Camille Simeone and Wright Lab program manager Victoria Misenti provided administrative and logistical support.

Maruyama said, "We are very excited we were able to initiate and support this program at Wright Lab this summer. Middle school years are a perfect time to try out new things, especially in a supportive environment. Students of this age range have the foundation to appreciate and carry out complicated problem solving, and I was so happy to see them collaborating and working together—just as we do for our physics experiments at Wright Lab—to create code, move their robots, test laws of gravity, and create music and a mini city."

Maruyama continued, "I'm looking forward to see these middle schoolers continue to grow and create."

The 2024 program was sponsored by the Yale Department of Physics, the Michele Dufault Endowment for Yale Women in Science, the Yale Wright Laboratory, and Yale University.

Communicating science and public engagement

Wright Lab members also communicate science to the public through the media and special events, including:

Wright Lab observes 2024 solar eclipse

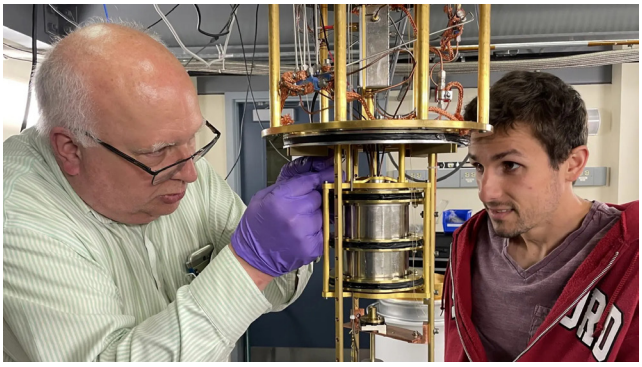
Members of Yale Wright Laboratory (Wright Lab) and the surrounding community gathered on April 8, 2024 outside of Wright Lab on the top of the Pierson Sage Garage to view the solar eclipse. Wright Lab postdoctoral associate Pranav Sanghavi set up two 21cm radio telescopes to take data of the eclipse. The telescopes are usually used for outreach led by the Newburgh Lab.

2024 Pint of Science Festival in New Haven

Wright Lab postdoctoral associates Fernando Flor, Pranav Sanghavi, and Jorge Torres coordinated the 2024 Pint of Science Festival in New Haven from May 13-15, 2024. Wright Lab assistant professor Laura Havener and research scientist Prakhar Garg presented talks. The Pint of Science Festival is an annual global event, begun in 2013, that takes place all over the world. In the U.S., the event was held in Los Angeles, Houston, Philadelphia, Boston, and New Haven.

Lamoreaux explains physics of football pass for PBS Nova

Steve Lamoreaux, professor of physics, and a member of Yale's Wright Lab, explained the physics of the perfect spiral football pass in a clip for PBS' science program "Nova" that appeared on their Facebook page to coincide with the Super Bowl. This is the second time that Lamoreaux has explained the physics of football for the media; the first was for ESPN's NFL countdown in November 2021.



HAYSTAC experiment featured on Bluefors website

HAYSTAC is featured in an article about their setup and their search for the axion candidate of dark matter using quantum-enhanced detection technologies on the Bluefors website. Bluefors offers industry standard cooling solutions for quantum technology, fundamental physics research, and groundbreaking applications. The article is called "Detecting Dark Matter: The HAYSTAC experiment at Yale University".

Weiss chosen as 2023 Next-Generation Fellow of the Physicists Coalition for Nuclear Threat Reduction

Wright Lab graduate student Talia Weiss has been chosen as one of five 2023 Next-Generation Fellows of the Physicists Coalition for Nuclear Threat Reduction. Wright Lab alum Nathaniel Barbour, '18, now a physics Ph.D. candidate at the University of Maryland, is also a 2023 fellow.

Throughout the next year, the fellows will work together with Coalition experts to grow their science advocacy skills and build their knowledge of nuclear weapons policy.

Weiss said, "I am excited for this opportunity to connect physics knowledge with policy research and advocacy in an effort to reduce dangers posed by nuclear weapons. Physicists have a rich legacy of promoting arms control and conducting key technical analyses, given our field's central role in creating nuclear weapons. The Physicists Coalition Fellowship program is helping my generation to continue this legacy, and I'm so grateful for that."

Weiss' research in the Heeger group centers on measuring the neutrino mass using tritium beta decay with the Project 8 experiment. She holds an M.A. in Political Science from the University of Chicago and a B.S. in Physics from MIT.

Weiss said, "I look forward to applying the physics that I've learned at Yale to my work for the Fellowship, and to bringing the Fellowship's issues and approaches to the Yale Physics community."

At Yale, Weiss created and leads the Kimball Smith Series (*see p. 64*), a program that tackles issues at the intersection of science and global affairs—ranging from nuclear weapons risks to artificial intelligence policy. Previously, she developed a similar event series for the *Bulletin of the Atomic Scientists*.

Weiss serves as Deputy Director of International Student/Young Pugwash (ISYP), a global network of young professionals who engage in cross-national dialogue on topics in science and security. She has written and spoken on the history of scientific self-regulation, lessons learned from the case of Nazi nuclear physicists, and how the inventors of CRISPR gene editing viewed the ethics of their research.

Pagan hones science communication skills

Wright Lab graduate student Samantha Pagan participated in a workshop called ComSciCon-SciWri2022 to further develop her science communication skills.

According to Pagan, "this consisted of a few days of science writing/journalism workshops, and then we attended the ScienceWriters2022 conference in Memphis, TN."

Pagan continued, "during ScienceWriters2022, all ComSciCon-SciWri2022 participants were assigned to a conference session to cover in a news story for the Council for the Advancement of Science Writing (CASW) website. It was a fun and very helpful experience!"

The article Pagan composed during the experience is called "Data visualization reveals hidden wonders from telescopes".

Connecting science and the arts and humanities

Wright Lab has a legacy of connecting art and science through exhibits and programming to educate, inspire, entertain, enrich, and engage people of varied ages and backgrounds, including:

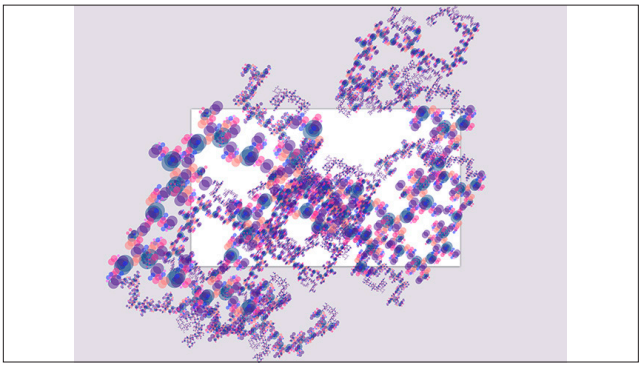
Visualize Science Competition

In April 2024, artists and scientists convened at the Yale Center for Collaborative Arts and Media (CCAM) for the third iteration of the Visualize Science contest; co-sponsored by Wright Lab, CCAM and YQI. The objective is for teams of artists and scientists to work together to create a conceptual model of a scientific concept, and realize it in either two- or three-dimensional format using materials provided for the competition. The concept chosen for this year's competition was dark matter. See: wlab.yale.edu/visualize for more info.

