5 Year Report 2017-22

Exploring the Invisible Universe

Yale Wright Laboratory, also known as Wright Lab, is a research facility with a broad research program in experimental nuclear, particle, and astrophysics; with initiatives in instrumentation development and quantum science.

Wright Lab has distinguished itself by advancing the frontiers of fundamental physics, building a vibrant and diverse community, and coordinating active education and outreach programs. This report gives an overview of the exciting research and activities of the program that is now taking place at Wright Lab.

Wright Lab houses a research program affiliated with the Physics Department, as well as several Yale University core facilities that serve researchers across Yale's Science Hill and beyond.

Wright Lab officially opened in May 2017 following the end of the accelerator program at the Wright Nuclear Structure Laboratory (WNSL) in 2011. You can learn more about the legacy and transformation on our website.

Following the pandemic, Wright Lab has returned to its full program of in-person activities, including hosting two successful summer research programs for undergraduates, postgraduates, and high school students. We are excited to welcome new faculty into our research community, and we are building new experiments at Wright Lab and expanding our collaboration and activities in quantum sensing and quantum science.

Instrumentation development is a strong component of the Wright Lab program, which benefits from the existing on-site shop and instrumentation facilities. Wright Lab continues to provide an important role in the pursuit of the University's scientific priorities in instrumentation development.

I invite you to discover Wright Lab in the following pages of this report, on our website at wlab.yale.edu, and in person — we welcome visitors and offer frequent tours to visiting researchers, Yale alumni and the local community of all ages.

--Karsten Heeger, Director

Wright Laboratory

2017-2022

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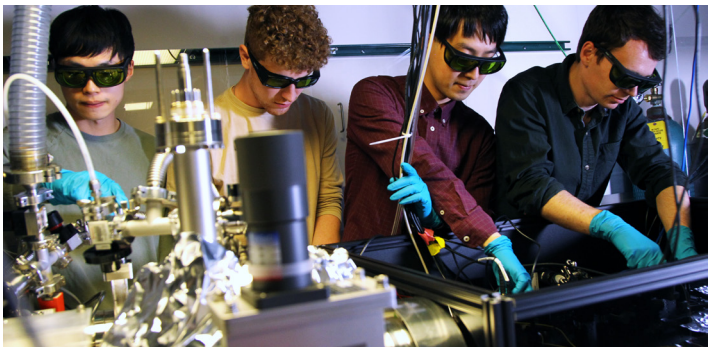
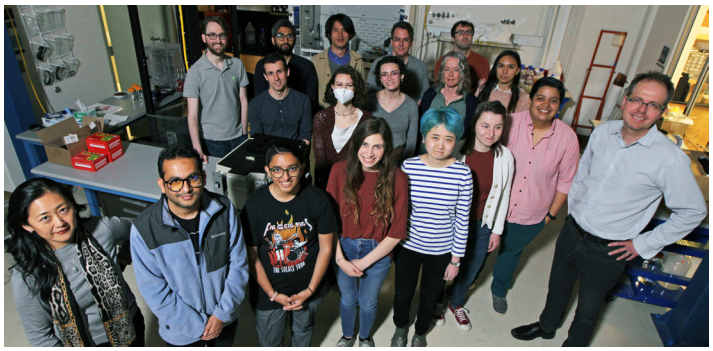
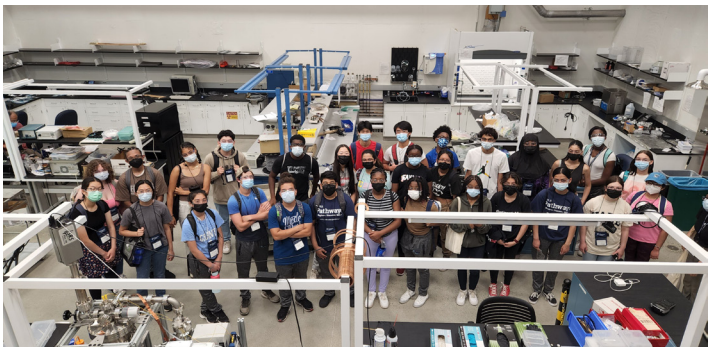
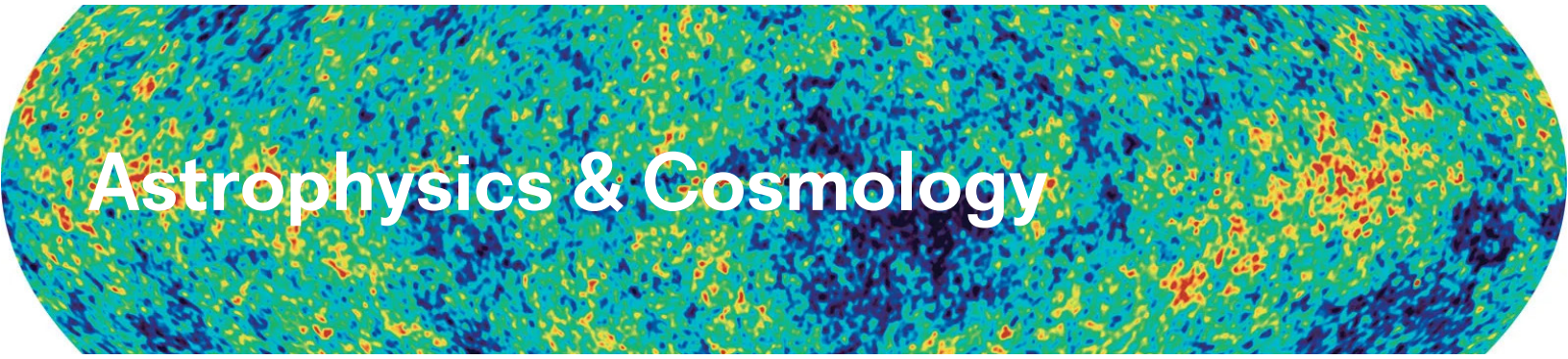
Discover what's in the report









Astrophysics & Cosmology

Searching for dark matter

Dark matter is one of the greatest mysteries in contemporary astrophysical research. By matching theory with observations, scientists believe that approximately 80% of the matter in the Universe is composed of dark matter, yet researchers have been unable to directly detect dark matter, and the nature of this substance is unknown. A worldwide effort, including experiments led by Wright Lab researchers, is underway to detect dark matter and investigate its properties. (*See also pp. 19-21 for information about Wright Lab's quantum search for dark matter.*)

DM-ICE& COSINE-100

Reina Maruyama, PI; Govinda Adhikari, postdoc; Eleanor Graham and Sophia Hollick, graduate students

DM-Ice is a direct-detection dark matter experiment designed to test the DAMA Collaboration's claim that they have made a direct detection of dark matter with their thallium-doped sodium iodide (NaI(Tl)) detectors. DM-Ice aims to understand the origin of DAMA's signal and search for their reported annual modulation signature by using the same target and detector material.

DM-Ice is a phased experimental program; the first phase was located at the NSF South Pole Station and the current phase, called COSINE-100, has been running since Fall 2016 at the Yangyang Underground Laboratory (Y2L) in South Korea. It is the only dark matter experiment with access to both Northern and Southern Hemispheres.

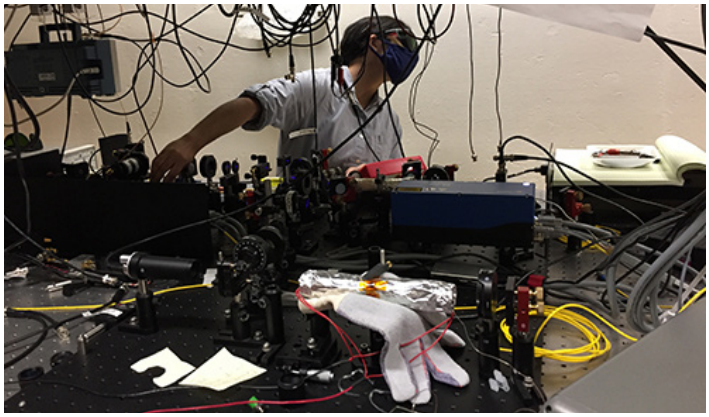
Maruyama is the Principal Investigator of COSINE-100 and the scientific co-spokesperson of the experiment. Alumni since 2017 include postdoctoral associate J. H. Jo, graduate students E. Barbosa de Souza and W. Thompson, and undergraduate students L. Chambers, J. Gunderson, D. Heimsoth, and E. Ruddy.

Results of COSINE-100 improve understanding of how to search for dark matter

Wright Lab scientists and their collaborators, led by postdoc Govinda Adhikari, have analyzed three years of data from the COSINE-100 experiment.

Their paper (Phys. Rev. D 2022), discusses the dark matter searching techniques in the form of an annual modulation signature, featuring improved event discrimination that allows for lowering the energy threshold and improving the experimental sensitivity. The result is consistent with both DAMA-observed annual modulation and no modulation with 3 years of data. The paper suggests larger exposure and improved analysis techniques to continue searching for the direct detection of dark matter.

Searching for dark matter



RAY

Reina Maruyama, PI; Sid Cahn, senior research scientist; Yuqi Zhu, postdoctoral associate; Sumita Ghosh and Eleanor Graham, graduate students; and Elsa Durcan, undergraduate

To extend the mass range accessible by axion search experiments (*see HAYSTAC, p. 19*), the Rydberg Atom at Yale (RAY) group is developing Rydberg atom-based photon sensing detection scheme for axion searches.

Alumni since 2017 include postdoctoral associate D. Speller; undergraduates S. Getz, A. Giman, A. Zheng, L. Zhou; and high school student A. Srivastava.

Transformative Research at the South Pole

Professor Reina Maruyama's research has taken her to the South Pole twice to work on the international physics projects IceCube and DM-Ice. The South Pole is perfect for such activities because the experiments require a thick covering of rock or soil to shield cosmic rays, and large areas of stable, transparent material, such as ice, in order to detect the light given off during particle interactions.

In a 2022 interview for the Heising-Simons Foundation's "1400 degrees," Maruyama said creating and leading DM-Ice "made me want to continue doing physics. It was with DM-Ice that my various expertise merged, and I was the only person who could lead that experiment. That, and my experience of working with a phenomenal team of engineers, managers, and physicists was really exciting. It felt like we were playing music; that everybody was in sync—it gave me goosebumps."

IceCube

Reina Maruyama, PI

IceCube is the world's largest neutrino detector, encompassing a cubic kilometer of ice at depths between 1,450 and 2,450 meters at the South Pole. IceCube uses 5160 photomultiplier tubes (PMTs) to search for neutrinos from the most violent astrophysical sources: events like exploding stars, gamma-ray bursts, and cataclysmic phenomena involving black holes and neutron stars. IceCube is a powerful tool to search for dark matter and could reveal the physical processes associated with the enigmatic origin of the highest energy particles in nature. In addition, IceCube studies the neutrinos themselves.

The main goal of the experiment is to detect neutrinos in the high energy range. Maruyama's focus is in the low energies. In this range, IceCube can detect neutrinos coming from nearby supernovae. The Maruyama group studies how supernovae explode as well as fundamental properties of neutrinos. With the addition of DeepCore, the group can study atmospheric neutrino oscillation and dark matter collected in the Sun, Earth, and the Galactic Center.

Jim Haugen

Investigating the expansion of the Universe

HIRAX

Laura Newburgh, PI; Brian Koopman, postdoctoral associate; Lauren Saunders, Will Tyndall, grad students

The Hydrogen Intensity and Real-Time Analysis eXperiment (HIRAX) is an upcoming interferometric array of 256 6m radio dishes, to be located in South Africa. It will study high-redshift large-scale structure for a constraint on Dark Energy, and transient science to understand the nature of fast radio bursts.

The Newburgh group is involved in measuring the beam shape of HIRAX. One of the techniques possible for HIRAX is mapping the beam shape with a quadcopter drone. Newburgh is leading the team developing the hardware and analysis for this aim.

Alumni since 2017 include postdoctoral associate B. Saliwanchik; graduate student E. Kuhn; and undergraduate E. Smith.

Science Highlights from the Newburgh Group

- **Brian Koopman** published an overview of the group's data acquisition and control framework
- **Emily Kuhn, Ph.D.'22** published both her work on measurements in a 'vat' she built at Wright Lab to assess noise temperature and also on antenna properties for the HIRAX antennae
- **Ben Saliwanchik** published a paper on the HIRAX dish design and requirements
- **Lauren Saunder**s published her work writing and developing the software to control telescope platforms
- **Will Tyndall** was the second author on a paper that used simulations to assess timing and signal-to-noise requirements for a new digital calibration source we're collaborating on with collaborators at West Virginia University

Drone Calibration

Laura Newburgh, PI; Will Tyndall, graduate student; and Audrey Cesene, Spencer Greenfield, Ana Maria Melián, and Audrey Whitmer, undergraduates

The Newburgh group is involved in research and development on techniques and equipment to map the beam shape of radio telescopes with a quadcopter drone.

The team has tested drone calibration in several locations, including the Greenbank Observatory in West Virginia; Brookhaven National Laboratory on Long Island, and at Wright Lab in New Haven, CT.

Alumni since 2017 include postdoctoral associate B. Saliwanchik; graduate students E. Kuhn, A. Polzin; undergraduates M. Harris, A. Polish, and R. Walker.

Investigating the expansion of the Universe

CHIME

Laura Newburgh, PI; Pranav Sanghavi, postdoctoral associate; and Alex Reda, graduate student

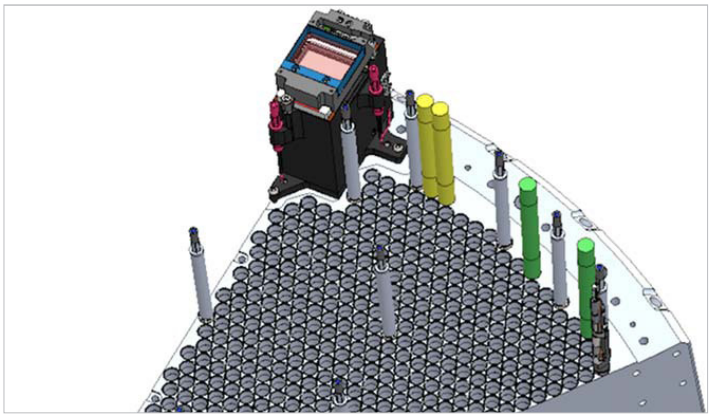
The Canadian Hydrogen Intensity Mapping Experiment (CHIME) is radio interferometer telescope with a set of 4 cylindrical dishes, each 100m long x 20m wide, located at the Dominion Radio Astrophysical Observatory (DRAO) in British Columbia, Canada. Data will be processed to form a 3-dimensional map of hydrogen density, which will be used to measure the expansion history of the universe and discover insights about Dark Energy, a mysterious component that makes up ~72% of the energy density of the Universe and is causing the expansion of the Universe to accelerate.

The Newburgh group uses a technique known as holography to map the beam shape of the CHIME instrument. This instrument characterization is critical to remove interloper emission from other sources.

Alumni since 2017 include undergraduates D. Eggerman, A. Murray, M. Pradier, S. Ramanathan, W. Wilson.

CHIME makes breakthroughs in understanding fast radio bursts

In 2019, CHIME reported in "Nature" the discovery of a fast radio burst (FRB) that pulses at regular intervals from a nearby galaxy; demonstrating the first evidence that some FRBs repeat regularly. A second repeating FRB discovery by CHIME followed. Another CHIME paper in 2020 posits that magnetars, a type of neutron star with a powerful magnetic field, could be the source of some FRBs. For her contribution to these results, assistant professor Laura Newburgh shared the 2022 Berkeley Prize with her CHIME collaborators.



DESI

Charlie Baltay, PI; David Rabinowitz, senior research scientist; Will Emmet, senior mechanical engineer; and Forrest Hutchison, undergraduate

The Baltay group is a founding partner of the DESI (Dark Energy Spectroscopic Instrument) project. This project has been designed to measure the distance (via their redshift) and thus a three-dimensional distribution of a large number of galaxies in the universe. Such a spatial distribution of galaxies will provide important constraints on the nature of Dark Energy, different but complementary to the information that comes from the supernova surveys. Since these cosmological measurements are so difficult, and the questions asked are of such fundamental importance, it is of great value to have several independent methods of measurements of the basic parameters involved.

The DESI project uses the 4m Mayall telescope at Kitt Peak Observatory in Arizona, with a spectroscopic instrument designed and built by the DESI Collaboration.

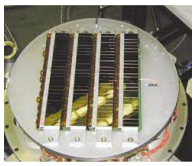
The Yale group designed and built the Fiber View Camera System that enables the instrument to place the fibers leading to the spectrometers at the position of the target galaxies with sufficient precision to obtain the desired spectra of the galaxies that lead to the redshift, and thus the distance measurements of the galaxies.

Investigating the expansion of the Universe

Southern Hemisphere Supernova Surveys

Charlie Baltay, PI; David Rabinowitz, senior research scientist; Will Emmet, senior mechanical engineer; and Tom Hurteau, research and development technician

Supernovae are stars exploding at the end of their lifetimes. They are very bright, even outshining the galaxies they are in, and can thus be seen at distances half way across the universe. Comparing the properties of the light emitted by very distant supernovae with that of very near supernovae tells us about the expansion history of the Universe, and thus the desired properties of the Dark Energy that drives this accelerated expansion.

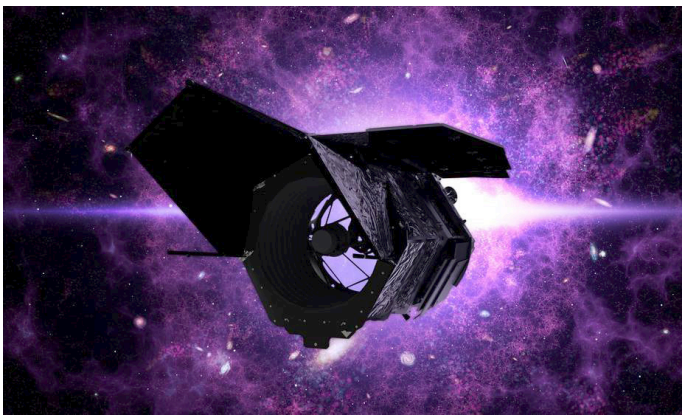


The La Silla QUEST Southern Hemisphere Supernova Survey (QUEST), utilized the QUEST camera, which covered the full field of view of the 40" European Southern Observatory (ESO) Schmidt Telescope at the La Silla Observatory in Chile to observe a large sample of bright nearby supernovae.

The QUEST camera (silicon detector instrumentation) was designed and built at Yale and Indiana University, and the Baltay group carried out the QUEST survey, now complete. The group obtained a large sample of supernovae, now published, from this survey.

The Baltay group is now upgrading the QUEST camera to have twice the aerial coverage on the sky with more modern silicon detectors for the future "LS4" survey, with several international collaborating groups to exploit the very rich data set that will be obtained in the survey.

Alumni since 2017 include undergraduates N. Barbour. L. Grossman, K. Ment, R. Montesi, and K. Sato.



Nancy Grace Roman Space Telescope Mission

Charlie Baltay, PI; David Rabinowitz, senior research scientist

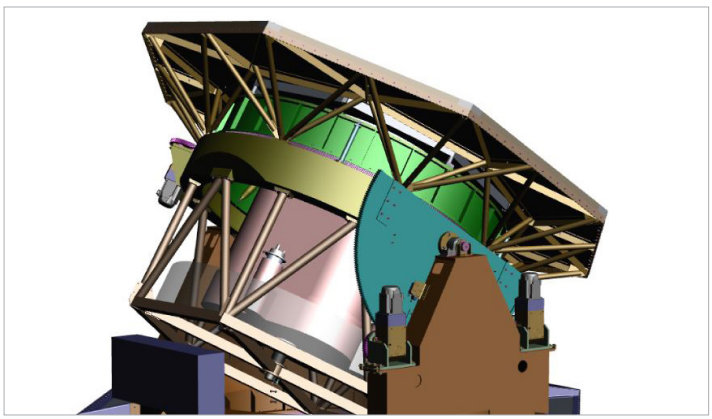
A collaboration of university groups, including Yale, proposed an experiment called SNAP (SuperNova Acceleration Probe), which was selected by NASA as their highest priority next major space observatory, the Wide Field Infrared Survey Telescope (WFIRST); eventually renamed the Nancy Grace Roman Space mission. It consists of a 2.4 meter optical telescope with a wide field optical/near infrared photon detector and a prism spectrometer.

Baltay was part of NASA's Science Definition Team to design the mission, and chaired it for several years. Baltay was deputy PI, along with Saul Perlmutter, for the design of the supernova survey and its instrumentation. The design team has completed its design work and submitted its detailed Design Report. NASA is now well into the construction of the mission, with a launch expected in 2026. The Yale group, in collaboration with other university and observatory groups, is now developing the algorithms and the required software packages to analyze the data as quickly as possible as soon as it arrives.

The Roman telescope will enable the Baltay group to observe far away, faint supernovae outside of Earth's obscuring atmosphere and, in combination with the information gained from their southern hemisphere supernova surveys, provide important new information about the nature of the mysterious acceleration of the expansion of our Universe and Dark Energy.

Alumni since 2017 include undergraduate and postgraduate R. Howard.

Probing the beginnings of the Universe



Simons Observatory

Laura Newburgh, PI; Brian Koopman, associate research scientist; Jack Lashner, software engineer; and Sanah Bhimani, David Nguyen, and Lauren Saunders, graduate students

Simons Observatory (SO) is a new millimeter observatory, designed to make the most sensitive measurements of the Cosmic Microwave Background (CMB), light the Universe emitted when it was 400,000 years old. SO will consist of four new telescopes in the Atacama desert in Northern Chile: one 6m diameter dish and three 0.5m refractor telescopes.

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

Alumni since 2017 include undergraduates S. Day-Weiss, N. Kerman, and S. Tsai; and visiting undergraduates J. Guo and A. Karanam.

CMB-S4

Laura Newburgh, PI; Brian Koopman, associate research scientist and Sanah Bhimani and Lauren Saunders, graduate students

CMB-S4 is a 2030-era observatory sited in the South Pole and Chile. It will make measurements of the Cosmic Microwave Background (CMB), with an order of magnitude or more detectors than any current experiment. The collaboration brings together members of the CMB community from across all major experiments in the field.

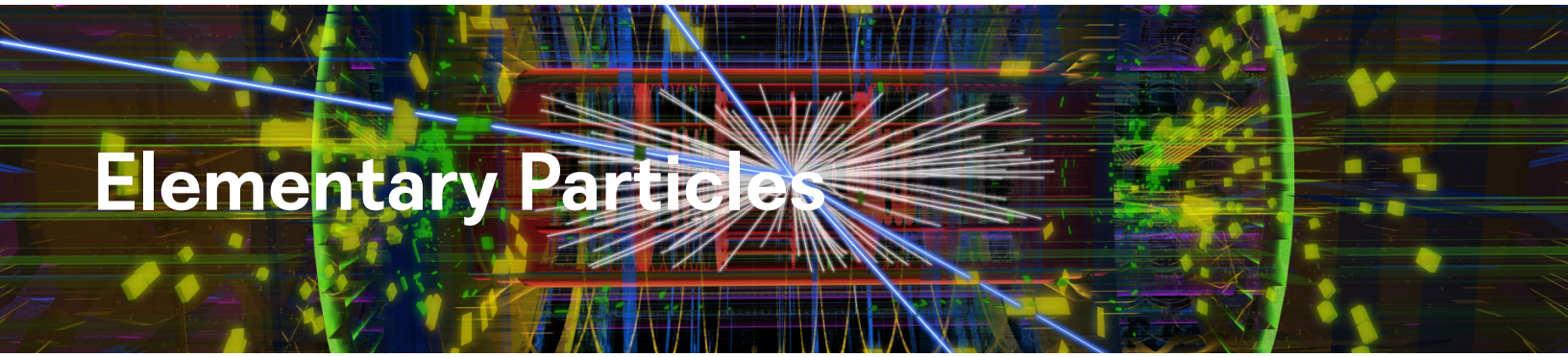
Newburgh leads the data acquisition and control group, mainly building software to control and acquire data from the telescopes.

Alumni since 2017 include postdoctoral associate B. Saliwanchik.

Atacama Cosmology Telescope

Laura Newburgh, PI; Brian Koopman associate research scientist

The Atacama Cosmology Telescope (ACT) is a 6m radio telescope dish located in the Atacama Desert in Northern Chile. The Yale team used the telescope to make high resolution measurements of the Cosmic Microwave Background (CMB), which is the relic light from the Universe when it was ~380,000 years old. Measurements of the CMB have been a workhorse in precision cosmology, constraining parameters like the geometry of the Universe and its constituents (dark matter, baryonic matter, neutrinos, dark energy), and provide the high-precision measurements required for additional constraints from Large Scale Structure.



Elementary Particles

Exploring the fundamental nature of the Universe

Wright Lab researchers question existing scientific models of the physical Universe and search for new understanding of how the Universe works, discovering new particles and investigating new aspects of space and time.

ATLAS

O. Keith Baker, Sarah Demers, and Paul Tipton, PIs

ATLAS is one of two general-purpose detectors at the Large Hadron Collider (LHC), located at the Center for European Nuclear Research (CERN) in Geneva, Switzerland. The ATLAS collaboration is a collection of ~3500 collaborators from ~33 different countries. Yale's involvement dates back two decades, since its initial planning phase, and Yale is part of the ATLAS leadership in physics, operations and the upgrade.

The LHC is at the energy frontier of science; it is where we are most likely to produce new particles or measure the effects of new forces. It investigates a wide range of physics, from the search for the Higgs boson to extra dimensions & particles that could make up dark matter.

ATLAS data has contributed to well over 1000 scientific publications, including the joint discovery of the Higgs Boson in 2012. Baker, Demers, and Tipton all played a role in the confirmation of the Higgs Boson, and they all continue to investigate the new physics made possible by this discovery with ATLAS.

Keith Baker group

O. Keith Baker, PI; Jingjing Pan, Nathan Suri, Mira Varma, graduate students; Argyris Manes, undergraduate

The Baker ATLAS Group sets new limits on searches for physics that are beyond the standard model of particle physics in the following areas:

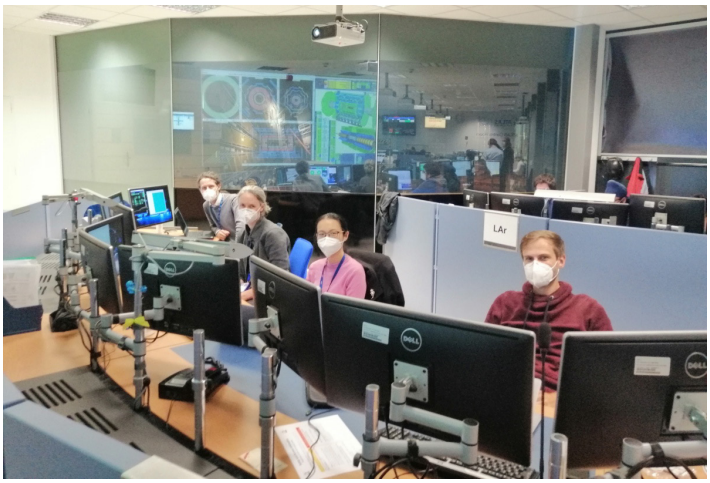
(i) Quantum entanglement in Higgs boson decays, entanglement entropy in high energy physics, and quantum information science at high energies. The group also demonstrates applications of machine learning, quantum computing, and quantum algorithms in particle physics analyses at high energies. In this way, we are showing how this can be applied to better understand certain anomalies in the data from high energy particle physics experiments.

(ii) Making use of the Higgs boson as a possible portal to new physical phenomena that is undetectable by other Standard Model means. An example is our searches for dark sector physics (dark matter, dark force carriers) and other aspects of nature that are not clearly understood.

(iii) Research and development of monolithic CMOS silicon sensors for use in high energy physics. This makes use of Field Programmable Gate Arrays (FPGA's) and appropriate software such as Finite Element Analysis, as well as analysis programs and programming tools. The group has additionally made use of the low energy proton accelerator in the Sloane Physics Lab at Yale.

Alumni since 2017 include graduate student C. Weber; undergraduates V. Da Silva, M. Durogene, A. Gagliardi, G. Iskander, M. Ogego, D. Qenani, M. Tyler, W. Wilson.

Exploring the fundamental nature of the Universe



Sarah Demers group

ATLAS

Sarah Demers, PI; Gianantonio Pezzullo, associate research scientist; Jesse Farr, Runze Li, Gregory Penn, graduate students; Caitlin Gainey, Alexandra Haslund-Gourley, Matthew Murphy, Dawson Thomas, undergraduates

The interactions in the ATLAS detectors create an enormous flow of data. To reduce the data volume, ATLAS uses an advanced "trigger" system to tell the detector which events to record and which to ignore. The Demers group develops the ATLAS trigger system and focuses on using tau leptons to probe for and characterize physics beyond the Standard Model at ATLAS, including:

A search for Higgs decaying to tau leptons, when the Higgs was produced in association with a Z or W boson. This is a small fraction of the entire production of the Higgs, but provides a nice, clean way to trigger on the events of interest given that the tau decays themselves are difficult to identify with high purity and efficiency.

A search for a new, exotic Z' boson that decays to tau pairs. If there is a preferential coupling of new physics to the heavy and short-lived 3rd generation particles, this channel provides a fantastic probe. It also is an excellent arena for studying high momentum taus.

A measurement of the tau polarization in Z boson decays. This measurement provides access to the weak mixing angle and provides a test-case for a measurement pioneered by the Demers group to measure tau polarization at a hadron collider, carried out in the W->tau nu decay chain. This tool has the ability to probe for and eventually characterize new physics.

Demers is the ATLAS Deputy Data Preparation convener, was formerly a co-convener of the ATLAS Upgrade Physics group, was co-lead on the ATLAS Data Quality Group, and is the chair of the US ATLAS Institute Board. With her leadership, Yale is an ATLAS Trigger and Data Acquisition Institute with design and validation responsibilities.

Alumni since 2017 include graduate students E. Castiglia, M. Pettee, annd S. Thais; and undergraduates I. Bhalla-Ladd and C. Laffan.

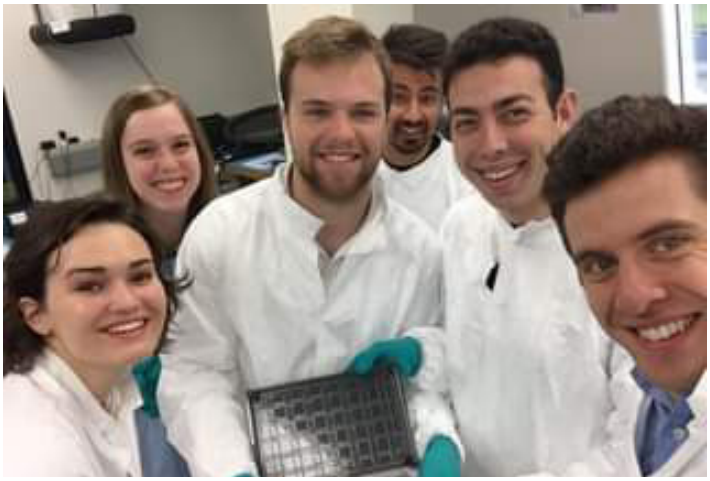
Mu2e

Sarah Demers, PI; Gianantonio Pezzullo, associate research scientist; Matthew Stortini, graduate student; and Dawson Thomas and Audrey Whitmer, undergraduates

Mu2e, located at Fermilab in Illinois, will search for the conversion of a muon directly to an electron in the field of a nucleus. This process, all but forbidden in the standard model, is enhanced in some compelling extensions to the Standard Model and a signal at Mu2e would be a clear sign of new physics. The Demers group is heavily engaged with development on the Mu2e trigger. Construction of the experiment has begun and first beam commissioning is expected to start in early 2025.

Pezzullo is co-leader of the Trigger and Data Acquisition group, for which we have written and optimized many algorithms. Demers is on the publications board and she led the "Engaging Non-Experts" group to help new people transition into the collaboration by developing computing tutorials and documentation.

Alumni since 2017 include undergraduates R. Branson, T. Hossain, and C. Laffan.



Exploring the fundamental nature of the Universe

Paul Tipton group

ATLAS

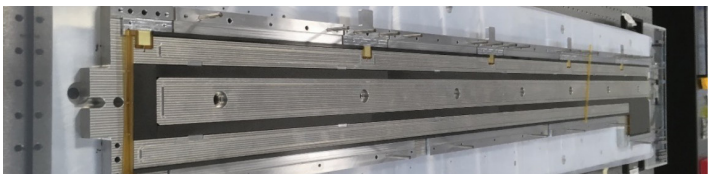
Paul Tipton PI; Jeff Ashenfelter, project manager; Tom Hurteau, research and development technician; and Arianna Garcia Caffaro, graduate student

In order to probe further into unexplored physics territory we seek to collect more collision data per second. The Tipton group, as well as the other ATLAS groups at Yale, accomplish this through a series of staged upgrades of both the LHC and ATLAS.

In the Wright Lab clean rooms, the Tipton group has been conducting R&D and prototyping the construction of state-of-the-art low-mass structures to hold sensors (i.e., particle detectors) that will track particles as they leave the interaction point. The structures, called stave cores, are the basic building block of a new tracking detector for ATLAS. The stave cores precisely locate the sensors, while also providing cooling and electrical connections into and out of the interaction region.

We plan to fabricate approximately 225 stave cores over the next three years (2023-2025), then ship them to Brookhaven National Lab, where the sensors will be mounted on them, before their journey on to CERN, where they will be installed in the upgraded ATLAS detector. Yale's part of this DOE-funded $190M project has a total cost of $6.7M.

Alumni since 2017 include graduate student J. Vasquez.



A milestone, and a new beginning, for Wright Lab ATLAS researchers

July 4, 2022 marked the 10th anniversary of the announcement during a seminar at CERN (the European Organization for Nuclear Research) that the discovery of a new fundamental particle (joining other fundamental particles, such as electrons and quarks), called a "Higgs boson," was confirmed. This discovery enables a search for new models of how scientists explain the physical world, and continuing studies of the Higgs boson are expected to lead to new scientific discoveries, including possibly the nature of dark matter.

Wright Lab's Keith Baker, D. Allan Bromley Professor of Physics, Sarah Demers, professor of physics, and Paul Tipton, professor of physics, were all part of the ATLAS experiment collaboration's role in the confirmation, and they all continue to investigate the new physics made possible by this discovery using ATLAS and other experiments across the world.

To add to the excitement, July 5, 2022 was the beginning of the third scientific run of CERN's Large Hadron Collider, the instrument that discovered the Higgs Boson. Baker, Demers, and Tipton are looking forward to investigating what secrets of the invisible Universe might be revealed in this next-generation run of the experiment. Demers was interviewed several times that week about the initiation of the run.

Baker said, "When Galileo constructed his first telescope, he took a tool that was meant to be used to detect distant ships that are coming to attack, but he pointed it at the moon and he saw mountains. It was a new tool that allowed us to do many things that we could not have done before in physics."

Baker continued, "The Higgs Boson is also a new tool for physics. It is unlike any other fundamental particle that we know in the entire universe and it may even be a portal to some new phenomena that is beyond the Standard Model of particle physics, which we call dark matter. I use the Higgs to look for this new phenomena, which is why both the discovery of the Higgs ten years ago and the current run of the LHC are exciting to me."

Neutrinos & Fundamental Symmetries

Searching for neutrinoless double beta decay

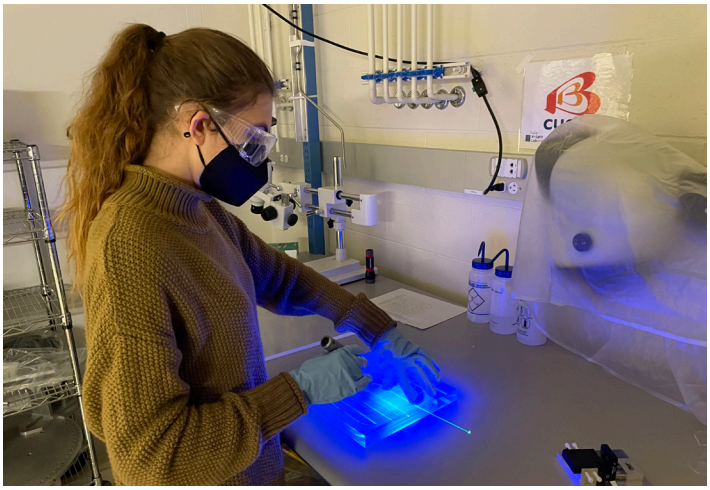
Wright Lab researchers are involved in and leading several experiments that are searching for a previously undetected process called neutrinoless double beta decay. If such a process is observed, it would mean that neutrinos are their own antiparticles, and may hold the clue to why we live in a Universe of matter, and not antimatter.

CUORE & CUPID

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

CUORE stands for "Cryogenic Underground Observatory for Rare Events". Located at the Gran Sasso National Underground Laboratory in Italy, the main goal of the experiment is to look for neutrinoless double beta decay in 130Te. Additionally, CUORE is used to look for dark matter and other rare, low-energy events.

CUPID (CUORE Upgrade with Particle IDentification) is an upgrade that will use CUORE infrastructure for a bolometric experiment that is able to operate in the zero-background conditions and explore the inverted hierarchy of neutrino masses, searching for the violation of the lepton number and the Majorana neutrino (a neutrino that is its own antiparticle).



The CUORE group at Yale has been responsible for the design, construction, and commissioning of the CUORE Detector Calibration System; the analysis and simulation of CUORE data; and leadership of the collaboration.

The Wright Lab team is also involved in research and development for CUPID. They are currently re-designing a muon veto system for CUORE that will assist in reaching the background goals for CUPID.

Maruyama has been involved in CUORE since 2004 and Heeger joined in 2006. Heeger and Maruyama are Principal Investigators of CUPID, and Heeger is the scientific co-spokesperson of CUPID.

Alumni of the team since 2017 include: research scientist T. Wise, postdocs K. E. Lim and D. Speller, grad students J. Cushman and C. Davis, and undergraduates B. Daniel, S. Dutta, C. Gainey, G. Hoshino, N. Ma, K. Melbourne, and I. Wanta.

CUORE team places new limits on the mysterious behavior of neutrinos

A 2022 paper in *Nature* demonstrates that CUORE, operating optimally just 10 millikelvin above absolute zero, has placed some of the most stringent limits yet on the strange possibility that the neutrino is its own antiparticle (called a "Majorana neutrino" after the researcher who proposed this theory).

CUORE has pushed the state of the art on three frontiers: the sheer mass held at such ultralow temperatures, operational longevity, and the low levels of ionizing radiation emanating from the cryogenic infrastructure. With this setup, CUORE has found no evidence for neutrinoless double beta decay ($0\nu\beta\beta$) and has set new limits for being able to find $0\nu\beta\beta$ in future experiments.

EXO-200 & nEXO

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

The Moore group has been among the leaders of the development of liquid Xenon (LXe) time projection chambers (TPCs) to search for double beta decay as part of both EXO-200 and nEXO.

EXO-200 (the Enriched Xenon Observatory) is a detector that contains ~150 kg of liquid ^{136}Xe in a radiopure TPC installed underground at the Waste Isolation Pilot Plant (WIPP) in Carlsbad, NM. EXO-200 is searching for the extremely rare neutrinoless double beta decay of ^{136}Xe.

nEXO is the multi-ton successor to EXO-200, currently planned to be installed underground at SNOLAB in Sudbury, Ontario, which will search for neutrinoless double beta decay with half-life sensitivity beyond 10^{28} years using 5 tons of LXe.

Moore is the subsystem scientist for the nEXO photon detector, and the major responsibility of the group at Wright Lab is to help build the photon detector for nEXO's large array (4.5 square meters) of ultra low background silicon photomultipler photosensors that sense light emitted by the xenon. The Wright Lab group is working very closely with scientists from Brookhaven National Lab, where the final photodetector system will be assembled and tested.

The Moore group also performs simulations for nEXO as well as lab tests at Wright Lab of new readout techniques for large liquid xenon detectors, on the kiloton scale, which would enable half life sensitivities possibly as long as 10^{30} years.

Alumni of the team since 2017 include: graduate students A. Jamil and S. Xia; postgraduate A. Kilby; undergrads S. Borden, Z. Chen, S. Day-Weiss, M. Holmes, I. Kaufman, C. Kavaler, A. Lathem; and visiting undergrad T. Buzzigoli.

EXO/nEXO science highlights

- **Ako Jamil** led a search for dark matter depositing MeV energies in EXO-200 and led the development of a detailed light simulation of nEXO at Wright Lab.
- **Zepeng Li** has searched for possible $0\nu\beta\beta$ decays in which additional bosons (i.e. "Majorons") are emitted.
- **Shilo Xia** was one of three primary analysis team members responsible for the results of the final EXO-200 search for$0\nu\beta\beta$.
- **The Moore group** has played major roles in two recent estimates of nEXO sensitivity; has made the first modern, low-systematics measurement of charge and light yields at MeV energies in LXe; and has developed a resolution model to guide future LXe TPC development.

Investigating the properties of neutrinos

The neutrino is a mysterious, ghostly particle that passes through most matter in the universe without being affected. Experiments have shown that neutrinos have mass, yet many questions remain and the nature of neutrinos continues to challenge the Standard Model of physics. Wright Lab researchers lead and participate in a number of game-changing neutrino experiments across the globe to find answers to these questions.