From Stars to Strokes: The Art of Physics

In December 2023, fifteen local high school students from Yale Pathways to Science came to Wright Lab to participate in a unique intersection of art and physics.

Celín Hidalgo, Wright Lab DOE research trainee, led the students in a half day event where they created multi-tiered painted "clocks of time" that represented the history of the Universe in conversation with the history of art.



Flor's work featured in "Data as Art" exhibition at Yale Medical Library

Art created by Fernando Flor, NSF MPS-Ascend postdoctoral fellow in physics and a member of Yale's Wright Lab, was on exhibit at the Yale Harvey Cushing/John Hay Whitney Medical Library in 2024. According to Flor, his work "Copy of a..." shows the relative yields of final state hadrons emerging out of central Pb-Pb Collisions recorded by the ALICE detector at center-of-mass energy of 5.02 TeV."

Wright Lab featured in School of Art thesis project

Tanner Pendleton, MFA Candidate at the Yale School of Art, photographed some rarely seen spaces of Wright Lab for a thesis project.

Discover more at wlab.yale.edu/media/arts

Ahn uncovers history of physics as Yale Presidential Visiting Fellow

Eun-Joo Ahn, lecturer in physics, 2023-24 Yale Presidential Visiting Fellow, and a member of Yale's Wright Lab, is an astrophysicist and historian of science. She received her Ph.D. in astronomy and astrophysics from the University of Chicago in 2006 with the thesis "Early stages of ultra high energy cosmic ray air showers as a diagnostic of exotic primaries" and a second Ph.D. in History from the University of California Santa Barbara in 2023 with the thesis "Factory Observatory at Mount Wilson: Astronomy, Regional Development, and Place, 1900-1930."

Ahn came to Yale in 2023 as a postdoctoral associate in the Yale Center for the Study of Race, Indigeneity, and Transnational Migration with a joint appointment in physics, and has since been appointed lecturer in physics. She taught the Yale College course "Asian Americans and STEM" in Fall 2023 and Fall 2024 and is preparing a new course, "History of Physics at Yale". In addition to teaching courses, Ahn has been engaged in uncovering the history of Yale's Wright Lab and physics at Yale, with several projects underway.

WNSL archiving projects

From 1985-1987, the Wright Nuclear Structure Laboratory (WNSL, now known as Wright Lab) upgraded its MP-1 tandem van de Graff accelerator to become the Extended Stretched TransUranium (ESTU) accelerator. The conversion made the ESTU the most powerful stand-alone tandem accelerator in the world until the end of its operation in 2011. The research at today's new facilities for the study of exotic unstable nuclei is an outgrowth of earlier studies with these advanced tandem accelerators, and relativistic heavy ion accelerators have a parentage in machines like Yale's tandem.

Peter Parker, professor *Emeritus* of physics, who was the associate director of WNSL during the upgrade, and later its director, documented the upgrade process by taking and labelling almost 3,000 photographs. Ahn is now cataloging and describing these photographs, which eventually will be reposited at the University Archives, in collaboration with Parker, as well as Jeff Ashenfelter (Wright Lab associate director of operations) and Frank Lopez (Wright Lab research and development technician), who also worked at WNSL as head of accelerator operations and accelerator operator/research and development technician, respectively. Ahn plans to use these photographs to prepare a photo essay of the 1985-87 accelerator upgrade and to write a scholarly article.

Ahn explained that this project intrigued her because it is demonstrating "science in action," and that the organized photograph collection enables the story to unfold, enhanced by the commentary provided by the people who were there to see it happen.

Ahn further explained that this project allows for a "better understanding of how the science of high energy physics and nuclear physics evolved in the United States in the twentieth century". She said, "the existing history of science narrative, especially in these fields, mostly follows the research of national laboratories after the second World War, with the universities and other smaller laboratories providing the manpower," but she has learned that the history of WNSL is "challenging this narrative".

She said, "I didn't know before how prominent WNSL was [in this time period]. D. Allan Bromley, the director of WNSL, developed the original accelerator and its upgrade, and was able to implement it here."

In tandem with the photograph project, Ahn is also preparing documents that span the entire history of WNSL for the archive, including lecture notes, course syllabi, computer logbooks, and correspondences.

Oral history project

Ahn received a grant from the American Institute of Physics (AIP) to interview Parker during Spring 2024, with a transcript available on the AIP website.

AIP Oral History Interviews offer unique insights into the lives, works, and personalities of modern scientists. Interviews range in date from the early 1960s to the present and cover the major areas and discoveries of physics from the past 100 years. Thirty-eight former and current affiliates of Yale have been interviewed thus far, including Wright Lab members Richard Casten, Sarah Demers, Reina Maruyama, and Parker.

Yale Physics administrative hallway project

Ahn is also working to develop an exhibit that is a timeline of the history of physics at Yale, to be installed in the hallway by the administrative offices of the Sloane Physics Laboratory.

Ahn plans to create an exhibit that is dynamic, inclusive, and not definitive that will contribute to existing studies in the history of physics and find new leads.

Ahn said, "The Yale Physics department is one of the few places in the United States where we can trace how the natural philosophy curriculum of academic institutions in the 1700s changed into today's physics."

Ahn noted that the timeline would not be one long panel, but rather several panels hung separately, to allow for exhibit to change over time.

Ahn said that the plan is to not show the history of the department and the development of physics from natural philosophy as "progressive," as some timelines do, but rather, the exhibit will "provide an opportunity to consider what factors are in play" on each stage of the journey. "What motivated the study of natural philosophy back in the 1700s, and what motivates the study of physics now?"

Ahn's interest in undertaking these projects is "to better understand why we are doing science and physics this way today by learning more about what happened in the past." Through uncovering the history of physics at Yale, building on the work of scholars who have chronicled the history of physics (in particular Suha Gursey) and astronomy (Dorrit Hoffleit and William F. van Altena) at Yale and the Yale and Slavery Research Project (David W. Blight, et al), she has also developed her appreciation for the University. Ahn said, "Yale is not just a fancy name to me now. It became more personal, and I got to understand Yale better."