Project 8

Karsten Heeger, PI; James Nikkel, research scientist; Penny Slocum, associate research scientist; Pranava Teja Surukuchi, postdoc; Arina Telles and Talia Weiss, graduate students; Trent Rayford, postgraduate; and Aaron Chizhik and Shayaan Subzwari; undergraduates

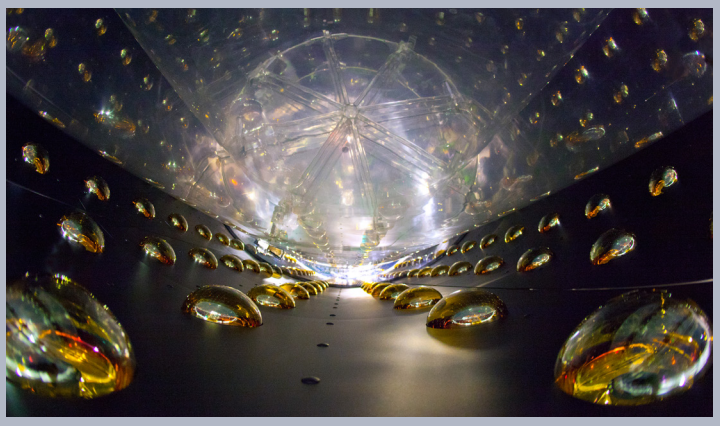
Project 8 (P8), located at the University of Washington in Seattle, utilizes a novel technique dubbed Cyclotron Radiation Spectroscopy (CRES) to perform precision beta-electron spectroscopy from a gaseous Tritium source in an effort to measure the effective neutrino mass. Totaling 9 institutions, the Project 8 collaboration has for the first time successfully measured single-electron radiation directly. This fundamentally new approach to precision beta spectroscopy is set to push the current limit on sensitivity in direct neutrino mass experiments.

P8 achieves neutrino measurement benchmark

For the first time, P8 has used a precise technique to set an upper limit on the neutrino mass, which involves measuring the frequency of light emitted by electrons moving in a magnetic field to determine the electrons' energies. P8 obtained an energy spectrum that encodes information about the neutrino mass: the tritium beta decay spectrum. This data includes key features that demonstrate the power of P8's spectroscopy technique: 1) P8 did not observe any background events in a large energy region with no tritium data, 2) P8 was able to measure electron energies with high precision by optimizing its apparatus setup. P8's result opens the door to even more advanced measurements—which could actually pin down the neutrino mass.

The Heeger group is performing R&D towards a novel experiment to measure and determine the absolute neutrino mass. The Wright Lab team supports the digitization and ongoing development of algorithms in the data analysis, as well as works on a detailed Monte Carlo simulation of the CRES experiment to understand and optimize the energy resolution of the detected electrons.

Alumni of the team since 2017 include: graduate students Harper Cho, Luis Saldana, visiting graudate student Patrick Bolton (Fall 2019), and undergraduate student Joshua Swerdlow.



Daya Bay

Karsten Heeger, PI

Daya Bay is a US-China-Russia collaboration to search for and measure the yet unknown neutrino mixing angle theta13. The experiment is located at the Daya Bay nuclear power plant near Hong Kong, China, and ended operations in 2022.

The Yale group had overall responsibility in the US for the design and construction of the antineutrino detectors and is involved in data analysis and measurements. Together with the University of Wisconsin Physical Sciences Laboratory, the Yale group oversaw the assembly and installation of the antineutrino detectors at Daya Bay.

Alumni of the team since 2017 include: postdoctoral associate T. Langford; graduate students B. Foust, J. Gaison.

Exploring new physics in the neutrino sector

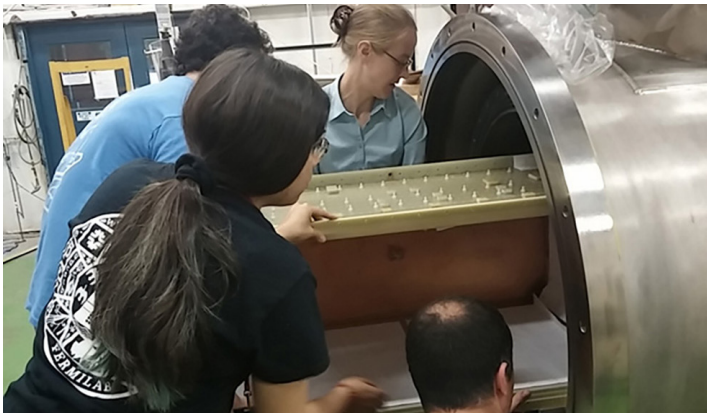
The High Energy Neutrino group at Yale is an experimental group focusing on new physics in the neutrino sector, developing technologies and accelerator neutrino detectors called Liquid Argon Time Projection Chambers (LArTPCs) for current and future experiments in order to search for sterile neutrinos and CP violation in the neutrino sector.

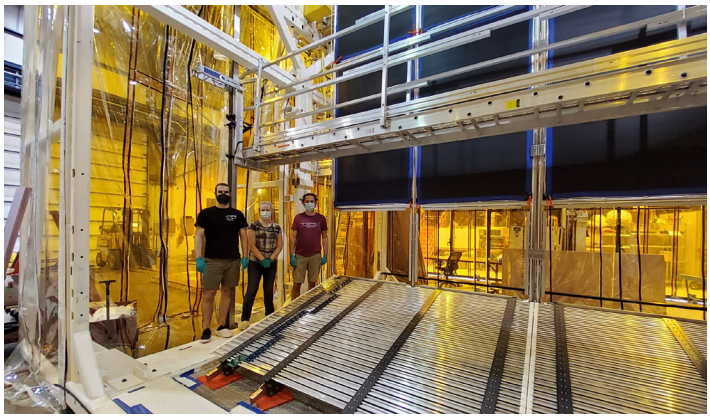
Argon Neutrino Test (ArgoNeuT) & Liquid Argon TPC in a Testbeam (LArIAT)

Bonnie Fleming, PI

ArgoNeuT, an R&D experiment designed to detect and record neutrino interactions from the Neutrinos at the Main Injector (NuMI) beam at Fermilab, was the first LArTPC operating in a low energy neutrino and antineutrino beam, the region of interest for current short-baseline and future long-baseline experiments. In addition to demonstrating technology for larger detectors and contributing to the development of reconstruction algorithms that will be useful in future experiments, ArgoNeuT has provided a wealth of physics results on neutrino interaction mechanisms, and is still yielding new intriguing outputs from the on-going studies. The Yale team played a leading role in the project and the group is currently analyzing and using the data for several research programs.

LArIAT uses a repurposed ArgoNeuT TPC in the Fermilab Test Beam Facility (FTBF) in order to calibrate the LArTPC technology.





Short Baseline Near Detector (SBND)

Bonnie Fleming, PI

The SBND is a near detector experiment being developed on the Booster Neutrino Beamline at Fermilab upstream from MicroBooNE. While MicroBooNE will determine whether or not the low energy excess observed by MiniBooNE is electrons or photons, SBND will look for this excess at a near location to look for a baseline dependence of what MicroBooNE observes. The Yale team co-founded the experiment and is involved in the design of the SNBD detector and sensitivity studies. The Yale team is also constructing components of the TPC at Wright Lab, including the TPC field shaping system, the high voltage feedthrough and part of the scintillation light collection system.

ArgonCube detector technology

Bonnie Fleming and Antonio Ereditato, PIs; Domenico Franco, associate research scientist; Lee Hagaman and Giacomo Scanavini, graduate students

The Wright Lab team joined the research and development (R&D) effort for a new detector technology that is being developed for use by the international ArgonCube collaboration. ArgonCube, with its novel modular LArTPC detector design and innovative technique of pixelated charge readout, will serve as the near detector for the Deep Underground Neutrino Experiment (DUNE). The ArgonCube collaboration consists of more than 100 physicists from 23 institutes.

Exploring new physics in the neutrino sector

Micro Booster Neutrino Experiment (MicroBooNE)

Bonnie Fleming, PI

MicroBooNE is a short baseline accelerator neutrino oscillation experiment at Fermilab designed to investigate the source of the low energy excess observed by the MiniBooNE experiment, perform a unique set of low energy neutrino cross section measurements, and conduct R&D towards development of massive LArTPC detectors. Yale's roles include fabrication and assembly of the TPC and DAQ systems, development of the analysis techniques and tools necessary to analyze the data, and oversight of the collaboration.

MicroBooNE experiment's first results show no hint of a sterile neutrino

In October 2021, the MicroBooNE collaboration announced that MicroBooNE's first results, coming from four separate analyses, do not find a hint of a theoretical new particle called the sterile neutrino, which, if found, would lead to a radical shift in our understanding of the basic building blocks of the universe. This result is the most comprehensive finding thus far for an accelerator-based search for sterile neutrinos (other searches, including Yale's PROSPECT experiment, are based at nuclear reactors).

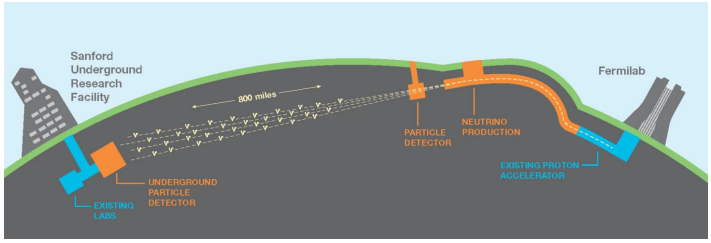
Various researchers in Fleming's group at Wright Lab have been integral to the analyses that led to this new result, with part of the group investigating electrons (including Jay Hyun Jo, Xiao Luo, London Cooper-Troendle, Kaicheng Li, and Brooke Russell), and the other part investigating single photons (including Lee Hagaman and Giacomo Scanavini).

Deep Underground Neutrino Experiment (DUNE)

Bonnie Fleming, Karsten Heeger, PIs

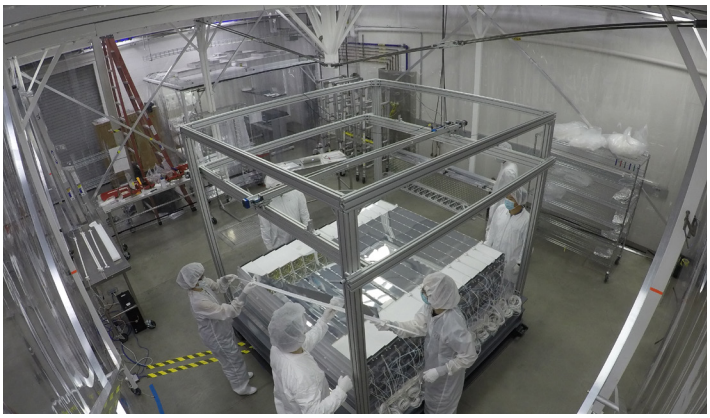
DUNE is a planned neutrino experiment with a detector composed of multiple LArTPCs. This experiment will send a high energy neutrino beam through the Earth's crust over a distance of 1,300 km from Fermilab in Batavia, IL to the Sanford Underground Research Facility (SURF) in Lead, South Dakota. DUNE will be used to study low-background physics, such as proton decay and supernova detection, to measure the parameters that characterize three-flavor neutrino oscillations, and to study a phenomenon known as CP-violation, which may help explain the matter-antimatter imbalance in the universe and determine the relative neutrino mass-differences.

The Heeger group is preparing for a precision measurement of neutrino oscillations with DUNE.



Alumni of the High Energy Neutrino Group since 2017 include professor B. Fleming; visiting professor A. Ereditato; research scientist D. Franco; postdocs J.H. Jo, X. Luo, and S. Tufanli; graduate students C. Adams, S. Balasubramanian, L. Cooper-Troendle, E. Gramellini, A. Hackenburg, L. Hagaman, K. Li, B. Russell, G. Scanavini, A. White; visiting undergraduate A. Ferraloro (Summer 2022); and undergraduates A. Chizhik, M. King, N. Pereira, N. Wright, J.P. Dervan.

Precision studies of neutrino oscillations



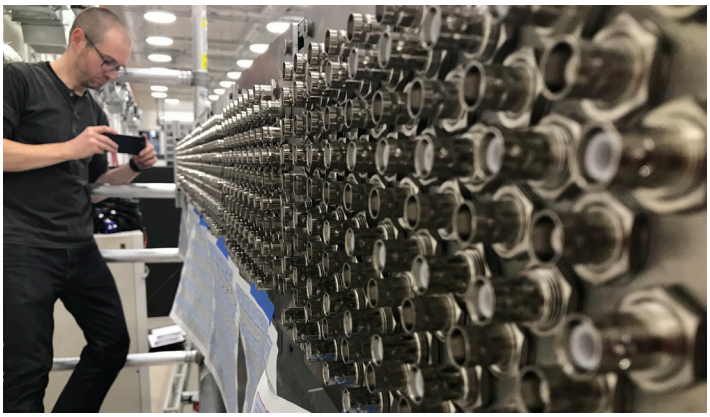
PROSPECT

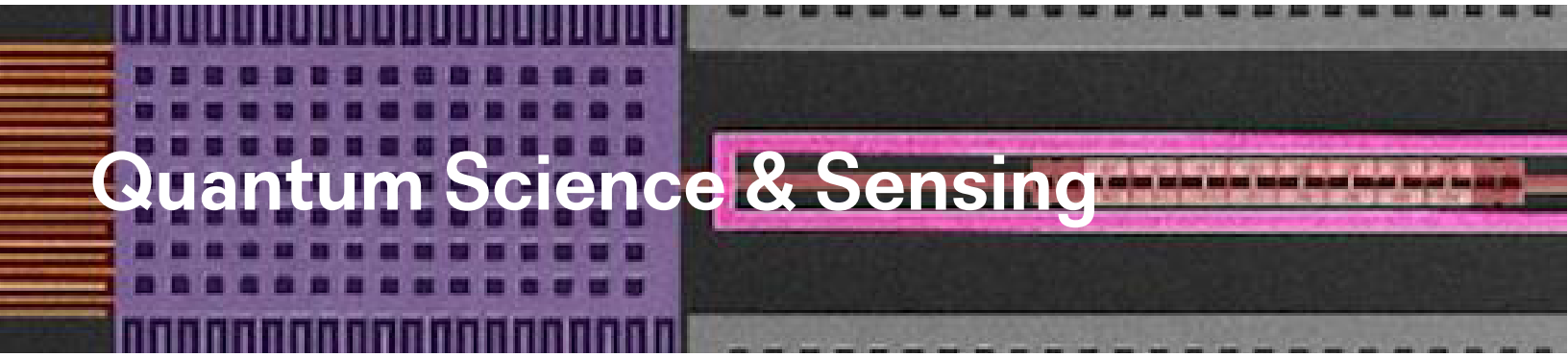
Karsten Heeger, PI; Pranava Teja Surukuchi, postdoctoral associate; James Nikkel, research scientist; Arina Telles, graduate student

The Precision Oscillation and Spectrum Experiment (PROSPECT) is a reactor neutrino experiment at very short baselines designed to make a precision measurement of the flux and energy spectrum of antineutrinos emitted from nuclear reactors. PROSPECT searches for the oscillation signature of sterile neutrinos and tests our understanding of the emission of antineutrinos from the fission products in a nuclear reactor. The measurements of PROSPECT will test our understanding of the Standard Model of Particle Physics, deepen our understanding of nuclear processes in a reactor, and help develop technology for the remote monitoring of nuclear reactors for safeguard and non-proliferation.

PROSPECT was built at Wright Lab, ran at the High Flux Isotope Reactor (HFIR) at Oak Ridge National Laboratory in Tennessee, and now is back at Wright Lab for an upgrade. The Wright Lab team is probing the existence of sterile neutrinos with PROSPECT.

Alumni since 2017 include researcher J. Ashenfelter, postdoc T. Langford; graduate students B. Foust, J. Gaison, D. Norcini; and undergraduates L. Baker, I. Bhalla-Ladd, J. Roth, and N. Stemen.





Quantum Science & Sensing

Quantum science is one of five top priority areas identified by Yale University's Science Strategy (*see p. 38*). Yale's Wright Lab is exploring the applications of quantum science and sensing to tests of fundamental physics.

The quantum search for dark matter

HAYSTAC

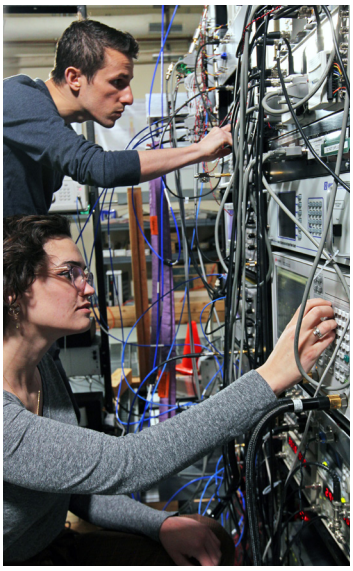
Steve Lamoreaux, Reina Maruyama, PIs; Sid Cahn, senior research scientist; James Nikkel, research scientist; Michael Jewell, Yuqi Zhu, postdoctoral associates; Xiran Bai, Sumita Ghosh, Eleanor Graham, Claire Laffan, graduate students; Matthew Dobre, Quinn Ennis, undergraduates

Haloscope At Yale Sensitive To Axion CDM (HAYSTAC) is looking for dark matter in the form of Axions, which are very low mass particles that are predicted in the context of the standard model of electroweak interactions (quark, gluon, W, Z, Higgs, etc. are all part of this model). If they do indeed exist and form dark matter, they will convert to radiofrequency photons in the presence of a strong magnetic field. The photon energy, hence frequency, is essentially determined by the axion mass, and is expected to be in the 1-20 GHz region.

The heart of our experiment is a tunable radiofrequency (microwave) cavity resonator, which serves to build up the axion signal, and a quantum limited amplifier based on the Josephson effect, which occurs when Cooper pairs tunnel though an insulating layer separating two superconductors.

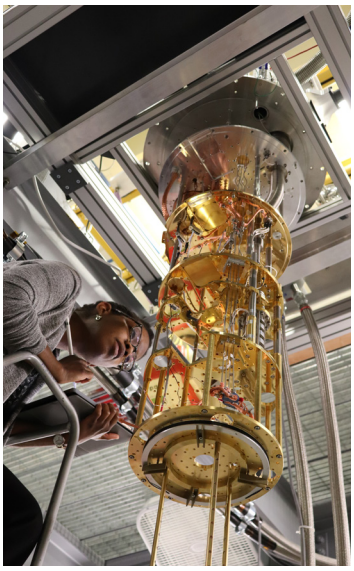
HAYSTAC is located at Wright Lab, and the Yale team is responsible for systems engineering, cryogenics, and magnetics. HAYSTAC uses Josephson Parametric Amplifiers (JPAs), photon sensors often used for quantum computing. It also uses a quantum noise squeezing technique to speed up the data taking of the experiment. HAYSTAC and LIGO are the only two experiments to successfully implement quantum squeezing to improve data taking.

Alumni since 2017 include postdoctoral associate L. Zhong; graduate students K. Backes and B. Brubaker; undergraduates A. Giman, A. Kilby, C. van Assendelft, and H. Wang; and high school student A. Srivastava.

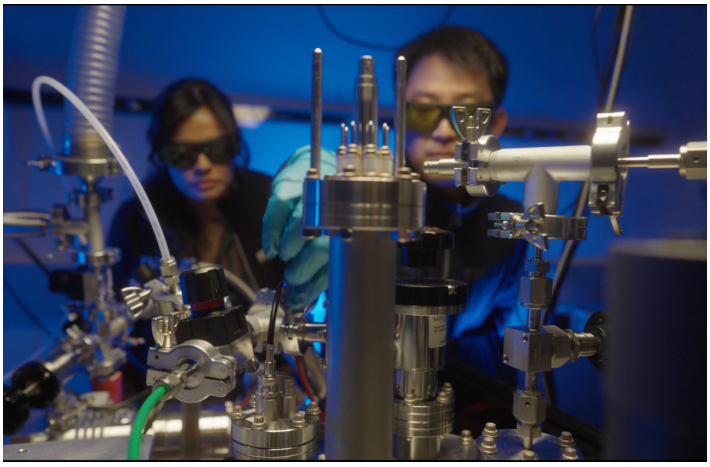


Looking for dark matter in a HAYSTAC — with some quantum squeezing

A study in the journal *Nature* (2021), led by then graduate student Kelly Backes, Ph.D. '21, demonstrated that the HAYSTAC team has improved the sensitivity of the detector by using a technique known as "quantum squeezing" that reduces the amount of quantum "noise" the axion signal must compete with so the search for the axion can proceed at a faster rate. The tools used were initially developed for quantum computing labs. The fact that they could also enhance axion detection highlights what is possible when two fields of physics, in this case dark matter detection and quantum information, come together.