APC Spotlight: The New Haven Harbor Living Laboratory

James Nikkel, research scientist and director of the Wright Lab Advanced Prototyping Center (APC), and his collaborators in the APC, the Yale School of the Environment, and The Sound School-New Haven Public Schools have, with the support of a seed grant awarded by the Yale Planetary Solutions Project, been expanding and enhancing the Sound School's artificial oyster reef in a New Haven harbor in the City Point neighborhood in order to develop and implement solutions to three current challenges for our planet: pollution, climate change, and loss of biodiversity.

The reef contributes to addressing these challenges by improving local water quality through filtration by the oysters, decreasing the effects of increased storm and wave action, and increasing local biodiversity by providing additional habitat and nursery areas for a multitude of species. Furthermore, the reef provides a "living laboratory" that both Sound School and Yale students and scientists can use to study the impacts of artificial reef building on CO_2 chemistry, biodiversity, and eutrophication in the New Haven Harbor.

In addition to Nikkel, collaborators include Arina Telles, graduate student in physics and deputy director of the APC; Peter Raymond, professor of ecosystem ecology at Yale; Peter Solomon and Nicole Bouve, aquaculture science teachers at The Sound School; and John Buell, chair of the Sound School-New Haven Harbor Foundation.

Building up the reef

The reef project was begun by The Sound School in the Fall of 2016, and a temporary reef was approved by CT DEEP in 2017. The school created a prototype reef with 10 reef balls (artificial reef modules, designed to mimic natural reefs; placed in the ocean to provide habitat structure for reef growth), but needed a permit for the reef to remain as a permanent structure.

In 2022, the Yale Planetary Solutions Project awarded the seed grant to Buell, Nikkel, Raymond, and Solomon to support the work needed to go through the legal process to acquire a permit for the reef and continue the project. The permit was approved, and the fabrication and installation of 17 additional reef balls by a small cohort of students, teachers and scientists began in July of 2023 during The Sound School's summer program. The current reef was also monitored for oyster density and size distribution.

Three days a week, the group would sample the water in different places and produce 100-kilogram concrete oyster reef balls. Each ball took a few hours to make using a mold on site at the school. The balls were then left for the concrete to set overnight; then taken out of the mold and left outside to air dry for a few weeks until the ball was hard enough to deploy.

The group, including Nikkel and Telles, would also dive once or twice a week to do surveys and measure the life in the reef area, near the

reef, and on some control sites 100-meters away. The control sites have no reef balls and low biodiversity, because the area is mostly mud flats, so there are no structures for oysters or other life to cling to. Adding the reef balls allows the shellfish and other life forms to establish residence.

The group reported that they have observed clear signs of increased biodiversity on the current reef area and expect that to increase as the reef continues to expand.

Nikkel said, "We are not just providing a place for the oysters, but a breakwater area. A place for little crabs and eels and all sorts of animals living around these structures. It provides them a little safety from other predators."

Enabling long-term data acquisition and visibility of reef balls at the APC

Nikkel and Telles worked on a combination of developing and customizing off-the-shelf instrumentation for students and scientists to be able to study the impacts of the reef. They developed and fabricated a standard data acquisition package that was placed on a buoy near the reef with sensors providing real-time environmental data that is important for understanding life in the reef, such as water temperature, water quality, pH, salinity, dissolved oxygen, and water depth.

Nikkel explained that the scientists who study water quality at Yale generally make a one-time water collection or send out a probe for a day and make intensive measurements from this data, but the reef study needs more long-term data collection. The instruments, therefore, were made to be durable; to be left out for months collecting data, with uploads in real time.

There are challenges to leaving instruments out long term, including the growth of phytoplankton in the area, which are the primary food for oysters, and precisely measuring turbidity. Nikkel and Telles have been working through these challenges in their instrumentation development.

Nikkel and Telles also made individual tags for the oyster balls at the APC. Nikkel said, "In the New Haven Harbor, visibility is typically low, and you will eventually have a big field of 100 oyster balls 1.5-meters apart. If I am diving down there to measure a particular ball, I would not know where I am, so we have made a very tactile oyster-shaped tag."

Future considerations and opportunities

Nikkel said that the concrete reef balls that the group is making will be essentially permanent structures, especially in the current area of mud flats—where a natural reef is unlikely to grow on its own—but there is some interest to consider developing structures that will dissolve in areas where a natural reef will build up around it over time.

Additionally, the group found that, in the underwater surveys, considerably higher species diversity and abundance was found on the reef than on the control site. However, the oyster population itself does not currently appear to be self-sustaining. Due to the limited size of the current reef, the group suspects that high predation and low recruitment is preventing the oyster population from stabilizing and suggests that increasing the size of the reef with additional broodstock will address this.

Nikkel said that the New Haven Living Laboratory is a long-term Sound School project and is "an interesting local opportunity for University researchers to be involved with, with the ability to provide small, well-defined projects for students to participate in research".

APC Spotlight: Atmospheric CO_2 monitoring

In 2023, Wright Lab research scientist James Nikkel and the Wright Lab Advanced Prototyping Center (APC) were awarded, along with their collaborators, a Yale Planetary Solutions Project seed grant for their project on atmospheric CO_2 monitoring called "Deployment of a Low-Cost Sensor Network to Measure CO_2 Emissions and Pollution Exposure Across the City of New Haven". Wright Lab graduate student and APC deputy director Arina Telles is leading the instrumentation effort for the project. This is the second seed grant that Nikkel and the APC have been awarded by the Planetary Solutions Project (*see also p. 75*).

The project aims to create a reliable and accurate network of low-cost CO_2 sensors throughout New Haven. The APC is making sensor packages to measure CO_2, temperature, pressure, and humidity, and then transmit the data to a database for storage and analysis.

Telles has been working with the environmental scientists to instrument a variety of sensors and create weather-proof enclosures to test them outside. According to Telles, ensuring reliability of the sensor packages has been a challenge, since each low-cost sensor has its own interface and requires extensive testing to find and correct failure modes. As of now, they have a dozen sensors running in both environmental chambers and outdoor tests to calibrate their behavior and prepare for more widespread outdoor deployment.

The Planetary Solutions Project seed grant program distributed over $1.5 million to 23 projects building novel solutions to improve human health in a changing climate, capture carbon more efficiently, cool our cities, and enhance the ability of plants and animals to thrive in 2023.