The quantum search for dark matter



SIMPLE

David Moore, PI; Thomas Penny, postdoctoral associate; Ben Siegel, Yu-Han Tseng, Jiaxiang Wang, and Molly Watts, graduate students

The Moore group is developing technologies to search for new physics that may have extremely weak couplings to normal matter, such as dark matter. The key technical challenges to developing sufficiently sensitive sensors arise from fundamental constraints in the measurement process imposed by quantum mechanics. In particular, the development of quantum optomechanics (including by researchers at Yale) now allows the control and readout of the mechanical degrees-of-freedom of massive objects at sensitivities reaching (or in some cases exceeding) the "standard quantum limit" (SQL), i.e. precision and backaction at the Heisenberg limit for simultaneous measurement of an object's position and momentum.

The group has been among the leaders in developing ultra-precise sensors based on levitated optomechanical systems. In particular, they have developed techniques to optically levitate the most massive objects to date in high vacuum, control their charge and rotational degrees of freedom, cool their motion to microkelvin temperatures, and reach the world's best acceleration sensitivity for nanogram scale masses.

These technical developments enabled two recent searches for dark matter with world-leading sensitivity: 1) a search for dark matter particles with a tiny electric charge bound in matter and 2) a search for recoils from passing dark matter particles, demonstrating the first mechanical search for dark matter and reaching sensitivities exceeding that of even ton-scale underground detectors for certain classes of dark matter candidates.

These initial searches are a proof-of-principle for the use of these technologies in fundamental physics. However, future applications will substantially extend their reach. The Moore group has recently summarized a vision for applications of levitated optomechanical sensors to fundamental physics, and identified similar potential applications of trapped ions and electrons.

Moore was also a co-organizer of the "Quantum Optomechanical Architectures for Dark Matter Detection," workshop in 2019, supported by a Gordon and Betty Moore Foundation Fundamental Physics Innovation Award and leading to a community white paper describing these emerging ideas, followed by a second workshop in 2021. Realizing these ideas requires both improving the sensitivity of such sensors and scaling to large sensor arrays.

Ambitious future applications of such systems include a possible model-independent laboratory search for dark matter (through its gravitational interactions alone), or, possibly, entanglement of micron sized masses through their mutual gravitational interaction. Such exciting ideas require substantial advances beyond the state-of-the-art, and the Moore group will continue to lead development of these technologies in the coming decade and beyond to enable their realization.

Alumni since 2017 include postdoctoral associates G. Afek, F. do Rego Monteiro, and Z. Li; graduate students Z. Ding, C. Li, W. Li, and S. Ghosh; undergraduates S. Chowdhury, S. Dickson, A. Emser, A. Fine, R. Flynn, H. Lyu, M. Mossman, L. Mozarsky, E. Peng, J. Recoaro, T. Skidmore, and C. van Assendelft.

SIMPLE-fying the search for dark matter

SIMPLE has demonstrated the first search for dark matter using mechanical sensors by searching for "kicks" of an optically trapped nanogram mass. By measuring the motion of the microsphere, the group can precisely detect extremely tiny impulses. The setup exceeds the sensitivity of experiments using hundreds of kilograms or tons of mass in large underground detectors, and sets constraints on certain types of dark matter that could interact with normal matter via a stronger, gravity-like force. Future searches using mechanical sensors may open up an entirely new window in the search for dark matter, as new experiments are developed to take advantage of these types of sensors.

The quantum search for dark matter

Single phonon detection using quantum acoustics

Jack Harris, PI; Yogesh Patil, research associate; Igor Brandao, Theophilus Human, Daniel Sibilia, Yiqi Wang, Lucy Yu, graduate students; Juan Recoaro and Giovanna Truong, undergraduates

Jack Harris's group is developing new technologies to control and readout mechanical degrees of freedom of 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 particular, they fill high-quality optical and acoustic cavities with superfluid helium, and measure the photon-by-photon and phonon-by-phonon behavior of these devices.

In one experiment, the group uses miniature, optical fiber-based cavities that are cooled in a dilution refrigerator and immersed in superfluid helium. Cavity mirrors (formed on the optical fibers) confine high-quality standing-wavemodes of both light and sound, and the light and sound waves interact with each other. At the quantum level, this interaction allows a photon to occasionally emit or absorb a single phonon. When it does so, its wavelength is red-shifted or blue-shifted. The group collects light from the cavity, filters out all of the unshifted light, and passes only the shifted light to a single-photon detector. Each photon registered by this detector corresponds to the detection of a single phonon being added to, or removed from, the sound wave in the cavity. The ability to detect individual phonons, each with an energy in the micro-EV range, is quite novel. The group is exploring the possibility of using this type of control to prepare specific quantum states of sound that are particularly well suited to test fundamental physics, the Standard Model, and to search for dark matter.

In a second experiment, the Harris group is exploring similar scientific goals, but instead of filling a glass cavity with superfluid helium, they form the entire cavity out of superfluid helium that is free from any contact. The group does this by using magnetic levitation to suspend a millimeter-scale drop of helium in vacuum. The drop cools itself by evaporation, and the group has found that levitated drops thermal, mechanical, and optical properties agree well with theory.

The group is in the process of trying to trap photons in the drop's whispering gallery modes, with the goal of using single-photon and single-phonon techniques to study quantum features in the drop's motion.

These two experiments are table-top experiments. They are conducted in Wright Lab laboratories, and carried out by Harris group members. The efforts are supported by a range of collaborations, but the experiments are carried out entirely in Wright Lab.

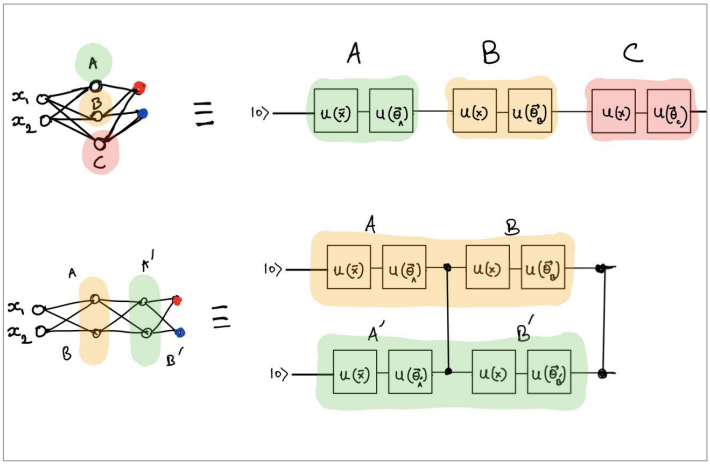
By taking advantage of the unique mechanical properties of superfluid He, sensors made by the Harris group might be able to enable new, ultra-sensitive searches for rare interactions from dark matter that would be complementary to other kinds of dark matter searches undertaken by Wright Lab researchers (*see pp. 4-5, 19-20*).

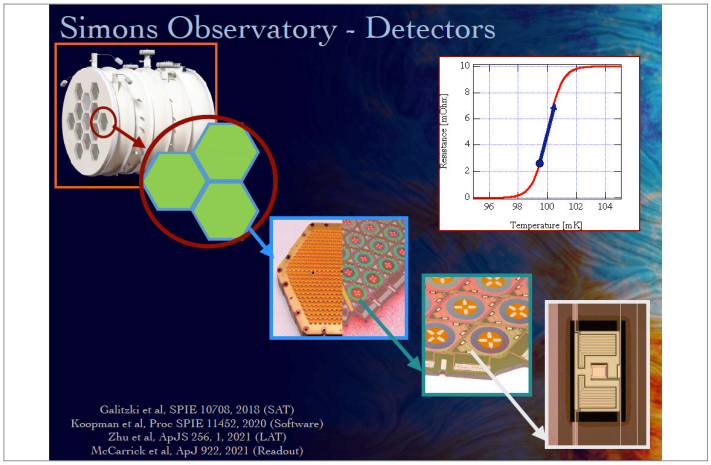
Alumni since 2017 include postdoctoral associates G. Harris, K. Johnson, M. Namazi; graduate students C. Brown, S. Frazier, C. Guria, A. Kashkanova, A. Shkarin; undergraduates W. Sun, T. Uysal, Y. Zhang; and visiting undergraduates J. Fox, T. Wise.

Quantum optomechanics in a liquid

The Harris team and their collaborators, in a paper co-led by graduate students A. Shkarin and A. Kashkanova, have directly observed quantum behavior in the vibrations of a liquid body for the first time. They detected the sound wave's quantum properties: its zero-point motion, which is the quantum motion that exists even when the temperature is lowered to absolute zero; and its quantum "back-action," which is the effect of a detector on the measurement itself.

The quantum search for dark energy





Wright Lab Quantum Information Science in High Energy Physics

Keith Baker, PI; Ryan Leong, Jingjing Pan, graduate students; Argyris Giannisis Manes, undergraduate

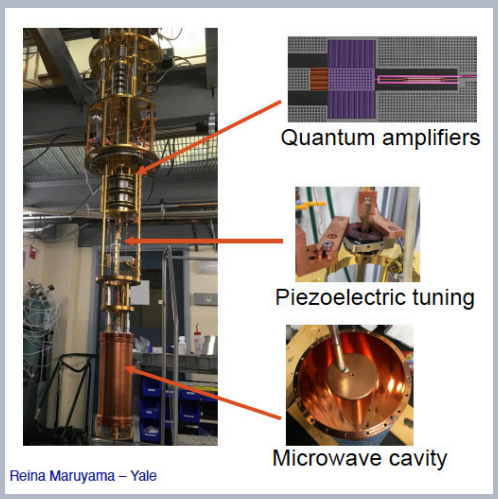
The Baker group uses ATLAS (*see p. 10*) to study quantum entanglement in Higgs boson decays, entanglement entropy in high energy physics, and quantum information science at high energies. The group also demonstrates applications of machine learning, quantum computing, and quantum algorithms in particle physics analyses at high energies. In this way, we are showing how this can be applied to better understand certain anomalies in the data from high energy particle physics experiments.

Alumni since 2017 include graduate student C. Weber and undergraduate D. Qenani

Quantum sensors in instrumentation for millimeter wave cosmology

Laura Newburgh, PI

The Newburgh Lab is part of Simons Observatory and CMB-S4 (*see p. 9*), 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. The Newburgh group is focused on software development for these experiments.



2022 Wright Lab Quantum Sensing Workshop

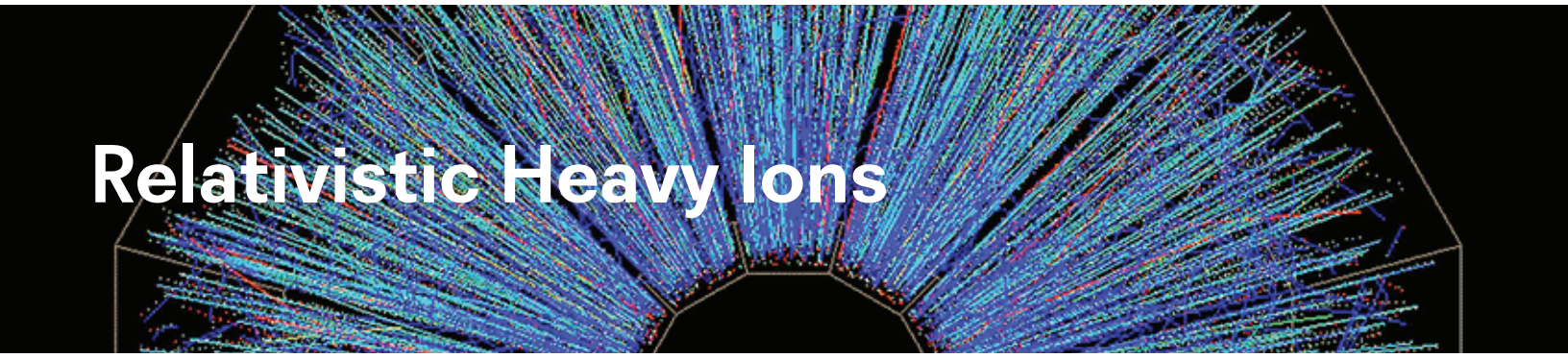
On April 8, 2022, about 50 people gathered for the *Wright Lab Quantum Sensing Workshop*, which kicked off "Quantum Week" at Yale.

Keynote: Dr. Dmitry Budker of the Helmholtz Institute Mainz at Johannes Gutenberg University and University of California, Berkeley.

WL Plenary talks: Keith Baker, Reina Maruyama, Jack Harris, Laura Newburgh, David Moore.

Lightning talk competition for students & postdocs: Graduate student Sumita Ghosh and postdoctoral associate Yuqi Zhu tied for first place

Discover more at **wlab.yale.edu/wright-lab-quantum-sensing-workshop**



Relativistic Heavy Ions

Relativistic heavy ion physics is of international and interdisciplinary interest to nuclear physics, particle physics, astrophysics, condensed matter physics, and cosmology. The primary goal of this field of research is to recreate in the laboratory a new state of matter, the quark-gluon plasma (QGP), which is predicted by the Standard Model of particle physics (Quantum Chromodynamics) to have existed ten millionths of a second after the Big Bang (origin of the Universe) and may exist in the cores of very dense stars.

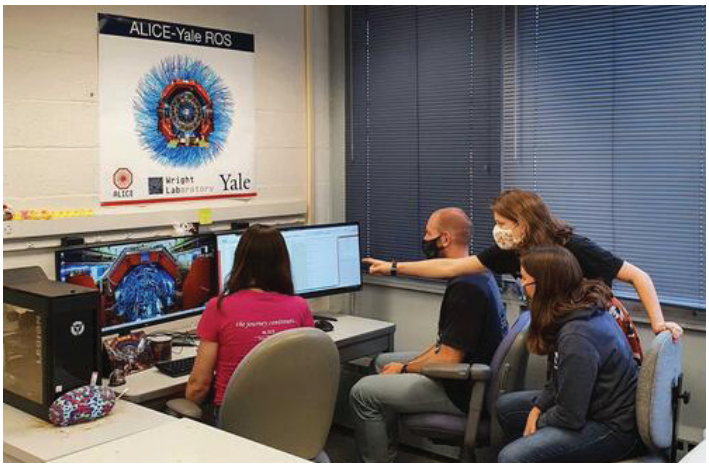
Recreating conditions of the early Universe

Relativistic Heavy Ion Group (RHIG)

Helen Caines, John W. Harris, PIs; Jurgen Schukraft, Thomas Ullrich, adjunct professors; Mesut Arslandok, Nikolai Smirnov, research scientists; Laura Havener, associate research scientist; Fernando Flor, Isaac Mooney, Michael Oliver, postdocs; Caitie Beattie, Hannah Bossi, Tong Liu, Daniel Nemes, Ananya Rai, Youqi Song, Andrew Tamis, Sierra Weyhmiller; graduate students.

The Caines-Harris experimental research group uses collisions of heavy nuclei accelerated to ultra-relativistic speeds to "melt" the nuclei into a soup of quarks and gluons (collectively termed partons), the fundamental particles of nature. This hot and dense state of nuclear matter, called the Quark-Gluon Plasma (QGP) is one of nature's most extreme fluids. It has a specific viscosity that is smaller than that of any known substance, including that of superfluid liquid helium, and a vorticity that surpasses that of super-cell tornado cores and Jupiter's Great Red Spot. In addition to quark and gluon degrees of freedom, the Quark Gluon Plasma has an initial temperature of more than 10^12 Kelvin, conditions that last existed only a few microseconds after the Big Bang.

The group's research program focuses on measuring jets, the products of high momentum transfer scatterings in the collisions, and their substructure to further our understanding of the strong interaction, and the properties and evolution of the QGP. They perform their studies at the STAR experiment at the Relativistic Heavy Ion Collider (RHIC) and Brookhaven National Laboratory in New York and at ALICE at the Large Hadron Collider (LHC) in CERN, Geneva Switzerland. By comparing and contrasting results from these two experiments, our investigations provide unique information on the properties of the Quark Gluon Plasma. In addition, the group has initiated hardware development studies for the detector that is being designed for installation at the newly approved Electron-Ion Collider.



Recreating conditions of the early Universe

RHIG, cont.

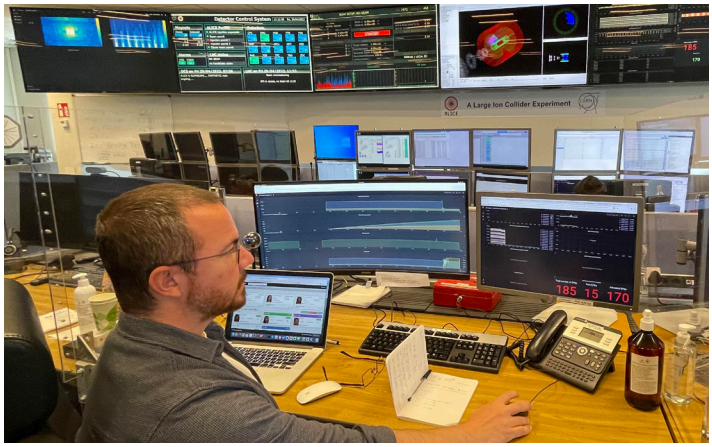
Over the past 5 years, via a comprehensive set of jet measurements, carried out at both STAR and the ALICE, the group has performed a detailed exploration of the length-scale and system size dependence of parton energy loss to the QGP its properties. In addition, since jets are multi-scale objects that connect asymptotically free partons to confined hadrons, jet substructure measurements in vacuum have provided insight into parton evolution and the ensuing non-perturbative processes. Our investigations of small systems have also probed the role of the underlying event and initial state nuclear effects on the medium produced. In combination these studies have both furthered our understanding of the hot and dense medium created in relativistic heavy-ion collisions and lead to a deeper understanding of how fragmentation and hadronization occurs in both the perturbative and non-perturbative regimes of Quantum ChromoDynamics (QCD), the theory of the strong interaction between quarks mediated by gluons.

Measurements of event-by-event fluctuations have been used to clarify the relation of hadronic freeze-out conditions to the QCD phase transition. These studies, and a systematic study of identified particle production over a wide range collision energies, have also provided important information on the time-ordering and mechanisms of this particle production

STAR

STAR is a large–scale experiment at the Relativistic Heavy Ion Collider (RHIC) at Brookhaven National Laboratory (BNL) on Long Island, New York. The STAR experiment searches for signatures of quark-gluon plasma (QGP) formation and investigates the behavior of strongly interacting matter at high energy density. STAR is exploiting the versatility of RHIC by utilizing colliding beams of various nuclei, from protons to gold, Ruthenium and Zirconium, and varying the energies of the colliding beams to explore the phase diagram of nuclear matter. The goal is to obtain a fundamental understanding of the microscopic structure of hadronic interactions, at the level of quarks and gluons, at high energy densities.

Since 2017 Helen Caines has been the co-spokesperson of the STAR collaboration, which is composed of more than 700 scientists from 71 institutions from 14 countries. Over the past 5 years she has led STAR through the successful completion of a multi-year data program termed the Beam Energy Scan phase II, a key goal of which was to map the QCD phase diagram and search for landmarks such as the proposed Critical Point. Last year STAR also successfully installed and operated a new suite of detectors at angles close to the beam line aimed, which significantly extended the kinematic reach of the experiment.



ALICE

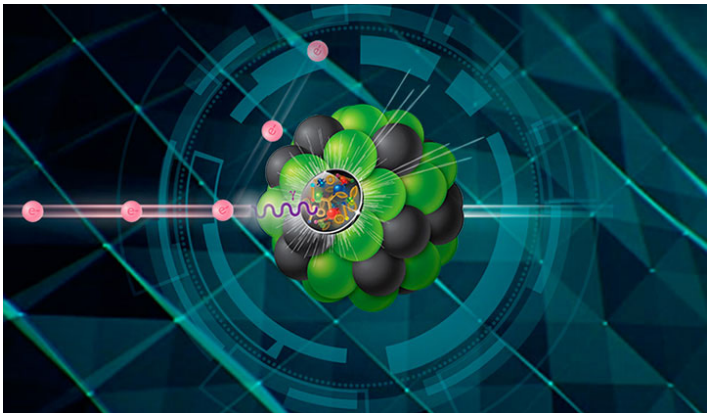
ALICE is a detector at the Large Hadron Collider (LHC) located at the Center for European Nuclear Research (CERN) in Geneva, Switzerland, that uses collisions of heavy nuclei, as well as proton-proton and proton-nucleus collisions, to study the physics of strongly interacting matter at the highest energy densities reached so far in the laboratory. The primary goal of the experiment is to re-create the quark-gluon plasma (QGP) state of matter, which is predicted by the Standard Model of particle physics to have existed ten millionths of a second after the Big Bang.

Recreating conditions of the early Universe

ALICE, cont.

In ALICE, group members, led by Dick Majka (*see p.57*), successfully constructed, tested and commissioned oft-he 45 ALICE TPC inner readout chambers (IROC) that formed part of the U.S. Barrel Tracking Upgrade sponsored by the DOE. This upgrade to quadruple GEM chambers allows ALICE to record the information of all tracks produced in lead–lead collisions at rates of 50 kHz, producing data at a staggering rate of 3.5 TB/s, which is two orders of magnitude higher than before. The first data taking with the upgraded TPC has just successfully started at CERN.