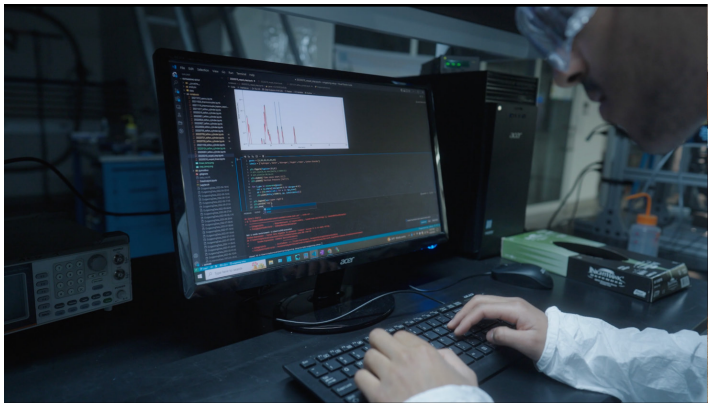
More information about the project is below.

Deployment of a Low-Cost Sensor Network to Measure CO_2 Emissions and Pollution Exposure Across the City of New Haven

Participants: Xuhui Lee, Yale School of the Environment; Drew Gentner, Department of Chemical and Environmental Engineering; Peter Raymond, Yale School of the Environment; James Nikkel, Wright Laboratory; Ravish Dubey, Yale School of the Environment

Cities are hotspots for carbon dioxide (CO_2) emissions, which drive climate change, and particulate matter air pollution, which causes respiratory and heart problems. In cities, these two types of pollution are highly correlated due to fossil fuel combustion. CO_2 emissions are generally measured at the country level, making the data too coarse to inform local climate mitigation actions. This team is developing low-cost Internet-of-Things sensors to measure outdoor air. They will monitor CO_2 and particulate emissions in and around New Haven, quantifying air pollution exposure in different neighborhoods and examining correlations between exposure, demographics, and socioeconomics. Their technical innovations could be deployed in cities worldwide, providing useful data to help city planners understand the sources and effects of emissions.

Computing



The goal of research computing at Wright Lab is to provide an open, secure, and reliable environment for its community of researchers and their global collaborators. Basic large-scale computation on several of Yale's compute clusters are available free of charge for researchers and students. Wright Lab also has a number of computing resources on-site and through partnership with the Yale Center for Research Computing.

Onsite servers

In the last few years, Wright Lab has deployed a new physical server named in honor of Emmy Noether. With 1TB of RAM and about 225TB of storage capacity this is a powerful local resource.

Collaboration with Yale Center for Research Computing

Wright Lab partners with the Yale Center for Research Computing (YCRC) on novel solutions to the research computing challenges in nuclear, particle, and astrophysics. YCRC operates four primary high-performance computing (HPC) clusters located at Yale's West Campus. YCRC personnel are in residence at Wright Lab, and the Wright Lab community has access to YCRC's HPC facilities, consultation services, training workshops, and support documentation.

Yale recently joined the Massachusetts Green High Performance Computing Center (MGHPCC), a not-for-profit, state-of-the-art data center dedicated to computationally-intensive research. We are pleased to announce our first installation at MGHPCC will be a new HPC cluster called Bouchet. Bouchet is named for Edward Bouchet (1852-1918), the first self-identified African American to earn a doctorate from an American university, a PhD in physics at Yale University in 1876.

The first installation of nodes, approximately 4,000 direct-liquid-cooled cores, will be dedicated to tightly coupled parallel workflows, such as those run in the `mpi` partition on the Grace cluster. Later on this year we will be acquiring and installing a large number of general purpose compute nodes as well as GPU-enabled compute nodes. At that point Bouchet will be available to all Yale researchers for computational work involving low-risk data.

Ultimately, Bouchet is the planned successor to Grace with the majority of HPC infrastructure refreshes and growth deployed at MGHPCC going forward. However, we are still in the early stages of planning that transition and will continue to operate the current Grace cluster.

Portions of the Grace HPC cluster are dedicated to astrophysics research and available to Wright Lab researchers. Grace is ideal for high-throughput or highly parallel work and has 24,000 CPUs, 20+ GPU nodes, and 5 bigmem nodes (1.5 TB RAM); a large collection of installed software modules; and support for custom software builds.

Seraphim McGann

Computing Support

I support the various IT needs of the researchers at Wright Lab. I am also one of the administrators of the lab's physical and cloud servers. This is my first job at a physics lab, although I have had a lifelong interest in science and physics. It will be exciting to see how the Wright Lab continues to develop as construction proceeds. I currently live in my hometown of Hamden. After living on the west coast for about twenty years, it is good to be near family again. I am a member of the Orthodox Church, and I often sing in the choir.

Faculty and Research Areas 2024-2025

Keith Baker
D. Allan Bromley Professor of Physics

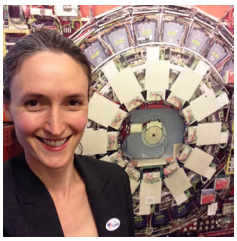
Elementary Particles, Quantum Science & Sensing
ALPHA, ATLAS, Axions, Hidden Sector Photons, Quantum Entanglement

Charles Brown
Assistant Professor of Physics

Astrophysics & Cosmology, Quantum Science & Sensing
ALPHA

Helen Caines
Horace D. Taft Professor of Physics, Director of Graduate Admissions

Relativistic Heavy Ions
STAR, ALICE, EIC



Sarah Demers
Professor of Physics

Elementary Particles
ATLAS, Mu2e

Jack Harris
Professor of Physics

Quantum Science & Sensing

Laura Havener
Assistant Professor of Physics

Relativistic Heavy Ions
ALICE, EIC

Karsten Heeger
Eugene Higgins Professor and Chair of Physics, Director of Wright Lab

Neutrinos & Fundamental Symmetries, Elementary Particles
ALPHA, CUORE/CUPID, DUNE, Project 8, PROSPECT

Steve Lamoreaux
Eugene Higgins Professor of Physics

Astrophysics & Cosmology, Elementary Particles, Quantum Science & Sensing
ALPHA, HAYSTAC

Konrad Lehnert
Eugene Higgins Professor of Physics

Astrophysics & Cosmology, Quantum Science & Sensing
ALPHA, HAYSTAC

Reina Maruyama
Professor of Physics

Neutrinos & Fundamental Symmetries, Astrophysics & Cosmology, Elementary Particles, Quantum Science & Sensing
ALPHA, CUORE/CUPID, COSINE-100, HAYSTAC, RAY

David Moore
Associate Professor of Physics

Neutrinos & Fundamental Symmetries, Quantum Science & Sensing
NEXO, MAST-QG, QuIPS, SIMPLE

Ian Moult
Assistant Professor of Physics

Astrophysics & Cosmology, Elementary Particles, Relativistic Heavy Ions
Theory

Laura Newburgh
Associate Professor of Physics

Astrophysics & Cosmology, Quantum Science & Sensing
CHIME, CMB-S4, HIRAX, Simons Observatory