John Harris served on ALICE Management Board and as Chair of the Collaboration Board until 2019.



EIC

The Yale group is engaged in simulations, R&D, design and prototyping of future detectors for a possible future Electron-Ion Collider (EIC) detector, which will be built at Brookhaven National Laboratory (BNL) on Long Island.

The EIC is a state-of-the-art research facility and partnership among the DOE, New York State, BNL, and the Thomas Jefferson National Accelerator Facility (Jefferson Lab) that will open a new frontier in nuclear physics; a field essential to our understanding of the visible universe with applications in national security, human health, and more.

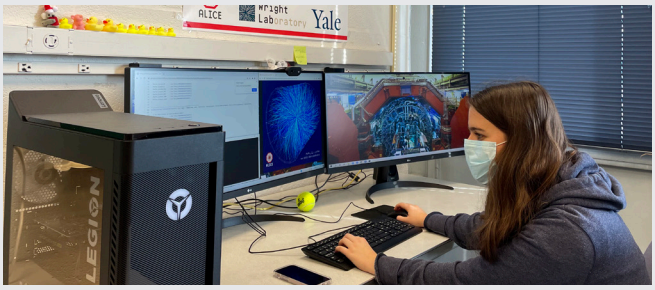
RHIG has been developing technologies for detectors at BNL for many years, and their expertise will be invaluable for designing and developing detectors for the EIC. Additionally, there may be opportunities for Yale researchers to get involved in EIC data and computing.

Yale University becomes official remote site for data taking for ALICE

With international travel restrictions still in place due to the COVID-19 pandemic, researchers in the Wright Lab Relativistic Heavy Ion Group (RHIG) applied for and received permission for Yale University to become an official remote site for data taking for ALICE (A Large Ion Collider Experiment) on the Large Hadron Collider (LHC) at CERN, and a new Remote Operations Site (ROS) is now installed and operational in Wright Lab West.

The LHC restarted operations in May 2021, in a data-taking run called "Run-3," and therefore ALICE data-taking shifts for the RHIG group and other ALICE collaborators also restarted at that time. Early shift work at ALICE included collecting data to continue the commissioning of the recently installed upgraded readout chambers of the Time Projection Chamber (TPC). RHIG members played a key role in construction and testing of the inner readout chambers.

The ALICE remote station is the second remote station installed at Wright Lab, joining the remote operations room in Wright Lab 218 that has been operating since the opening of the lab in May 2017, mostly to run shifts on experiments at Fermilab, such as MicroBooNE (*see p. 17*).

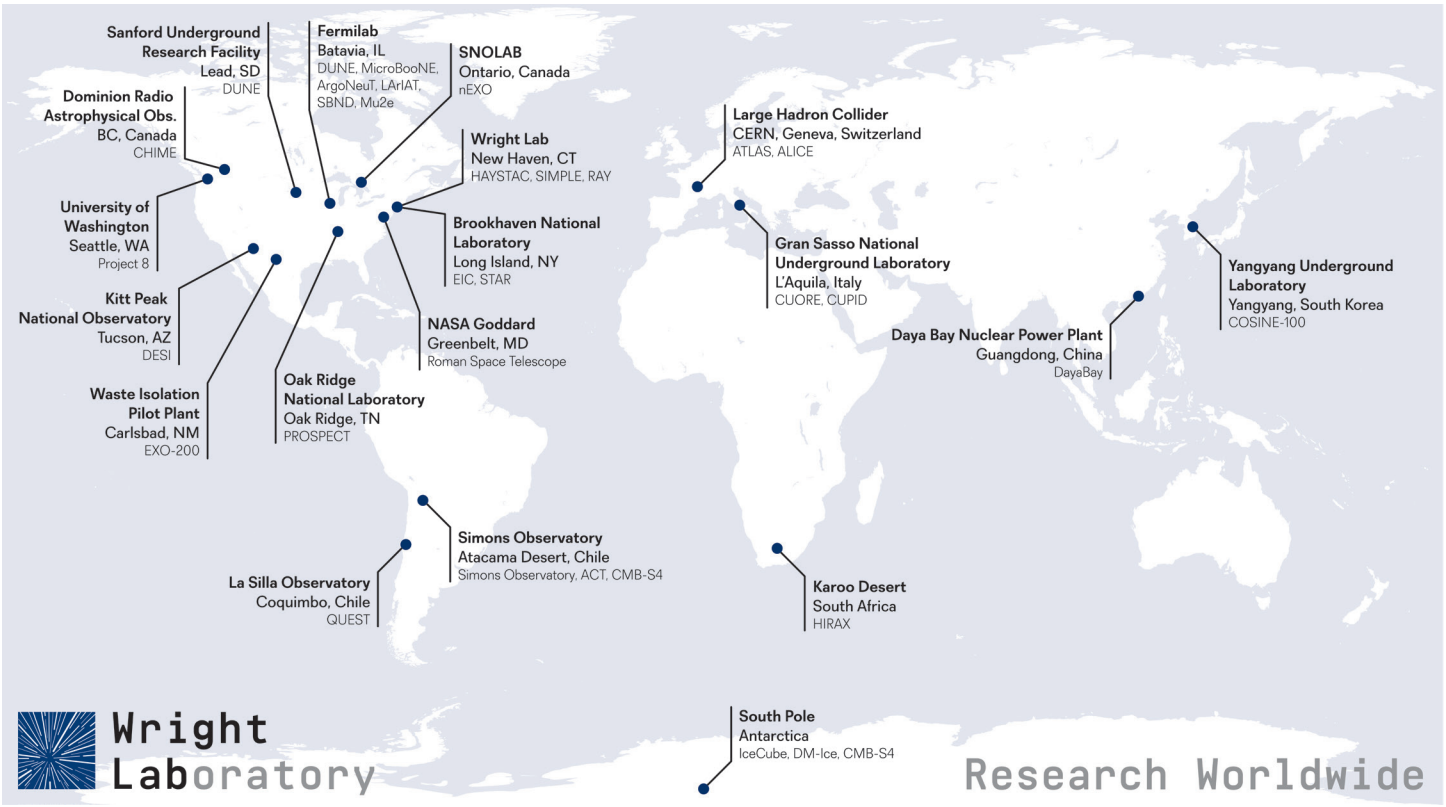


RHIG alumni since 2017 include visiting professors A. Mocsy, B. Mueller; senior research scientist D. Majka; research scientist R. Kunnawlalkam; postdoctoral associates E. Epple, A. Francisco, R. Haake, K. Lapidus, S. Oh, M. Sas, L. Yi; graduate students S. Aiola, E. Craft, R. Ehlers, S. Horvat, J. Lap, T. Lutz, J. Mulligan, S. Oh, and D. Stewart; undergraduates S. Checa, J. Chen, S. Nicholls, J. Purtell, B. Rosand; and visiting undergraduates G. Halal, Z. Zhang.

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.

National and International collaborations



Campus collaborations

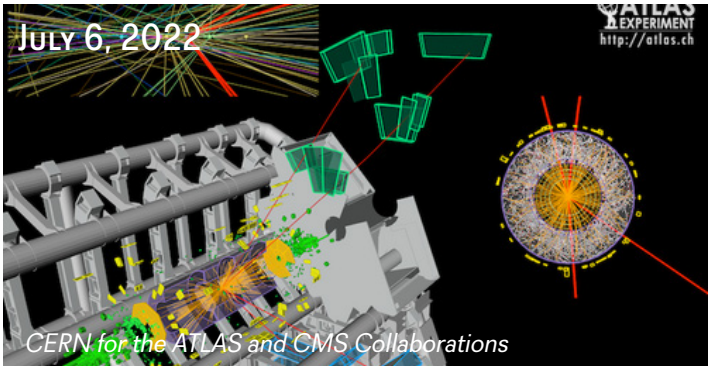
- **Yale Center for Astronomy and Astrophysics (YCAA)** - working towards understanding dark matter in the Universe through scientific investigations
- **Yale Center for Research Computing (YCRC)** - developing novel solutions to the research computing challenges in nuclear, particle, and astrophysics
- **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

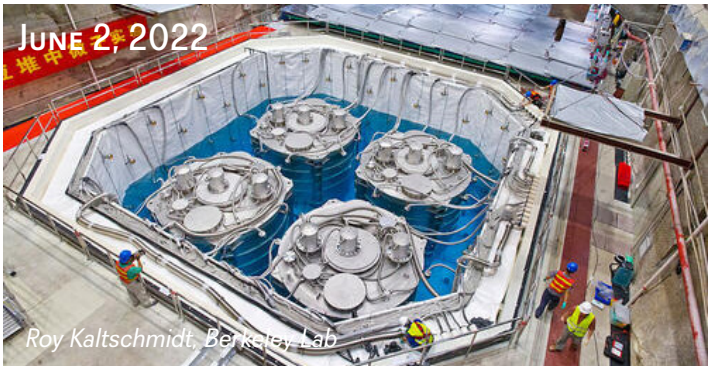
In the News

The following pages include highlights of Wright Lab research efforts in the news. **Discover more** Wright Lab news, including full articles and additional news items at **wlab.yale.edu/news.** *For news about awards and honors in the Wright Lab community, please see pp. 50-53.*



A milestone, and a new beginning, for Wright Lab's ATLAS researchers

July 4, 2022 marked the 10th anniversary of the confirmation of the discovery of the Higgs Boson, a new fundamental particle. Keith Baker, Sarah Demers, and Paul Tipton were all part of the ATLAS collaboration's role in the confirmation, and they all continue to investigate the new physics made possible by this discovery using ATLAS and other experiments across the world.

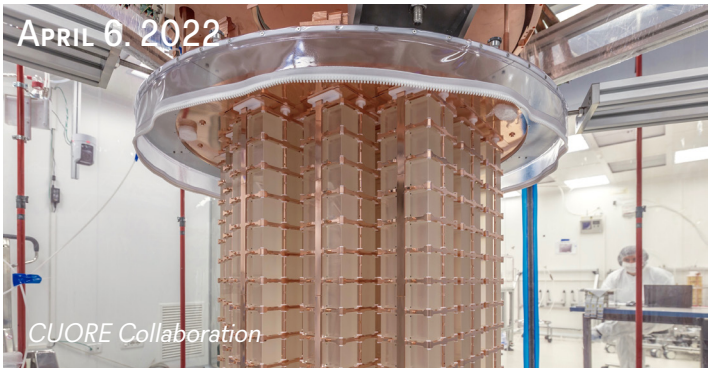


Physicists announce first results from Daya Bay's final dataset

The Daya Bay collaboration has reported the first result from the experiment's full dataset—the most precise measurement yet of theta13, a key parameter for understanding how neutrinos change their "flavor." Karsten Heeger's group played a leading role in the overall design, assembly, and commissioning of the US contribution to the eight Daya Bay antineutrino detectors.

CHIME Telescope Delivers Deepest-Ever Radio View of Cosmic Web

A recent CHIME result verifies the ability of the CHIME experiment to detect the 21cm signature of neutral hydrogen in galaxies that will allow the Newburgh group to make measurements of the distribution of galaxies farther back in the past than before, which will tell them about the expansion rate of the Universe at a critical era when Dark Energy began impacting the expansion.



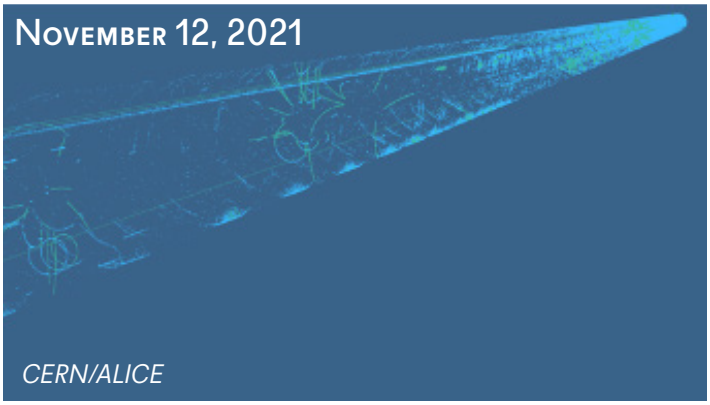
CUORE team places new limits on the bizarre behavior of neutrinos

CUORE has just published some of the most stringent limits yet on the strange possibility that the neutrino is its own antiparticle. The Wright Lab team has been involved in the calibration of the experiment, the production of the thermistors for the detector readout, and analysis. They are currently developing a muon tagger as an upgrade to reduce cosmogenic backgrounds.

In the News

DOE nuclear physics program strategy includes Neutrinoless Double Beta Decay experiments at Wright Lab

The DOE nuclear physics program is pursuing an international strategy to fund three tonne-scale experiments that are sensitive enough to search for evidence of neutrinoless double beta decay. Karsten Heeger, Reina Maruyama, and David Moore are involved in leading and building two out of the three experiments that will define the future of the effort – CUPID and nEXO.

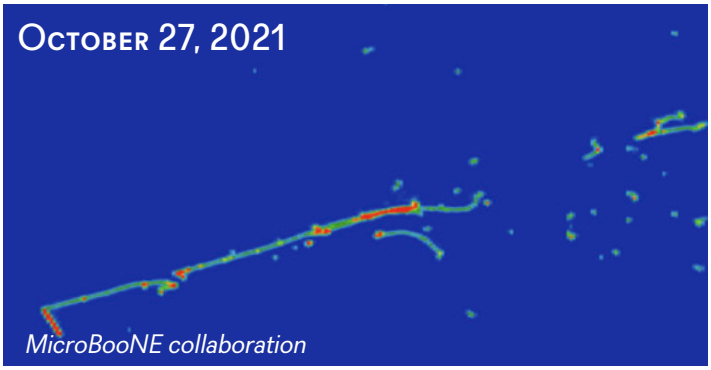


ALICE first collision data demonstrates success of Wright Lab detector upgrade

The Relativistic Heavy Ion Group has contributed to the upgrade of one of the LHC's detectors, ALICE, which started taking data on October 27. RHIG was responsible for the assembly and testing of ALICE's inner Gas Electron Multiplier TPC chambers and their readout electronics. ALICE expects to accumulate 50 times more heavy-ion collision data in the upcoming LHC Run 3 than in Runs 1 and 2 combined.

STAR Search

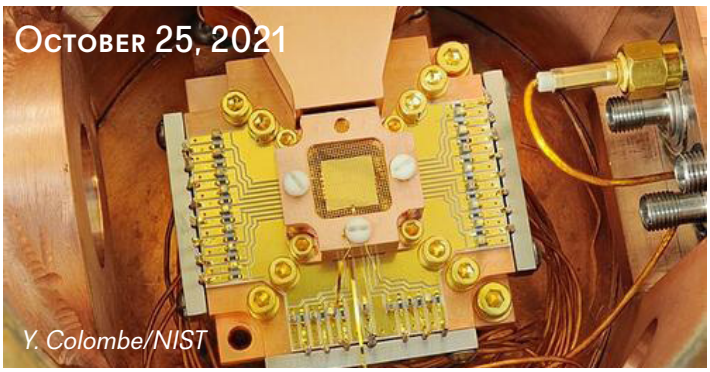
Wright Lab's Relativistic Heavy Ion group and the STAR Collaboration have released the results of a blind analysis of how the strength of the magnetic field generated in certain ion collisions affects the particles streaming out. The results represent a significant milestone and may possibly represent the most precise heavy ion measurement ever done and are expected to lead to a burst of theoretical activity.



MicroBooNE experiment's first results show no hint of a sterile neutrino

This result is the most comprehensive finding thus far for an accelerator-based search for sterile neutrinos. If evidence of a sterile neutrino were found, it would lead to a radical shift in our understanding of the basic building blocks of the universe. Bonnie Fleming's group has been integral to the analyses that led to this new result.

In the News



Using qubits to search for dark matter

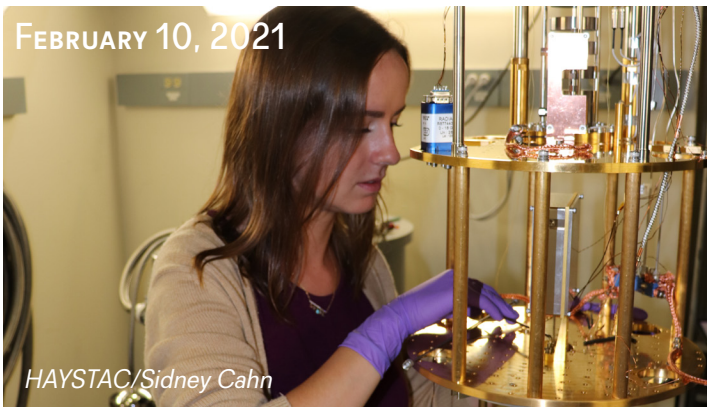
Wright Lab associate professor David Moore, along with three colleagues, recently proposed in *PRL* a novel idea of using trapped electrons and ions—technologies that are being developed as qubits for quantum computation—as ultra-sensitive particle detectors that may be able to enhance the search for the nature of dark matter, neutrinos, new forces, and more.

Yale University becomes official remote site for data taking for ALICE

Researchers in the Wright Lab Relativistic Heavy Ion Group (RHIG) applied for and received permission for Yale University to become an official remote site for data taking for ALICE (A Large Ion Collider Experiment) on the Large Hadron Collider (LHC) at CERN, and a new Remote Operations Site (ROS) is now installed and operational in Wright Lab West.

Fleming group installs SBND Field Cage at Fermilab

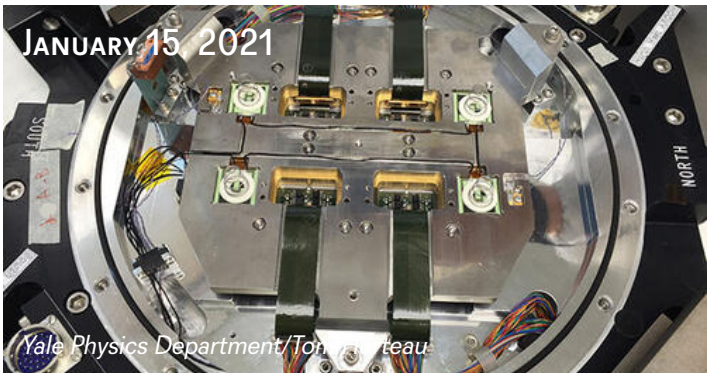
Associate research scientist Domenico Franco and graduate students Giacomo Scanavini and Angela White from Bonnie Fleming's group successfully mounted the Bottom Field Cage of the Short Baseline Near Detector (SBND) Time Projection Chamber (TPC) at Fermilab. The next step is to install the 4 Anode Plane Assemblies (APAs)–two of which were built at Wright Lab in 2018.



Looking for dark matter in a HAYSTAC — with some quantum squeezing

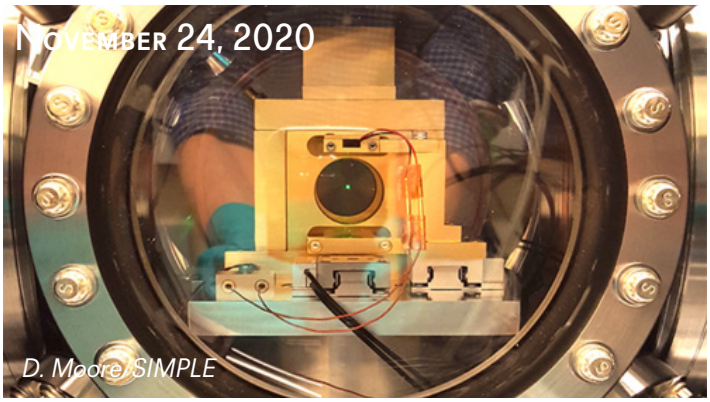
The HAYSTAC experiment hunts for axions, hypothetical particles that are a candidate for the identity of dark matter. New findings led by graduate student Kelly Backes show the team has improved the sensitivity of the detector using a technique known as "quantum squeezing" that reduces the amount of quantum "noise" the axion signal must compete with so the search for the axion can proceed at a faster rate.

In the News



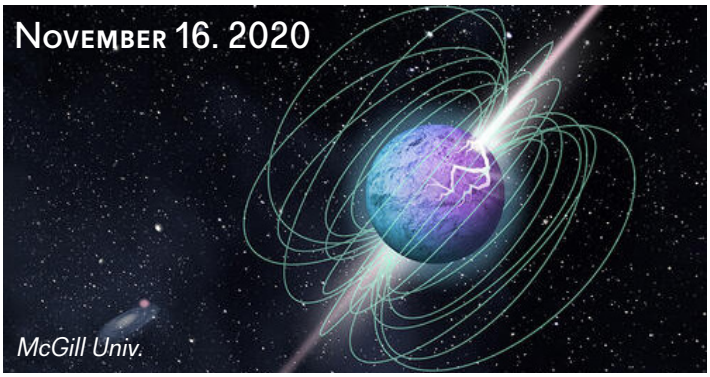
Baltay group contributes to largest ever map of the sky that will inform ambitious DESI survey

In 2015, professor Charles Baltay's group was an integral part of the team that rebuilt and installed an infrared CCD imager onto the Mayall telescope at KPNO in Arizona to undertake a sky survey, which has now contributed to the largest ever 2-D map of the sky. This map will be used to identify targets for the Dark Energy Spectroscopic Instrument (DESI).



SIMPLE-ifying the search for dark matter

Assistant professor David Moore and professor Jack Harris's groups are pioneering innovative mechanical sensing techniques for searching for dark matter. With the SIMPLE experiment, the Moore group has demonstrated the first search for dark matter using mechanical sensors in an optically trapped nanogram mass. Harris's group has developed sensors that can detect tiny excitations of quantized sound to enable new, ultra-sensitive searches for rare interactions from dark matter.



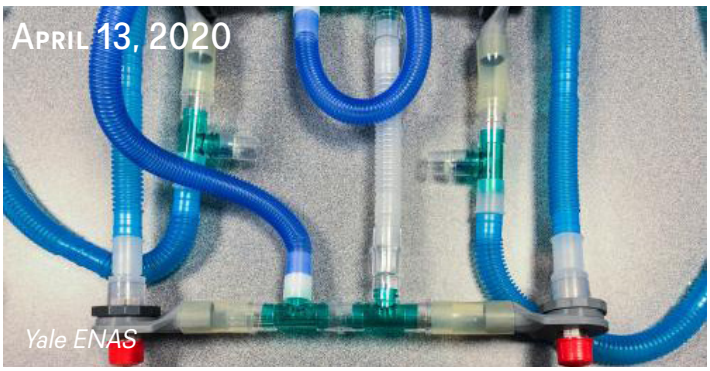
Newburgh interprets a magnetar's message

Assistant professor Laura Newburgh has developed pioneering analysis and measurements that helped establish the brightness of a fast radio burst (FRB) emanating from a nearby magnetar located in the Milky Way. Newburgh is a co-author of a new study in the journal *Nature*, which finds that magnetars, a type of neutron star believed to have an extremely powerful magnetic field, could be the source of some FRBs.

Newburgh's drones help calibrate Brookhaven National Laboratory telescope

Wright Lab assistant professor Laura Newburgh has been developing an innovative technique to calibrate radio telescopes across the world using radio sources attached to hexacopter drones. Newburgh collaborates with cosmologists at BNL to field test these drones by calibrating BNL's experimental prototype radio telescope, called the Baryon Mapping Experiment (BMX).

In the News

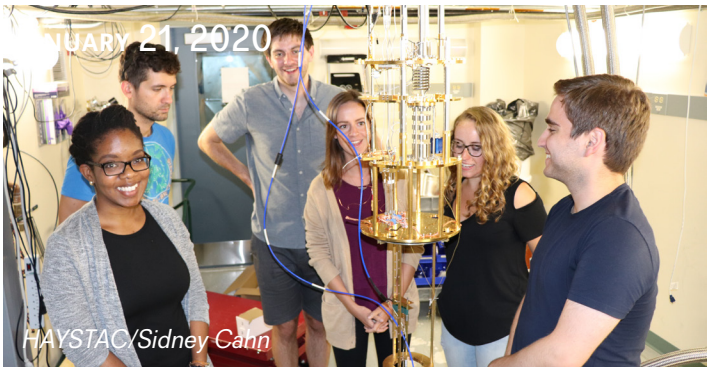


Wright Lab enables researchers to develop multi-patient ventilators

At the start of the COVID-19 pandemic, research scientist James Nikkel and the Wright Lab APC joined a Yale effort in exploring how to design a device that can be 3D-printed, added to a standard ventilator, and allow for the ventilation of multiple patients while still independently controlling the air flow to each, accommodating the differences in individual patients.

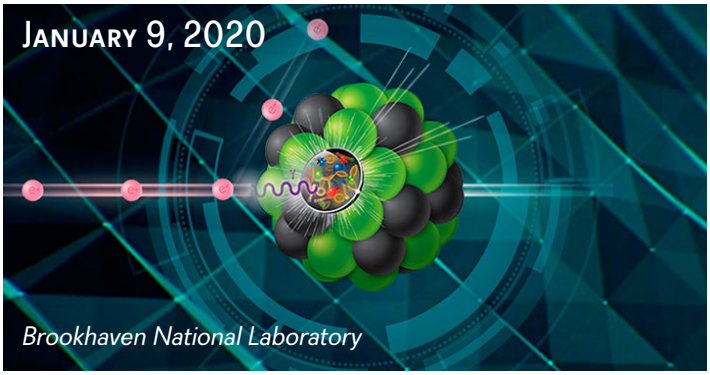
Latest CUORE release improves understanding of the neutrino

Wright Lab researchers in CUORE are searching for evidence of a rare particle process called neutrinoless double beta decay. CUORE recently released two years' worth of data collection, which did not show evidence of neutrinoless double beta decay, but it did yield a better idea of a neutrino's mass during such a process.



The other dark matter candidate

Wright Lab professor of physics Reina Maruyama and the HAYSTAC experiment were featured in an article in *Symmetry* magazine called "The other dark matter candidate" about the axion. Maruyama and professor of physics Steve Lamoreaux lead the HAYSTAC dark matter detector experiment, housed here at Wright Lab, which is searching for axions.



Yale research partner BNL chosen as site for next generation Electron-Ion Collider

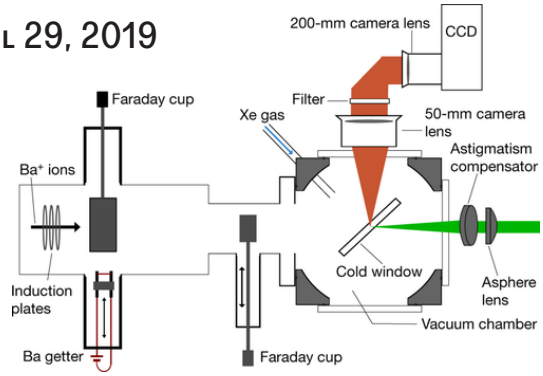
Congratulations in particular to Wright Lab adjunct professor Thomas Ullrich, who has been one of the key players in this success. The news is especially welcomed by the Relativistic Heavy Ion Group (RHIG) at Wright Lab. RHIG has been developing technologies for detectors at BNL for many years, and their expertise will be invaluable for designing and developing detectors for the EIC.

In the News

STAR's inner Time Projection Chamber Upgrade Project completed

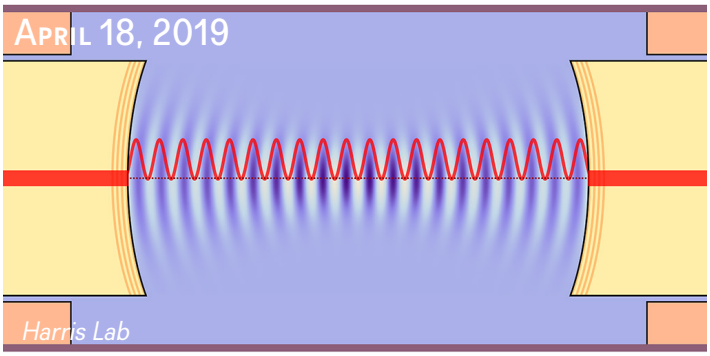
Wright Lab postdoc Saehansuel Oh was an integral member of the team that tested and installed new sectors for the inner Time Projection Chamber at STAR on RHIC at BNL. The iTPC increases STAR's ability to capture particles emerging close to the beamline in the "forward" and "rearward" directions, as well as particles with low momentum.

April 29, 2019



nEXO collaboration images single atom in a solid rare element for the first time

The nEXO collaboration, including associate professor David Moore's group, has successfully imaged & tagged a single barium atom in solid xenon. This is the first time single atoms have been imaged in a solid noble-element matrix, providing a key step towards using this technology to search for neutrinoless double beta decay, a process that has been theorized but not yet observed.



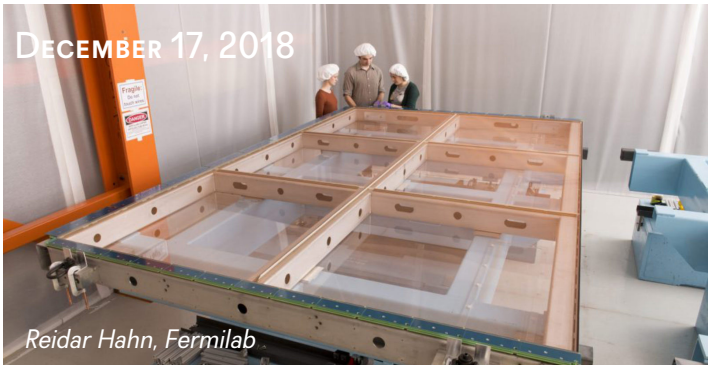
New experiment dives into quantum physics in a liquid

Jack Harris's lab and their collaborators have directly observed quantum behavior in the vibrations of a liquid body. They detected the sound wave's quantum properties: its zero-point motion, which is the quantum motion that exists even when the temperature is lowered to absolute zero; and its quantum "back-action," which is the effect of a detector on the measurement itself.

Laura Newburgh's research detects second repeating fast radio burst from other galaxy using the CHIME telescope

Assistant professor Newburgh is a co-author of two studies that have detected the second-known example of a repeating fast radio burst originating far outside the Milky Way galaxy. More than 60 FRBs have been observed to date, but this is only the second time researchers have found repeating bursts from a single source.

In the News



First critical components arrive from Wright Lab for SBND (article in *Symmetry*)

Professor Bonnie Fleming's group, in collaboration with the Neutrino Group at Syracuse University, have assembled an Anode Plane Assembly (APA) for the Short Baseline Near Detector (SBND) in the Wright Lab Vault and have sent the APA to he US Department of Energy's Fermi National Accelerator Laboratory (Fermilab).

Wright Lab-led COSINE-100 experiment investigates dark matter mystery

Reina Maruyama is the principal investigator of COSINE-100, an international experiment that challenges previous claims by the DAMA collaboration about the detection of non-luminous dark matter. COSINE-100 is the first experiment sensitive enough to test DAMA and use the same target material of sodium iodide and now has initial results that challenge the DAMA findings.

PROSPECT results inspire neutrino detectors for diplomacy

A group of international leaders, including Wright Lab Director Karsten Heeger, have published a letter in *Science* called *Neutrino physics for Korean diplomacy*, in which the authors propose using neutrino detectors for verifying reactor shutdown or conversion. The authors were inspired by the recent measurements and success of PROSPECT, which was assembled at Wright Lab.

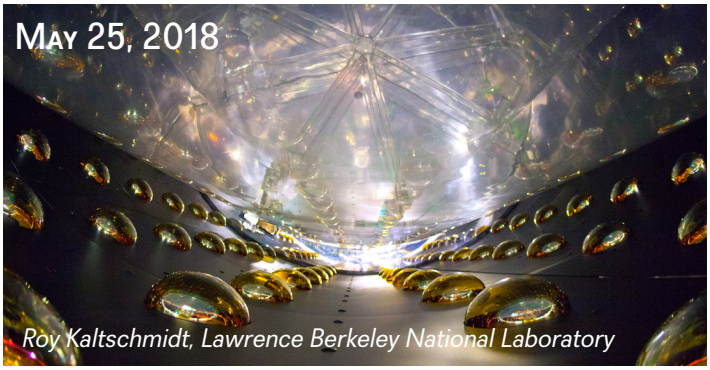
June 20, 2018 Reina Maruyama's search for rare events featured in *Symmetry*

Professor Reina Maruyama's search for dark matter with CUORE (Cryogenic Underground Observatory for Rare Events) is featured in the article *Waiting for a sign* in *Symmetry*.

Wright Lab instrumental in developing DUNE detector modules

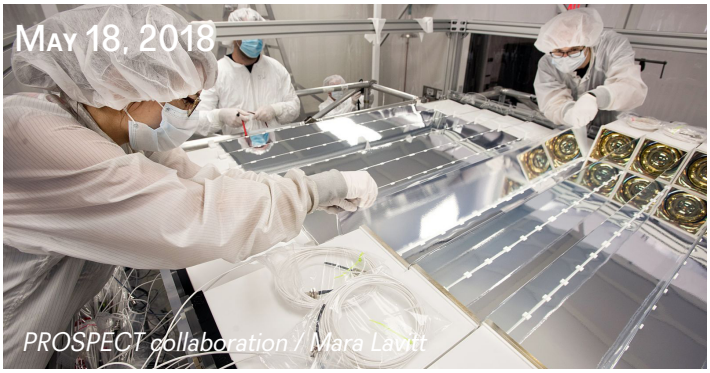
Yale is one of four U.S. universities chosen to design and plan the production of 150 particle detector assemblies for the Deep Underground Neutrino Experiment (DUNE). Professor Bonnie Fleming said the new work with DUNE is a natural extension of previous instrumentation work at Wright Lab, including the MicroBooNE wire chamber and the SBND wire frames.

In the News



Wright Lab leads the field in a number of game-changing neutrino experiments

Wright Laboratory leads and participates in a number of the experiments mentioned in the *Symmetry* article *Game-changing neutrino experiments*, including CUORE, Daya Bay, DUNE, Ice Cube, MicroBooNE, SBND, Project 8, and PROSPECT. Read even more about these experiments at **wlab.yale.edu/research**.



PROSPECTing for antineutrinos

The Precision Reactor Oscillation and Spectrum Experiment (PROSPECT), a novel antineutrino detector that will probe the possible existence of a new form of matter, which was constructed and assembled at Wright Lab, has begun taking data at the High Flux Isotope Reactor (HFIR) at the DOE's Oak Ridge National Laboratory (ORNL) to search for sterile-neutrinos and characterize nuclear reactions that power fission reactors.

March 21, 2018 Helen Caines featured in news release about RHIC's continuing innovation

Professor Helen Caines was featured in a news release about the continuing innovation of the Relativistic Heavy Ion Collider in its 18th year of operation. Caines is the co-spokesperson for the STAR experiment at RHIC.

First result from CUORE constrains limits for finding neutrinoless double-beta decay

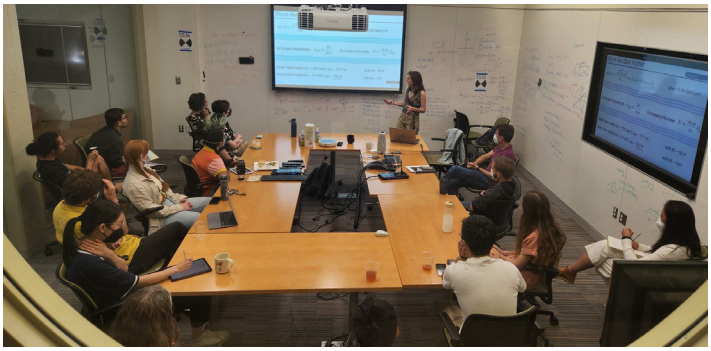
The Physical Review Letters (PRL) publication includes the result of Yale Ph.D. alum Jeremy Cushman's 2018 thesis, which "finds no evidence for double-beta decay and sets the world-leading limit on the rate of double-beta decay in 130Te". Additional Wright Lab co-authors are Christopher Davis, Karsten Heeger, Kyungeun Lim, Reina Maruyama, and Tom Wise.

How to Map the Phases of the Hottest Substance in the Universe

The Relativistic Heavy Ion Collider (RHIC) at Brookhaven National Laboratory is crucial to the research of the Relativistic Heavy Ion Group at Yale, led by professors Helen Caines and John Harris. This Department of Energy, Office of Science article sheds light on how RHIC is key for their research.

Seminars

Wright Lab's seminar programming complements the education of our community, bringing in experts in various fields related to their research and learning. Regular seminars, journal clubs and discussion groups include:



Nuclear Particle Astrophysics Seminars

cover recent results and new developments in experimental nuclear, particle, and astrophysics. NPA seminars are the main research talks at Wright Lab and draw a diverse audience interested in current topics in fundamental physics. NPA seminars are supported by the Flint Fund, Wright Lab, and Yale University.

WIDG

is a biweekly seminar held at Wright Lab, with talks generally given by Yale Physics graduate students and postdocs on a variety of topics, including Cosmology, Nuclear, Particle, Neutrino, AMO, & Theoretical Physics. The seminar is open to all members of the Yale community. WIDG talks are supported by Wright Lab, the Yale Physics Department, and Yale University.

Yale Physics Professional Development Organization (YPPDO)

is focused on providing physical science PhDs 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.

Please see yppdo.yale.edu for more information.

Instrumentation Lunch

is a forum for discussions on topics related to instrumentation, quantum sensors, and experimental methods. Everyone interested in instrumentation and its related applications in experiments and beyond is welcome. Instrumentation lunches are supported by Wright Lab and Yale University.

Discover more about Wright Lab seminars at **wlab.yale.edu/seminars**

Conferences, workshops, and collaboration meetings

From 2014-2022, Wright Lab has hosted at least 37 conferences, workshops, collaboration meetings, and site visits. For a full list, please see: **wlab.yale.edu/events/conferences-and-workshops**.

2018 Conference - Symmetries and Order: Algebraic Methods in Many Body Systems

A conference in October 2018 held in honor of Yale Physics professor Francesco Iachello, on the occasion of his retirement.

See **sites.google.com/yale.edu/symmetriesandorder** or the **AIP Conference Proceedings Volume 2150** for more information.

Wright Lab Quantum Sensing Workshop

Yale's Wright Lab is exploring the applications of quantum science and sensing to tests of fundamental physics. This workshop, hosted by Wright Lab as part of Quantum Week at Yale, brought together researchers from Wright Lab to discuss their work and future opportunities in this field. See **wlab.yale.edu/wright-lab-quantum-sensing-workshop** for more information.

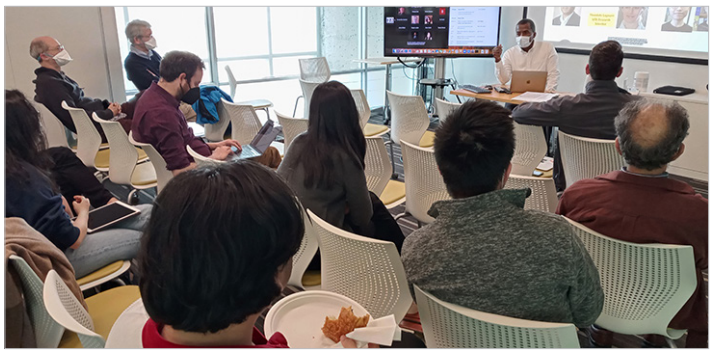
Collaboration meetings and workshops

for Wright Lab research collaborations, including:

ALICE, COSINE-100, CUORE, HAYSTAC, the La Silla-QUEST Southern Hemisphere Variability Survey, nEXO, Project 8, and PROSPECT

Yale Day of Instrumentation

Wright Lab has been involved in connecting instrumentation development efforts across Yale through co-sponsoring the 2018 and 2020 Yale Day of Instrumentation workshops and additional town halls and workshops. Input from these events has informed the University's commitment to building a new Advanced Instrumentation Development Center (AIDC) in the Physical Sciences and Engineering Building (PSEB), which includes an expansion of the Wright Lab facility.