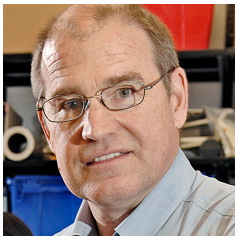
Paul Tipton
Eugene Higgins Professor of Physics

Elementary Particles
ATLAS

Adjunct Faculty

Flavio Cavanna
Professor (Adjunct) of Physics, Fermilab and University of L'Aquila

Neutrinos & Fundamental Symmetries
DUNE, LAr detector R&D



Harvey Moseley
Visiting Fellow, VP Hardware Engineering, Quantum Circuits

Astrophysics & Cosmology, Quantum Physics
COBE, JWST, KAO, SOFIA, Spitzer, Japan's X-ray astronomy

Ornella Palamara
Professor (Adjunct) of Physics, Fermilab and Laboratori Nazionali del Gran Sasso

Neutrinos & Fundamental Symmetries
SBND, DUNE

Sandro Palestini
CERN, Research Affiliate in Physics

Neutrinos & Fundamental Symmetries
DUNE

Jurgen Schukraft
Professor (Adjunct) of Physics and CERN

Relativistic Heavy Ions

Thomas Ullrich
Professor (Adjunct) of Physics and Brookhaven National Laboratory

Relativistic Heavy Ions
EIC

Yale Presidential Visiting Fellow

Eun-Joo Ahn
Lecturer in Physics, Yale Presidential Visiting Fellow

Emeritus Faculty

Charles Baltay
Eugene Higgins Professor Emeritus *of Physics*

Astrophysics & Cosmology
DESI, LS4, QUEST, Roman Space Telescope

Richard Casten
Professor Emeritus *of Physics*

Nuclear Structure

John Harris
D. Allan Bromley Professor Emeritus *of Physics*

Relativistic Heavy Ions
ALICE, EIC, STAR

Francesco Iachello
J.W. Gibbs Professor Emeritus *of Physics, Research Professor*

Neutrinos & Fundamental Symmetries
Theory

Peter Parker
Professor Emeritus *of Physics*

Nuclear Astrophysics

Welcome to new faculty & research scientists

Charles Brown, Assistant Professor

Charles D. Brown II, Ph.D. '19 returned to Yale in 2023 to join the Department of Physics as an assistant professor. Brown has expertise in the generation and measurement of quantum matter in liquid and gas form. He leads an experimental group at Yale that focuses on trapping atoms at nano-Kelvin temperatures in optical lattices to explore how geometry and topology affect emergent properties in exotic quantum materials. Brown is also a part of the ALPHA collaboration (*see p. 11*), using his knowledge of superconducting magnets to aid in the axion search.

Previously, Brown was a postdoctoral fellow at the University of California, Berkeley, where he worked with Dan Stamper-Kurn on experiments with ultracold atomic gasses trapped in optical lattices. Brown received his undergraduate degree from the University of Minnesota and his Ph.D. from Yale. As a graduate student in Jack Harris' group at Wright Lab, Brown performed experiments with superfluid-helium-filled optical cavities and constructed and characterized a new experiment for studying magnetically levitated drops of superfluid helium in vacuum.

Laura Havener, Assistant Professor

On July 1, 2023, Wright Lab welcomed Laura Havener, formerly an associate research scientist in the Wright Lab Relativistic Heavy Ion Group (RHIG), to the Yale Physics faculty as an assistant professor.

Havener's research in high energy nuclear physics focuses on experimentally studying quantum chromodynamics (QCD) using high-energy particle colliders. Specifically, she is interested in understanding the properties and dynamics of the deconfined state of QCD matter called the quark-gluon plasma (QGP), produced in heavy-ion collisions. As a member of the ALICE collaboration at the Large Hadron Collider (LHC), she studies high-energy particles known as jets and how they interact with the QGP. She specializes in using jet substructure techniques to explore the complex structure of jets, revealing the intricate nature of the QGP.

Havener is originally from High Point, North Carolina and received her bachelor's degree in physics from the University of North Carolina at Chapel Hill. She obtained a Ph.D. in physics from Columbia University in 2018 before coming to Yale as a RHIG postdoctoral associate.

Konrad Lehnert, Eugene Higgins Professor of Physics

Konrad Lehnert is a global leader in quantum science and sensing, the fundamental physics of quantum measurements, and the development of quantum technologies based on these concepts. Lehnert is recognized for his exceptionally deep knowledge of the phenomenology of superconductivity and of mesoscopic systems in the quantum context, with particular expertise in quantum noise.

Lehnert is a member of two experimental collaborations searching for the axion candidate of dark matter, HAYSTAC and ALPHA, both located at Wright Lab.

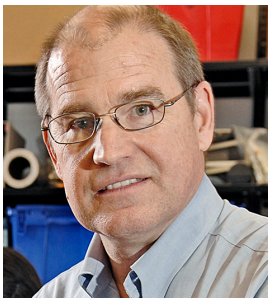
Lehnert previously was a fellow at the Joint Institute for Laboratory Astrophysics (JILA), a joint institute of the University of Colorado and NIST. He served as JILA Chair from 2022- 2024. Prior to his position at JILA, Lehnert was a post-doctoral scientist at Yale from 1999-2003, working with Robert Schoelkopf on qubit structures built from superconducting circuits. He received his Ph.D. in 1999 from the University of California at Santa Barbara.

Ian Moult, Assistant Professor

Ian Moult develops new theoretical frameworks and exploits theoretical advances to enable innovative new experimental strategies.

Moult has been developing new theoretical techniques to improve our understanding of real world collider experiments, with applications in particle and nuclear physics. He has played a leading role in the development of jet substructure, which takes advantage of subtle patterns in the structure of energy flow in collisions at the LHC to maximize the discovery potential for new physics and better understand the theory of the strong interaction. A number of the approaches Moult introduced were first demonstrated in measurements by Wright Lab Relativistic Heavy Ion Group graduate students Andrew Tamis and Ananya Rai.

Moult joined the Yale Physics Department in 2021. Previous to this position, he was a postdoctoral Fellow at SLAC/Stanford (2019-2021) and UC Berkeley/LBL (2016-2019). Moult received a Ph.D. in theoretical particle physics from MIT in 2016, and an undergraduate degree from the University of British Columbia in 2011.



Harvey Moseley, Research Affiliate

Harvey Moseley's career has been focused on conceiving and developing technologies to advance cosmology and astrophysics, and he has long experience with complex systems operating at cryogenic temperatures. In addition to his research affiliate role at Wright Lab, Moseley is currently the Vice President of Hardware Engineering of Quantum Circuits, Inc.