Discover more conferences and workshops at **wlab.yale.edu/events/conferences-and-workshops**

Conferences, workshops, and collaboration meetings

2022

November 29 - December 02, 2022: CPAD Instrumentation Frontier Workshop 2022
June 13-17, 2022: Project 8 workshop
April 8, 2022: "Wright Lab Quantum Sensing" workshop (as part of Quantum Week at Yale)
April 7-8 2022: Girls Advancing in STEM (GAINS) conference
May 27, 2022: Town Hall on the Advanced Instrumentation Development Center (AIDC) in the Physical Science and Engineering Building
January 5-7, 2022: nEXO Collaboration Meeting

2021

November 8-10, 2021: CUORE Collaboration Meeting
October 21, 2021: HAYSTAC Workshop

2020

May 22, 2020: Ideation Workshop on an Advanced Instrumentation Development Center in the Physical Sciences and Engineering Building
January 24, 2020: 2020 Yale Day of Instrumentation
January 17-19, 2020: APS Conference for Undergraduate Women in Physics (CUWiP)

2019

May 28-31, 2019: PROSPECT analysis workshop
April 1-5, 2019: Project 8 Collaboration Meeting

2018

November 16, 2018: 2018 Yale Day of Instrumentation
November 8-10, 2018: CUORE Collaboration Meeting
October 11-12, 2018: Project 8 Analysis Workshop
October 5-6, 2018: Symmetries and Order: Algebraic Methods in Many Body Systems - In honor of Francesco Iachello, on the occasion of his retirement. AIP Conference Proceedings Volume 2150
September 11-12, 2018: U.S. ATLAS Site Review
July 16-20, 2018: PROSPECT Analysis Workshop
June 17-30, 2018: National Nuclear Physics Summer School 2018
May 21-25, 2018: HAYSTAC workshop
March 13-14, 2018: 3rd COSINE-100 Collaboration Meeting
February 24, 2018: La Silla-QUEST Southern Hemisphere Variability Survey Workshop
February 1-2, 2018: Project 8 Software Workshop

2017

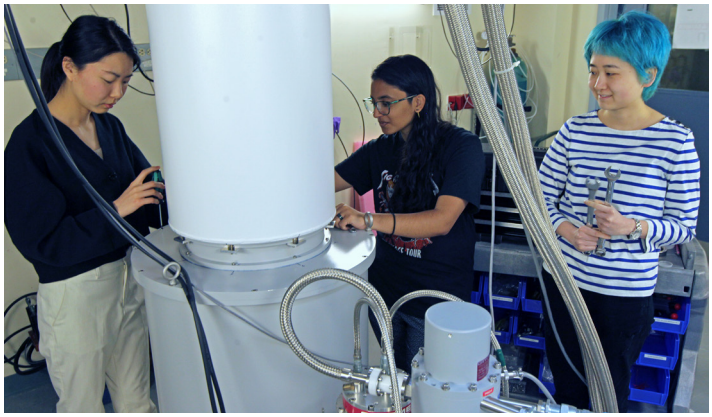
May 16, 2017: Wright Lab Transformed: public opening of new Wright Laboratory

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

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. The committee was asked to recommend priority areas for investment and mechanisms for better coordinating science at Yale. In a 2018 report, 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 aligns with these strategic priorities in the following ways:

Quantum sensors and measurement

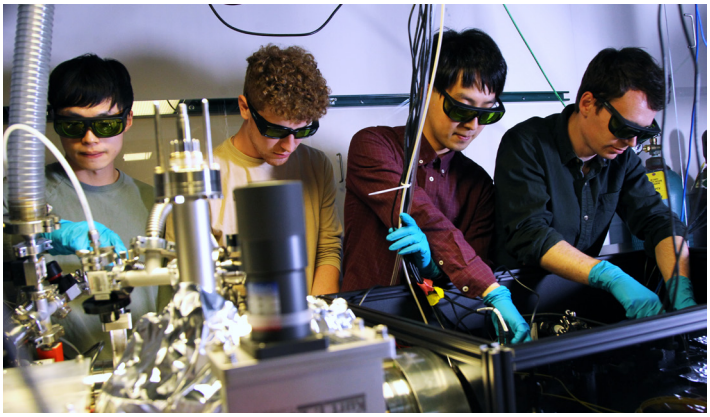


"Devices whose operations are based on quantum principles include the potential for radically new measurement devices and sensing techniques able to focus on tiny signals and (partially) ignore noise. . . [and] are beginning to even surpass the standard limit expected from . . . the famous Heisenberg uncertainty principle" - USSC report, p. 35. (*See pp. 19-22 of this report for more information on Wright Lab efforts in developing quantum sensing tools and techniques*.)

Data science and Machine Learning

"Yale's rich tradition in the theory and methods of data analysis and scientific computation sets it apart as a leader at the innovation frontier for the advanced tools and techniques that this torrent of complex data will require" - USSC report, p. 28. A growing number of Wright Lab research groups are applying data science and machine learning to research in fundamental science, enhancing their capability for discovery.

Instrumentation Development



"The newly renovated Wright Laboratory, which not only houses new research laboratories, but also our highly-coveted machine shops for the development of unique devices, is a bustling hub of instrumentation development." - USSC report, p. 21

Core Facilities

"State-of-the-art core facilities are crucial for innovation across the University. Research in every laboratory is dependent upon these services." - USSC report, p. 3. Wright Lab hosts four University core facilities (*see p. 64 of this report for more information*).

Diversity across the STEM pipeline

"Maximizing the ability of all scholars, including those at Yale, to thrive in the sciences, requires the development and support of diversity efforts throughout the scientific talent pipeline." - USSC report, p. 17. Wright Lab is committed to diversity and inclusion among all students, staff, and faculty. The goal of our lab community is to provide a safe and supportive environment for research, teaching, and mentoring. Diversity, equity, and inclusion are core principles of our workplace and part of the excellence we aim for. (*See more on p. 48.*)

Discover more at **research.yale.edu/ussc-report**

Graduate Student Support

Wright Lab regularly supports training, research, and research-related travel of its graduate students through faculty and departmental sponsorship, as well as by providing to all students the resources and infrastructure available at Wright Lab. Wright Lab students excel in their fields and often are awarded competitive external, Yale, and departmental fellowships (*see honors, p. 50, for more*). As mentioned in the USSC report (p. 14), a continued strategic investment in STEM graduate education at Wright Lab is needed to ensure sustained scientific excellence in the coming decades.

Yale Physics Graduate Diversity Fellowhip at Wright Lab

The Yale Physics Department initiated a Graduate Diversity Fellowship in 2021, and both of the fellows thus far have been Wright Lab students. The fellowship is 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.

2021-22
Iris Ponce
Fellowship Mentor: R. Maruyama

A study of how students enter or leave the Yale Physics undergraduate program.

Document with photographs women and other gender minorities in the department on social media for 2022 Women's History Month.

2022-23
Sanah Bhimani
Mentor: L. Newburgh

Focus on departmental climate survey, including review of past surveys and initiating new survey with a professional, external survey entity.

A legacy of collaboration between BNL and Yale

Maintaining the strong, ongoing legacy of collaboration and substantial partnership between Brookhaven National Laboratory (BNL) and Yale in instrumentation initiatives and research 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 USSC report.

Historical Impact

- Yale was part of the Founding of BNL (1947). Yale and 8 other universities began the effort in 1946.
- The invention of Liquid Argon (LAr) calorimetry in the early 1970's was spearheaded by Bill Willis (Yale), Veljko Radeka (BNL), and Howard Gordon (BNL).
- Heavy ion experiments at the Alternating Gradient Synchrotron (AGS) in the 1980's and 1990's.
- Rare kaon decay experiments at the AGS by Mike Zeller, (Yale) and Laurie Littenberg (BNL).
- The Muon G-2 experiment was started at BNL by Vernon Hughes (Yale) to greatly improve the measurement of magnetic properties of the muon. Muon G-2 moved to Fermilab in 2013 and is still running.
- The ATLAS transition radiation tracker development was led by Keith Baker, who is now at Yale.
- Daya Bay reactor antineutrino experiment - Karsten Heeger (Yale), Steve Kettell (BNL).

Ongoing Collaborations

Current projects with scientific engagement between Yale & BNL. See details in "Wright Lab Research" pp 4-34.

ATLAS
Elementary Particles

nEXO
Neutrinos & Fundamental Symmetries

DUNE
Neutrinos & Fundamental Symmetries

PROSPECT
Neutrinos & Fundamental Symmetries

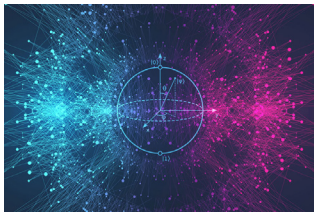
Electron Ion Collider
Relativistic Heavy Ions

sPHENIX
Relativistic Heavy Ions

MicroBooNe
Neutrinos & Fundamental Symmetries

STAR
Relativistic Heavy Ions

21cm cosmology
Astrophysics & Cosmology



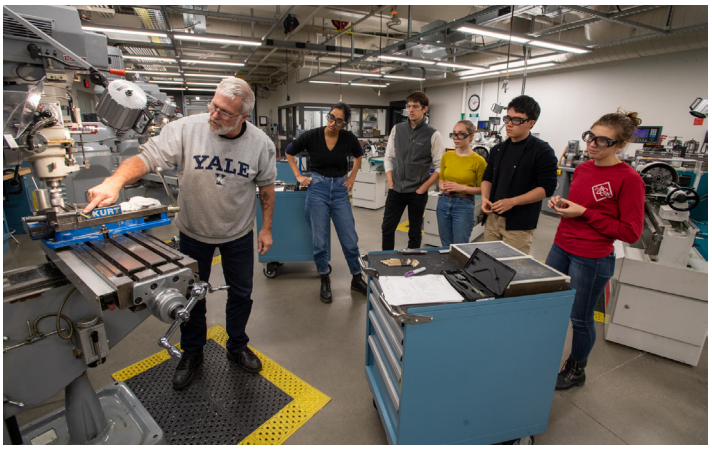
Quantum Science
Quantum Science & Sensing

Brookhaven National Laboratory

Yale

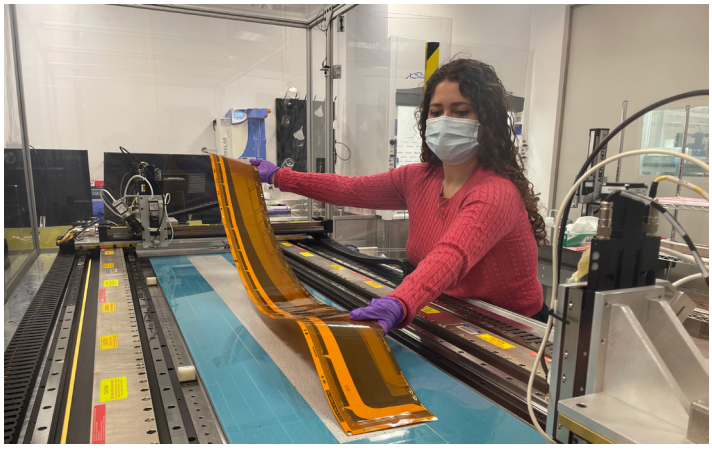
Preparing future scientists

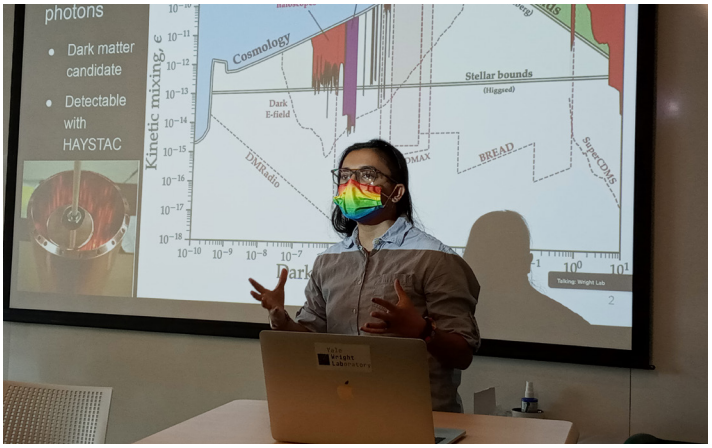
As part of a world-class academic institution, within the Yale Department of Physics, education is one of the pillars of Wright Lab's mission. We strive to educate and train a diverse community of scientists and future leaders in research and development through mentoring, hands-on research experience, career development, and outreach.

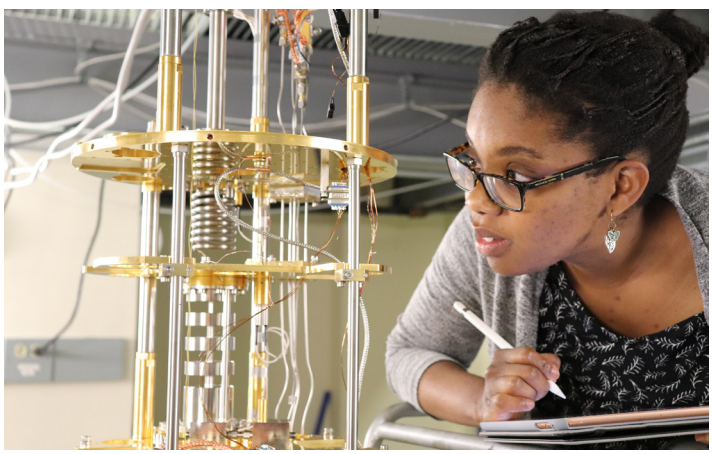


As Wright Lab is an entity that is closely related to, yet separate from an academic department, we have a holistic, interdisciplinary approach to education and training; serving graduate, postgraduate, and undergraduate students, postdoctoral associates across Yale's "Science Hill" and beyond, and the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

Wright Lab is a place of learning and teaching; a training ground to develop student and postdoctoral researchers into well-rounded experimental physicists and empower them to design and build their own research experiment and instrumentation, as well as analyze the data produced by their experiment and develop project management skills. Students at Wright Lab are central to the research at all stages.



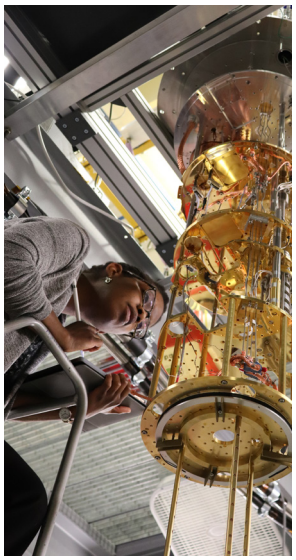




Discover more about education at Wright Lab through the voices of our students at **wlab.yale.edu/videos**

Postdoctoral training

With its focus on science, its world-class faculty mentors and its unique and facilities and infrastructure, Wright Laboratory is a prime place for training postdoctoral researchers, honing their skills for a research career, providing postdocs with:



Hands-on research experience & training

in nuclear, particle, and astrophysics (NPA) (*see pp. 4-34*). with mentorship from faculty who are leaders in the field (*see p. 72*) and collaboration with Wright Lab's specialized technical staff *(see p. 70)*; enabling postdocs to develop skills in instrumentation, analysis, publishing results, project management, mentorship, and more (*see also p. 75*).

Collaboration and Networking

enabled by Wright Lab's partnerships and leadership on campus and throughout the world (*see p. 26*); as well as our scientific programming that brings experts in the fields of NPA to Wright Lab for talks, workshops, conferences, collaboration meetings, and more (*see pp. 35-37, 46*).

Mentoring and Communicating Science

Wright Lab postdocs develop mentorship skills by working with Yale graduate and undergraduate students in the laboratory. Wright Lab and Yale also offer myriad opportunities for communicating science through both journal publications and outreach opportunities (*see p. 58*).

Postdocs by the numbers

2021-22	16
2017-2022 alumni total	22
Alumni in academia	6
Alumni at national labs/government	6
Alumni in industry	9

NSF MPS-Ascend Postdoctoral Fellow

Fernando Flor

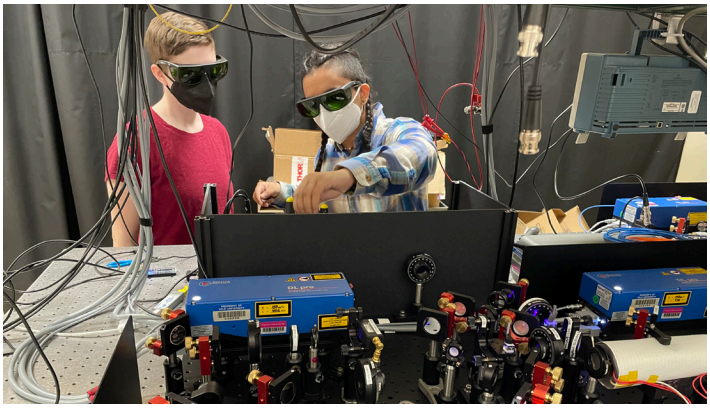
NSF MPS-Ascend Fellow

Relativistic Heavy Ion Group

Fernando Flor is the first postdoctoral fellow at Yale Physics to be supported by the NSF Mathematical and Physical Sciences Ascending Postdoctoral Research Fellowship (NSF MPS-Ascend), which supports postdoctoral fellows who will broaden the participation of groups that are underrepresented in MPS fields in the U.S. Flor is an experimental physicist interested in experimental heavy ion physics and nuclear phenomenology. He said, "I was born in Mexico City and have lived a majority of my life in Texas. As a first-generation college student, I have an immense amount of passion and interest in promoting diverse and inclusive spaces in STEM – with a particular focus on underrepresented minority groups from low-income communities."

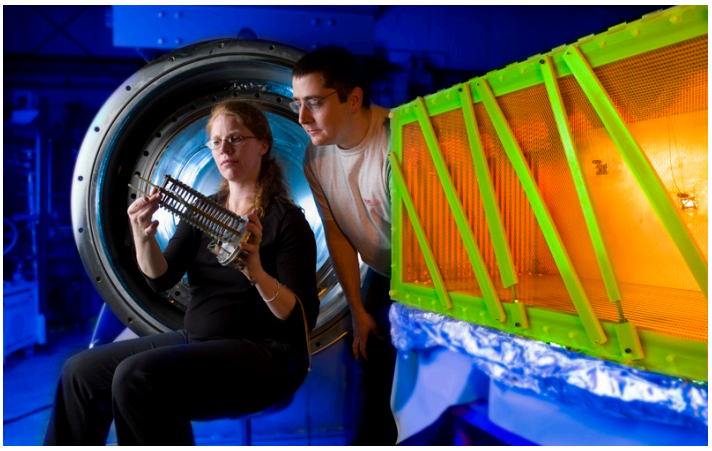
Graduate student training

Wright Lab enables graduate students in the Yale Department of Physics and related departments, including in particular Applied Physics, to experience hands-on research and professional mentorship with a Wright Lab faculty mentor. Students at Wright Lab have the unique opportunity to be an integral part of developing, building, and using research instrumentation during all stages of the process, from designing, machining, and assembling parts; to installing and using instruments at national and international research facility sites; to working on data analysis techniques; to analyzing data; and publishing results.



In addition to the dissertation defense at the end of the academic program, Wright Lab graduate students are provided the opportunity to give scientific presentations at national and international conferences and workshops in their field, as well as in Wright Lab's WIDG seminar. Our graduate students have also been finalists in Yale's annual 3-Minute Thesis Competition. Graduate students are encouraged to attend the professional seminars, trainings, and workshops hosted by Wright Lab (*see pp. 35-37, 46*).

Many of our graduate students are highly sought after by employers in data science and industry because of their unique skills that have been developed at Wright Lab. The Yale Physics Professional Development Organization (*see p. 55*) provides physical science Ph.D.s and postdocs who are interested in non-academic career opportunities with resources to inform their career development and goals. Those Wright Lab students who choose to remain in academia excel in their careers, often winning prestigious fellowships and continuing on to tenure-track faculty positions.



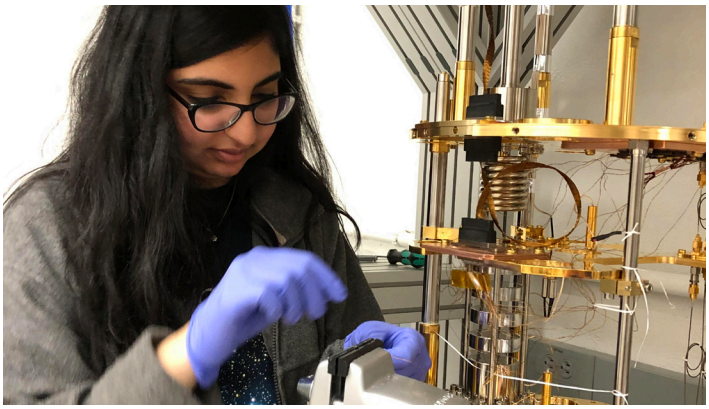
Wright Lab empowers students to do research while developing skills to be leaders in their field. At Wright Lab, graduate students learn how to be a scientist, a scholar, a mentor, a project manager, a resource for technical staff, a citizen. Graduate students at Wright Lab have myriad opportunities to mentor undergraduates and to assume leadership positions in our national and international research collaborations (*see p. 26*), on their research teams, and in organizations on campus (*see p. 54*).

Grad students by the numbers

2021-22 students (all classes)	64
2017-2022 alumni total	35
Alumni in academia	11
Alumni at national labs	11
Alumni in industry - technical/science	5
Alumni in industry - other fields	6
Alumni in science communication	1

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.



Postgraduate Alumni - Where are they now?









Sanah Bhimani (Newburgh) - is now a Ph.D. student in physics at Yale.
J.P. Dervan (Fleming) - is now a Ph.D. student in physics at Northeastern University.
Robert Howard (Baltay) - is now a Ph.D. student in astronomy at Indiana University Bloomington.
Andrew Kilby (Moore) - is now a Ph.D. student in physics at UCLA.
Claire Laffan (Maruyama) - is now a Ph.D. student in physics at Yale.
Annie Polish (Newburgh) - is now a Ph.D. student in physics at Harvard.
Arina Bykadarova Telles (Heeger) - is now a Ph.D. student in physics at Yale.
Field Rogers (Maruyama) - is now a postdoc at Space Sciences Lab at the University of California, Berkeley.
Jack Roth (DeMille, Cahn) - is now a Ph.D. student in physics at the University of California, Berkeley.