Moseley was a key member of the Cosmic Background Explorer science and development team, whose leaders Mather and Smoot won the 2006 Nobel Physics prize for its groundbreaking measurements of the early universe. Moseley also invented and led the advance of cryogenic X-ray microcalorimeters, which are central to the scientific capability of current and future X-ray astrophysics missions. He led the creation of microshutter arrays that provide multi-object spectroscopy on the James Webb Space Telescope (JWST). This innovation will allow the JWST to study the evolution of the earliest galaxies.

Prakhar Garg, Research Scientist

Prakhar Garg is a research scientist working with the Relativistic Heavy Ion Group (RHIG) at Wright Lab on tracking and particle identification detectors. He is involved in several detector projects, with a focus on Electron Ion Collider (EIC), soon to be under construction at Brookhaven National Laboratory (BNL). Garg is one of the deputy technical coordinators for the ePIC collaboration at EIC and one of the co-coordinators of gaseus detectors in the U.S. R&D Collaborations of CPAD.

He has been involved in the PHENIX experiment at BNL since 2009, and later in the sPHENIX experiment. His research spans various aspects of experimental nuclear physics, including detector R&D, design, construction, and operation. Before coming to Yale, he worked with the experimental Nuclear Physics Group at Stony Brook University as a research scientist and later as a research assistant professor on the construction and R&D of the Time Projection Chamber (TPC) installed at sPHENIX, development of production facility for GEM based trackers to be installed at the MOLLER experiment at Jefferson Lab, and tracker design for PIONEER experiment to be installed at PSI."

Wright Lab people by the numbers (2023-2024)

8	Administrative Staff	**29**	Faculty	**69**	Graduate Students
2	Computing Staff	**11**	Research Scientists	**4**	Postgraduates
16	Technical/Research Support Staff	**19**	Postdocs & Fellows	**56**	Undergraduates

Chris Macias, Associate Research Scientist

Chris Macias' research focuses on neutrino physics, specifically on instrumentation development and integrated systems for charge and scintillation properties of liquid argon.

Macias has been working on the Deep Underground Neutrino Experiment (DUNE) experiment since 2016. His past contribution for the DUNE experiment has been in R&D, commissioning, operations, and data analysis with the Photon Detection system for DUNE's ProtoDUNE-Single Phase. Currently, his focus is helping facilitate the production and R&D for DUNE's Far-Detector-2 Vertical-Drift (FD2-VD). Specifically, R&D on the production and installation on the Charge-Readout-Plane (CRP), as well as planning and preparations for the Yale DUNE-CR P assembly setup at Wright Lab. Further, Chris is working on the technical coordination of prototypes and anode detector components for FD2-VD for DUNE at CERN.

Macias received his undergraduate degree from California State Polytechnic University, Pomona and his PhD from Indiana University. Before coming to Yale, he was a Postdoctoral Research Scholar for The University of Iowa, where he worked on R&D and coordination for the ProtoDUNE experiments, located at CERN.

Welcome to new staff

Adminstrative support team

Monique Ancion, Senior Administrative Assistant

Monique provides administrative support for the NPA Seminars. Monique was previously an Executive Assistant for Steamatic. She also owns an event planning business called Marvelous Moments by Monique, specializing in balloon art and decorations.

Jennifer Arnone, Senior Administrative Assistant

Jenn provides administrative support to the Wright Lab Director. Jenn was previously the Executive Assistant/Director of Operations at Fix and Fashion Team at Keller Williams.

Layla Nayar, Administrative Services Supervisor

Layla supervises the administrative staff and services for the Yale Physics Department. Prior to joining Yale Physics, Layla served as a Senior Administrative Assistant in the School of Medicine and as an Executive Assistant and Project Manager in the marketing industry.

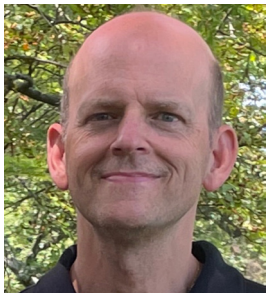
Maria White, Yale Physics Operations Manager

Maria is the Operations Manager for the Yale Physics Department. Prior to joining Yale Physics, Maria served as operations manager and director of budget and finance in the Yale School of Medicine.

Elena Siuzdak, Lead Administrator for Physics and Astronomy

Elena supports Wright Lab research and education by providing support for people, finances, and facilities at Wright Lab. The Lead Administrator monitors department finances, monitors compliance with university and sponsor guidelines, and helps faculty and staff navigate Yale's finance and administration policies and procedures.

Technical support team



Mark Haeckel, Research & Development Technician

Mark was hired in June 2023 as an R&D mechanical technician for the ATLAS project, specifically to help build the 220+ stave cores that will be used in the ATLAS detector at the Large Hadron Collider. Before coming to Yale, Mark worked at a manufacturing company (Schick) in Milford, CT for 20+ years. Mark also has a Bachelor of Arts degree in Marketing.

Jack Lashner, Software Engineer

Jack is a software engineer and physicist who is working with the Newburgh group to deploy the Simons Observatory, a collection or radio telescopes in Chile measuring the intensity and polarization of the Cosmic Microwave Background. Jack's focus is the development of data-acquisition and data-packaging software, in addition to writing and maintaining software used to operate the detector and readout systems.

Brandon Ramirez, Research & Development Technician

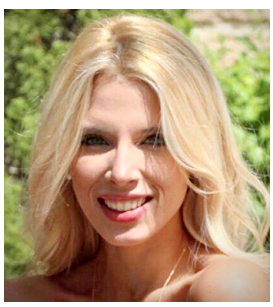
Brandon primarily supports Paul Tipton's ATLAS group, specifically in the fabrication and testing of stave cores, which are the basic building blocks for the high luminosity upgrade of ATLAS's inner tracker detector. The cores provide both mechanical support and thermal management for the associated electronics. Before joining the ATLAS collaboration group, Brandon worked at an automotive performance shop while completing his undergraduate mechanical engineering studies.

Wright Lab staff alumni

The following staff have retired or accepted other positions within the last year.

Camille Simeone
Sr. Administrative Assistant

Taylor Testone
Sr. Administrative Assistant



Samantha Turner
Sr. Administrative Assistant

Vincent Balbarin
YCRC Computer Support

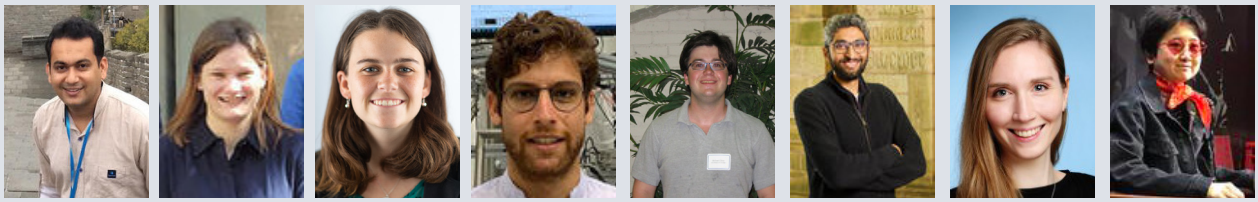
Hannah Carroll
Lead Administrator in Physics

2023-24 Research Scientist Alumni

Domenico Franco
Research Assistant Professor, University of Chicago

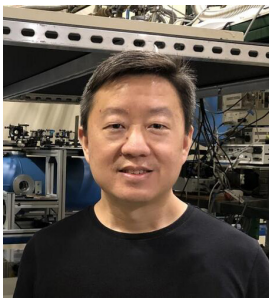
Laura Havener
Assistant Professor, Yale

2023-24 Postdoc Alumni



Govinda Adhikari (Maruyama): Senior Scientist in Radiation Detection, Actinia, Inc.
Caitie Beattie (John Harris): Medical Student, The University of Vermont, Larner College of Medicine
Hannah Bossi: Postdoctoral Researcher, Massachusetts Institute of Technology
Avinay Bhat (Moore): Postdoctoral Research Associate, University of Chicago
Michael Oliver (Caines): Data Science Engineer, Huski.ai
Pranava Teja Surukuchi (Heeger): Assistant Professor, University of Pittsburgh
Sabrina Zacarias (Maruyama): Currently seeking employment in Santa Barbara, CA
Yuqi Zhu (Maruyama): Postdoctoral Associate, Gratta Lab, Stanford University

Postdoc Alum Spotlight: Wei Guo



Dr. Wei Guo, who served as a research scientist and postdoctoral associate for the Daniel N. McKinsey group at Yale Physics from 2008-2012, has been a professor in the Department of Mechanical Engineering at Florida State University (FSU) since 2012; with associate appointments at the National High Magnetic Field Laboratory and the Department of Physics. Guo's research spans quantum fluid dynamics, helium-based dark matter search, cryogenic accelerator physics, quantum-fluid-based qubit R&D, and liquid hydrogen aviation. Guo completed his Ph.D. in physics at Brown University in 2008.

Guo's work has received support from federal agencies such as the National Science Foundation, the United States Department of Energy, NASA, and the Army Research Office, as well as support from national laboratories and industry partners. His contributions to research have garnered him several awards, including the JSPS Invitation Fellowship Award, the Moore Foundation Experimental Physics Investigators Award, and the Outstanding Research Accomplishment Award from the FAMU-FSU College of Engineering. In 2023, he was elected as a Fellow of the American Physical Society in recognition of his contributions to the quantum fluid research field.

Guo was interviewed by Daphne Klemme, senior administrative assistant in physics about how Guo's time at Yale Physics influences his career. Read the article at wlab.yale.edu/news/alumni-spotlight-wei-guo.

Graduate Alumni

Sanah Bhimani '24

Current institution: University of Chicago
Current position: Postdoctoral Research Associate
Dissertation title: *From Site to First Light: OCS Deployment and Defining Detector Quality Metrics for the Simons Observatory SAT-MF1*
Thesis advisor: Laura Newburgh

Varun Jorapur '24

Current institution: Argonne National Laboratory
Current position: Postdoctoral Scientist
Dissertation title: *Towards a Bose-Einstein Condensate of SrF molecules*
Thesis advisors: Steve Lamoreaux & David DeMille

Jakob Kastelic '24

Current institution: Stanford Research Systems
Current position: Instrument Design Engineer/Scientist
Dissertation title: *Search for Time-Reversal-Symmetry Violation in Thallium Fluoride Using a Cryogenic Buffer-Gas Beam Source*
Thesis advisors: Steve Lamoreaux & David DeMille

Tong Liu '24

Current institution: Squarepoint Capital
Current position: Quantitative Researcher
Dissertation title: *Inclusive Hadron Yield Analysis in Small and Mid-sized Collision Systems at √(s_NN)=200 GeV at STAR*
Thesis advisor: Helen Caines

Samantha Pagan '24

Current institution: Foley & Lardner LLP
Current position: Patent Engineer
Dissertation title: *Physics on the keV Energy Scale with CUORE: A Search for Solar Axions*
Thesis advisor: Karsten Heeger

Jingjing Pan '24

Current institution: Postdoctoral Associate
Current position: Brown University
Dissertation title: *Exploring the Standard Model and Beyond Through the Lens of Jet Substructure and Deep Learning with the ATLAS Experiment*
Thesis advisor: Keith Baker

Will Tyndall '24

Current institution: McGill University
Current position: Postdoctoral Associate
Dissertation title: *Drone Calibration Systems for 21 cm Cosmology Experiments*
Thesis advisor: Laura Newburgh

Caitie Beattie '23

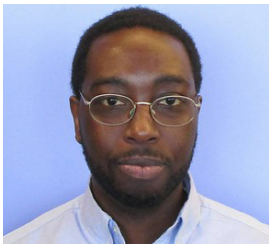
Current institution: The University of Vermont, Larner College of Medicine
Current position: Medical Student
Dissertation title: *Pathlength-dependent jet quenching in the quark--gluon plasma at ALICE*
Thesis advisor: John Harris

Hannah Bossi '23

Current institution: Massachusetts Institute of Technology, BNL
Current position: Postdoctoral Researcher
Dissertation title: *Novel Uses of Machine Learning for Differential Jet Quenching Measurements at the LHC*
Thesis advisor: John Harris

London Cooper-Troendle '23

Current institution: University of Pittsburgh
Current position: Postdoctoral Associate
Dissertation title: *First Measurement of Inclusive Muon Neutrino Charged Current Triple Differential Cross Section on Argon*
Thesis advisor: Bonnie Fleming



Eustace Edwards '23

Current institution: Raytheon Technologies
Current position: Senior Systems Engineer
Dissertation title: *Cold Thallium Fluoride Beam: Buffer Gas Cooling, Beam Production, and $B^3\Pi$ Excited State Hyperfine Spectra*
Thesis advisor: David DeMille

Sumita Ghosh '23

Current institution: Massachusetts Institute of Technology
Current position: Postdoctoral Associate
Dissertation title: *Harnessing HAYSTAC for Hidden Photons and Advancing Rydberg Atom-based Axion Detection*
Thesis advisor: Reina Maruyama

Kaicheng Li '23

Current institution: Uber Technologies, Inc.
Current position: Machine Learning Engineer
Dissertation title: *Low Energy Excess and Anomaly Search with MicroBooNEr*
Thesis advisor: Bonnie Fleming

Daniel Nemes '23

Dissertation title: *Semi-Inclusive Measurement of the Shared Groomed Momentum Fraction of Jets in Au+Au Collisions at STAR*
Thesis advisor: Helen Caines

Lauren Saunders '23

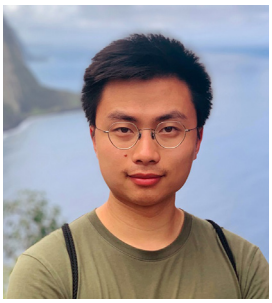
Current institution: Fermilab
Current position: Postdoctoral Research Associate
Dissertation title: *Telescope Pointing for the Simons Observatory: Data Acquisition & Control Software, Calibration, and Modeling*
Thesis advisor: Laura Newburgh

Giacamo Scanavini '23

Current institution: Weill Cornell Medicine
Current position: Postdoctoral Fellow
Dissertation title: *First measurement of neutral current neutral pion production differential cross sections on argon*
Thesis advisor: Bonnie Fleming

Oskari Timgren '23

Current institution: SentiLink
Current position: Sales Support Data Scientist
Dissertation title: *Progress towards a measurement of time-reversal symmetry violation in thallium fluoride*
Thesis advisor: Steve Lamoreaux & David DeMille



Yiqi Wang '23

Current institution: Harvard University
Current positions: HQI Prize Postdoctoral Fellow
Dissertation title: *Manipulating and measuring states of a superfluid optomechanical resonator in the quantum regime*
Thesis advisor: Jack Harris

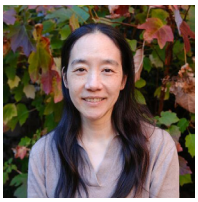
Lucy Yu '23

Dissertation title: *Toward the Quantum Control of the Motional State of Superfluid 4He in a Optomechanical Resonator*
Thesis advisor: Jack Harris

Have you recently switched positions or have other updates to share?

E-mail Wright Lab program manager **victoria.misenti@yale.edu** with your updates.
This information will be used to keep track of our alumni and added to our department database.
The career information will also be updated on our department websites.

Why I do science



"I do science because I want to understand the world. Science matters because it is a way to see our world using reliable knowledge, such as observation and experiment, that can be discussed and verified."— **Eun-Joo Ahn, Lecturer**

"Science matters because it allows us to better understand ourselves, to better understand the world around us, and to better understand the result of the mutual interactions between ourselves and the world. The scientific enterprise—and the knowledge it generates—is thus a critical part of both building and maintaining prosperous societies, and of attaining a greater quality of life for Earth's inhabitants." — **Charles Brown, Assistant Professor**

"Our innovations of recent decades have been like putting on glasses for the first time. People today are seeing the Universe with greater sight than any that came before. This new frontier has only just opened before us; it would be a waste to not explore it. I do physics to be one of the first that gets to see this sight." — **Sophia Hollick, Graduate Student**

"We do science for the same reason we make art—we simply can't help ourselves, and it is what makes us human. While art allows us to translate, understand and communicate the *internal*, science allows us to translate, understand and communicate the *external*. Like a painter's attempt to capture the grandeur of a mountain range in a landscape; a scientist's model to describe the Universe is only our best *approximation* of the world around us. . . Our urge to pursue science despite our limited tools to do so is an expression of our perseverance and drive to find truth. " — **Claire Laffan, Graduate Student**

"I do science for the same reason others play sports, make music, produce art, or raise children—because it's fun, I love doing it, it produces something beautiful, and it makes us human. Physics matters because it often provides simple explanations for what first appear to be vastly different puzzling aspects of nature — think correlations in the locations of galaxies, wavelike cloud formations, ripples on the surface of a pond." — **David Rabinowitz, Senior Research Scientist**

"I do science because I have always been curious about the fundamental nature of the world around me. Science provides the tools to explore the unknown and satisfy that curiosity." — **Tyler D. Stokes, postdoctoral associate**

"Science matters because our quality of life is not normal. We are the first humans to live with the conveniences we have. Sustaining this quality of life requires constant, collaborative scientific efforts. Not only for connecting to digital services, but also for fighting diseases and preventing infant mortality. Science matters because without it, our systems decay and all the comforts we earned in the past century start to become memories rather than moments."— **Anonymous Wright Lab member**

Wright Laboratory

FY2024

145 People in the Wright Lab Community

- 15 Faculty
- 6 Adjunct Faculty
- 5 Faculty *Emeritus*
- 9 Research Scientists
- 12 Postdocs
- 37 Graduate Students
- 32 Undergraduates
- 1 Postgraduate
- 6 Administrative staff
- 14 Technical support staff
- 1 Computing support staff
- 7 Graduate alumni in 2024

33 Awards and Honors

1,469 Publications

10,403 Citations

4 Yale University Machine Shops

- 20 Cranes
- 20 Mills
- 19 Lathes
- 4 Welders
- 3 Permanent clean rooms
- 3 3D printers
- 1 Water jet cutter
- 1 Laser jet cutter

585 Terabytes of Data

- 7 On-site servers
- 98 HPC users
- 6 Critical sites on Spin-Up

116 Events

- 59 Seminars & Journal Clubs
- 6 Dissertation Defenses
- 7 Outreach events
- 3 Workshops/Collaboration meetings
- 1 Wright Lab summer program
- 10 Summer program events

17,362 Flickr Photos

- 78 Videos
- 15 Accelerator pieces installed as art
- 8 Works of art inspired by Wright Lab
- 1 Art-science visualization contest

Wright Lab does research in **9** Countries on **6** Continents

1961 Start of Wright Nuclear Structure Laboratory

2017 Re-opening of transformed Yale Wright Laboratory

2024 Construction begins for Wright Lab Addition

Wright Lab Mission

The mission of Yale Wright Laboratory is to advance understanding of the physical world—from the smallest particles to the evolution of the Universe—by engaging in fundamental research, developing novel instrumentation and research techniques, training a diverse community of future leaders in research and development, educating scholars, promoting the value of science in society, and enabling discovery.

Wright Lab supports belonging, diversity, equity, and inclusion within our community of scientists, staff, and students and fosters cross-disciplinary collaborations across Yale University and worldwide.

What is the invisible Universe made of?

What is dark matter?

What are the properties of neutrinos?

What is the structure of matter?

What drives the evolution of the Universe?

How can we develop new tools to tell us more about the Universe?


wlab.yale.edu