Wright Lab DOE Research Traineeship for Diversity in Nuclear Physics

Wright Lab offers a Research Traineeship for Diversity in Nuclear Physics program for undergraduates and recent college graduates. We particularly welcome applications from underrepresented, first-generation, and low-income students. The traineeship is aimed at training a diverse cohort of next-generation scientists as future nuclear physicists and leaders in science. See more at wlab.yale.edu/wl-diversity-traineeship

Trent Rayford

Summer 2022 WL-DOE Research Trainee for Diversity

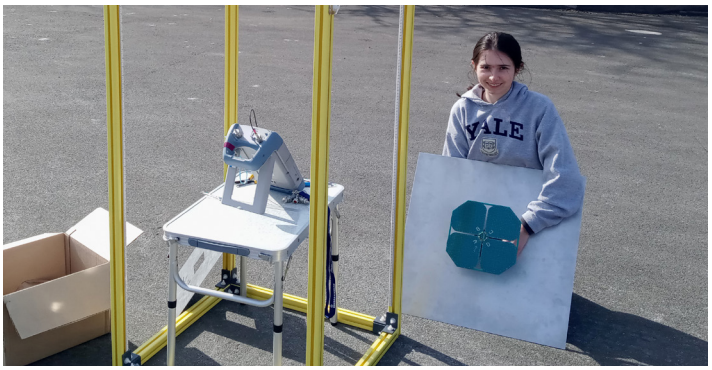
Mentors: Karsten Heeger, Pranava Teja Surukuchi, Arina Telles

Design of test stand to characterize antennas for the Project 8 experiment

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

Undergraduate training

Wright Laboratory has a strong commitment to undergraduate education. Wright Lab faculty teach a number of undergraduate courses in the Department of Physics, from introductory to advanced. In congruence, Wright Lab enables undergraduates to experience hands-on research training and mentorship with a Wright Lab faculty mentor.



Students at Wright Lab have the unique opportunity to be an integral part of all stages of the research process, including designing, machining, and assembling parts; installing and using instruments at national and international research facility sites; working on data analysis techniques; analyzing data; and publishing results.

Wright Lab undergraduates have a number of opportunities to present their research at Wright Lab's annual summer research symposium, 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 Division of Nuclear Physics' Conference Experience for Undergraduates.

Undergraduate students are encouraged to attend the professional seminars, trainings and workshops hosted by Wright Lab *(see pp. 35-37, 46)* to extend their knowledge and experience and enable their research.

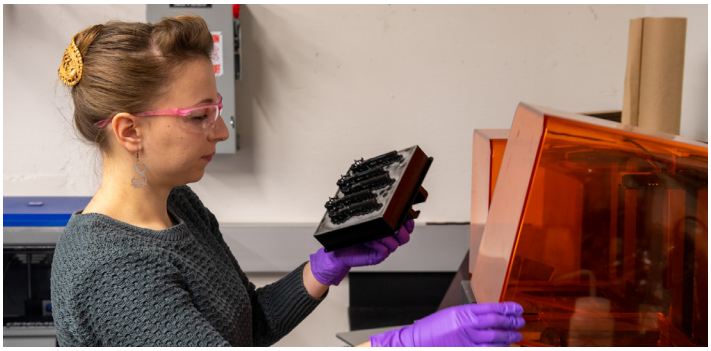
Wright Lab also has supported the Yale Undergraduate Aerospace Association (YUAA) CubeSat project since it received a grant from NASA in 2018 by providing facilities for and advisors to the project.

Wright Lab connects undergraduate student and faculty researchers through participation in the Physics Department's annual research fair and by hosting an annual tour of Wright Lab for the Yale Society of Physics Students (SPS), where undergraduates meet with researchers and tour the facility to learn about the variety of research opportunities and facilities available at Wright Lab.

Discover more about Wright Lab undergraduates at **wlab.yale.edu/people/undergraduate-research**

Training workshops

Wright Lab hosts regular training workshops and orientations for the Advanced Prototyping Center (APC), machine shop facilities and computing facilities at Wright Lab, as well as professional development opportunities.



Advanced Prototyping Center trainings

introduce capabilities and techniques for the APC:

- Introduction to design for rapid prototyping
- Introduction to design and fabrication
- Laser Cutter Workshop
- Abrasive Water Jet Cutting Workshop
- Micro-Controller Workshop

See **advancedprototyping.yale.edu/training**

Computing tutorials

cover a range of topics targeted for the types of computational work performed at Wright Lab, including:

- Introduction to Scientific Computing at WL
- Python for Data Analysis and Processing
- Scientific Parallel Processing
- Cloud Computing
- Github

Machine shop trainings and courses

enable researchers and students across Yale University to use the Wright Lab Teaching Shop for their projects.

- Introduction to the WL shop facilities
- Environmental Health & Safety orientations
- Laboratory in Instrument Design and the Mechanical Arts
- Advanced Mechanical Instrumentation

Professional development workshops

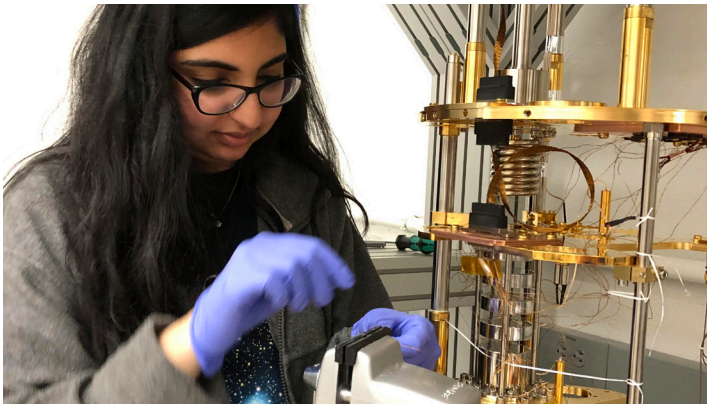
are a regular part of Wright Lab's programming:

- The academic job search and application prep
- Preparing for faculty positions
- Increasing your online presence in academia
- Resumes and websites workshop
- Granville Academy
- Applying to graduate schools panel
- Pitch your research and 3-Minute Thesis events

Discover more about Wright Lab training workshops at **wlab.yale.edu/events/training**

Summer programs

Wright Lab has hosted a summer school, two formal externally-funded research programs and a thriving annual summer research program for undergraudates. See more at: **wlab.yale.edu/events/summer-programs**.



DOE Research Traineeship for Diversity in Nuclear Physics at Wright Lab

The U.S. Department of Energy (DOE) has awarded support for a 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. This program will be offered in the academic year, as well as the summer.

2022 ONAOSI-Yale Undergraduate Research Experience in Instrumentation at Wright Lab

provided 7 students from Italy with hands-on research experience, training, and mentorship in instrumentation at Wright Lab and the medical school. Participants became integrated into the Yale community through living and dining on campus, and attending educational seminars, research group meetings, and other events. See **tinyurl.com/onaosi-yale** for more information.

2018 National Nuclear Physics Summer School at Yale

Wright Lab hosted the NNPSS at Yale in 2018, a two-week summer program for graduate students and early-career postdoctoral associates to join together to learn about recent developments and future directions in nuclear science through lectures, seminars, and tutorials, as well as a poster session and enrichment activities. See also **wlab.yale.edu/nnpss2018**.

Annual Summer Research Opportunities

are available to Yale College undergraduates, undergraduates from other institutions, postbaccalaureate researchers, and early start Yale first-year graduate students. Trainees are immersed in the Wright Lab and Yale research communities, and participate in hands-on research, mentoring, training, and enrichment activities. See **tinyurl.com/WL-summer-2022** for more.

Discover more about Wright Lab summer programs at **wlab.yale.edu/events/summer-programs**

A diverse and inclusive community

Wright Lab is committed to diversity and inclusion among all students, staff, and faculty. The goal of our lab community is to provide a safe and supportive environment for research, teaching, and mentoring. Diversity, equity, and inclusion are core principles of our workplace and part of the excellence we aim for.

A few highlights are below. **Discover more** at **wlab.yale.edu/about/diversity-equity-and-inclusion.**

Yale Physics, including Wright Lab, is now part of the **American Physical Society Inclusion, Diversity, and Equity Alliance (APS-IDEA)**, which is a new initiative with a mission of empowering and supporting physics departments, laboratories, and other organizations to identify and enact strategies for improving equity, diversity, and inclusion (EDI). It will do so by establishing a community of transformation. Discover more at **physics.yale.edu/aps-idea**

Wright Lab community members, within the Yale Physics Department, are leading a variety of efforts to create a more inclusive, equitable, and welcoming department community, including the undergraduate **Women in Physics (WiP)** and graduate **Women in Physics+** (WiP+); **QuARK** (Queer Affiliated fRiends of physiKs); **Girls Science Investigations**, **#BlackinSTEM**, and more. *See more information about Wright Lab leadership in these groups on pp. 54-55.*

Wright Lab co-sponsors and contributes to the leadership of educational initiatives, such as the annual **Granville Academy** of diversity, equity, and inclusion workshops for undergraduate students doing summer research in astronomy and physics, and the undergraduate course, **Being Human in STEM**, which seeks to examine, understand, and disseminate how diversity of gender, race, religion, sexuality, economic circumstances, etc. shape the STEM experience at Yale and nationally, and that seeks to formulate and implement solutions to issues that are identified.

Shared leadership: Wright Lab community members participate in the leadership and membership of the Yale Physics Department's advisory committees, including the **Postdoc Advisory Committee** (PDAC) **Graduate Student Advisory Committee** (GSAC), and the **Undergraduate Student Advisory Committee** (UGSAC),

Advocacy

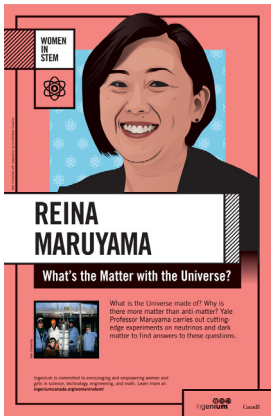
Wright Lab faculty are frequently recognized for their advocacy and efforts pertaining to diversity, equity, inclusion and belonging. A few highlights are below and at **physics.yale.edu/advocacy** and **wlab.yale.edu/news**.

Helen Caines is an advocate for diversity, equity, and inclusion in STEM. Among the courses she has taught at Yale is the **Being Human in STEM course**, which examines how gender, race, socioeconomic background, religion and sexuality shape the STEM experience, and she has been the chair of the **Yale Physics Department's Climate and Diversity Committee (CDC)** and is the co-chair of the **Yale APS-IDEA team**.

Sarah Demers is engaged with bringing science to the public realm and advocating for the equality of women in science through radio appearances, OpEds, podcasts, outreach experiences, and a variety of in-person events. She has also served as the faculty advisor for the **American Physical Society Undergraduate Conference for Women in Physics (CUWiP)** at Yale.

Bonnie Fleming initiated the **Girls Science Investigations** through her NSF CAREER grant in 2006. This is a Saturday program for 6-8th grade girls in New Haven, where they engage in hands-on science experiments at Yale, guided by a team of volunteer mentors. It continues today with private donations and funding through Yale University. Many of our other faculty mentors, postdocs, and undergraduate and graduate students at Wright Lab also participate in this quarterly outreach activity.

Reina Maruyama was **featured on a poster** for the Ingenium Women in STEM initiative, **recognized for mentorship** at Yale's Equity in the Job Search Symposium, chosen to give a **Yale STEM and Social Inclusion lecture**, and a **Granville Academy** talk on "Strategies for dealing with micro-aggressions or implicit bias," and featured on the **Heising-Simons Foundation's 1400 Degrees website,** a directory highlighting the extraordinary achievements and contributions of women and marginalized gender identities to the fields of physics and astronomy.



Awards & Honors

Faculty

Keith Baker

Elected to the **American Academy of Arts and Sciences** (2022); elected as an **American Physical Society (APS) fellow** (2021); appointed the **D. Allan Bromley Professor of Physics** at Yale (2021); named by the Community of Scholars as one of 1,000 **inspiring Black scientists in America** (2021); awarded U.S. Department of Energy (DOE) Office of Science High Energy Physics (HEP) **Quantum Information Science Enabled Discovery (QuantISED) grant** (2018).

Helen Caines

Elected as an **American Physical Society (APS) fellow** (2018); **co-spokesperson for the STAR collaboration** (2017-present).

Sarah Demers

Featured in the **American Institute of Physics (AIP) Oral History interviews**, (2022); served as **Deputy Chair (2018-2019) and Chair (2020-2021) of the US ATLAS Institute Board**.

Bonnie Fleming

Awarded the **American Physical Society (APS) Division of Particles and Fields (DPF) Mentoring Award** (2018).

Jack Harris

Vannevar Bush Faculty Fellowship from U.S. Department of Defense (2019); **Office of Naval Research (ONR) Basic Research Challenge (BRC) grant** to observe quantum behavior in the motion of levitated objects (2018).

Karsten Heeger

Co-Chair of Coordinating Panel for Advanced Detectors (CPAD) of APS DPF (2020-present); **Yale Department of Physics Chair** (2019-present); **co-spokesperson for CUPID experiment** (2021-present).

Reina Maruyama

Recognized for mentorship at Yale's Equity in the Job Search Symposium (2022); Elected to **Connecticut Academy of Science and Engineering (CASE)** (2021); Featured in **AIP Oral History interviews** (2021); Elected as an **APS fellow** (2020); **PI & Scientific co-Spokesperson for COSINE-100** experiment (2015-present) & **DM-Ice experiment** (2010-present); **Chair of CUORE council** (2015-2018); featured on **Ingenium Women in STEM poster** (2019); awarded **QuantiSED grant** for developing technologies for axion searches using techniques used in quantum information (2018).

David Moore

Awarded Yale's **Arthur Greer Memorial Prize for Outstanding Scholarly Publication or Research** (2022); **Sloan Research Fellowship** (2018); **ONR BRC grant** to study rotational degrees of freedom of levitated spheres (2018).

Laura Newburgh

Co-recipient of **Lancelot M. Berkeley – New York Community Trust Prize for Meritorious Work in Astronomy** for breakthroughs in the understanding of a mysterious phenomenon known as fast radio bursts (2022); awarded **NSF CAREER** award to develop and use radio telescopes to map out the expansion history of the Universe (2018).

Awards & Honors

Associate Research Scientists, Postdoctoral Associates and Fellows

Fernando Flor was awarded the 2022 National Science Foundation Mathematical and Physical Sciences Ascending Postdoctoral Research Fellowship (NSF MPS-Ascend).

Both **Eliane Epple** (2015-19, *pictured*) and **Rudiger Haake** (2018-19, *not pictured*) were supported by a Feodor Lynen Research Fellowship from the Humboldt Foundation.

Danielle Speller accepted a position as an assistant professor in the Physics and Astronomy Department at Johns Hopkins University in July 2020.

Jay Hyun Jo was selected as a "Rising Star in Experimental Particle Physics" at the University of Chicago in 2021.

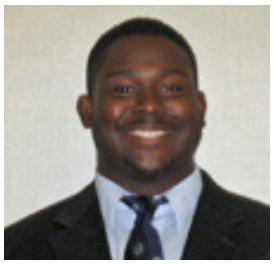
Graduate Student Fellowships & Awards

Kelly Backes was awarded the D. Allan Bromley Fellowship from Yale University in 2020.

Caitie Beattie was awarded the George DeForest Lord Scholarship from Yale University in 2020.

Sanah Bhimani was awarded the Yale Physics Graduate Diversity Fellowship for 2022. She previously was awarded the Warren A. and Hibernia S. Tyrrell Fellowship in 2020.

Hannah Bossi was awarded the Nada Ledinko Fellowship from Yale University and the National Science Foundation Graduate Research Fellowship in 2020.



Charles Brown was awarded the Ford Foundation Dissertation Fellowship in 2018.

Benjamin Brubaker was awarded the American Physical Society's Tanaka Dissertation Award in Experimental Particle Physics in 2019.

Emily Kuhn was awarded the 2022 NASA Postdoctoral Program (NPP) Fellowship. Previously she was awarded the 2019 Francis Englesby Loomis Fellowship, 2018 National Science Foundation Graduate Research Fellowship Program Fellowship (NSF GRFP) and the 2018 NASA Space Technology Research Fellowship (NSTRSF).

Awards & Honors

Graduate Student Fellowships & Awards

Iris Ponce Pinto was chosen as the Graduate Student representative on the American Physical Society (APS) Division of Particles & Fields (DPF) Ethics Advisory Committee (EAC). Previously she was awarded the Yale Physics Graduate Diversity Fellowship in 2021 and the Professor Horace D. Taft Award in 2020.

London Cooper-Troendle was awarded the U.S. Department of Energy's (DOE) Office of Science Graduate Student Research (SCGSR) program in 2019.

Sean Frazier was awarded the Warren A. and Hibernia S. Tyrrell Fellowship in 2019.

Sumita Ghosh was accepted into the triplet program of the Quantum Information Science and Engineering Network (QISE-NET) in 2020.

Lee Hagaman was awarded the 2022 Department of Energy Office of Science Graduate Student Research Program grant.

Ako Jamil was awarded the Graduate Instrumentation Research Award (GIRA) - honorable mention in 2020.

Danielle Norcini was awarded the D. Allan Bromley Fellowship Fund for Graduate Research in Physics in 2018.

Samantha Pagan was awarded the National Science Foundation Graduate Research Fellowship in 2020 and the Dean's Emerging Scholars Fellowship in 2019.

Alex Reda was awarded the Leigh Page Prize in 2019.

Lauren Saunders was awarded the Francis Englesby Loomis Fellowship from Yale University in 2020.

Benjamin Siegel received the NSF Graduate Research Fellowship Honourable Mention in 2019.

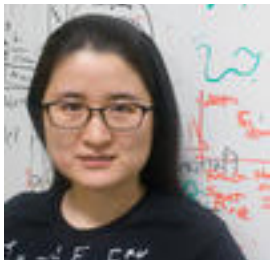
Awards & Honors

Graduate Student Fellowships & Awards

Arina Telles was awarded the Yale John Sloane Fellowship in 2020. She previously was awarded the National Science Foundation Graduate Research Fellowship in 2020, the 2019 Leigh Page Prize and the DeForest Pioneers Prize in 2018.

Savannah Thais was awarded the D. Allan Bromley Fellowship Fund for Graduate Research in Physics in 2018.

Sierra Wilde was awarded the 2022 National Science Foundation Graduate Research Fellowship.



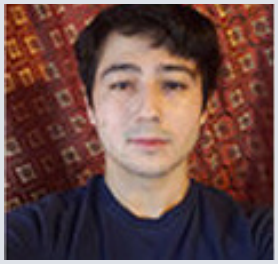
Shilo (Qing) Xia was awarded the 2018 Graduate Instrumentation Research Award (GIRA) honorable mention.

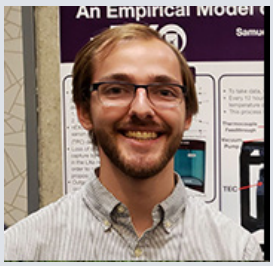
Luna Zagorac was awarded the Leigh Page Prize for Excellence in Graduate Student Teaching in 2021.

Undergraduate Student Fellowships & Awards

Matthew King was awarded the National Science Foundation Graduate Research Fellowship in 2022.

Claire Laffan was awarded the 2022 National Science Foundation Graduate Research Fellowship.





(L-R) **Sukhman Singh, Krish Desai, Shoumik Chowdhury, India Bhalla-Ladd** and **Gabe Hoshino** were awarded the 2021 Howard L. Schultz Prize. **Sam Borden, Lukas Baker** (not pictured), and **Elizabeth Ruddy** were awarded the 2020 Howard L. Schultz Prize. **Cady van Assendelft** was awarded the 2019 Howard L. Schultz Prize.

Student Organizations

Wright Lab members are leaders in student organizations, groups, and clubs within the Yale Physics Department and Yale University, including:

American Physical Society Inclusion, Diversity, and Equity Alliance (APS IDEA) is a new initiative with a mission of empowering and supporting physics departments, laboratories, and other organizations to identify and enact strategies for improving equity, diversity, and inclusion (EDI). It will do so by establishing a community of transformation.

History and Foundations of Physics Reading Group (HoFoP) is an interdisciplinary group of students and faculty at Yale dedicated to exploring and discussing topics in the philosophy and history of physics, and of science more broadly. We engage with foundational texts as well as with contemporary ideas and guest speakers.

QuARK (Queer Affiliated fRiends of physiKs) is an organization focused on inclusion and support of members of the LGBTQ+ community in physics. Open to all queer-identifying members of the department, we coordinate regular gatherings of a casual nature to discuss topical issues and foster community.

Society for the Advancement of Chicanos and Native Americans in Science (SACNAS) is an inclusive organization dedicated to fostering the success of Chicano/Hispanic and Native American scientists in attaining advanced degrees, careers, and positions of leadership in STEM.

The **Society of Women Engineers'** (SWE) mission is to stimulate women to achieve full potential in careers as engineers and leaders, expand the image of the engineering profession as a positive force in improving the quality of life, and demonstrate the value of diversity.

As part of Yale's Society of Women Engineers, Wright Lab graduate students Emily Kuhn and Samantha Pagan have developed a STEM education kit called "SpinWheel," which teaches computer science and physics through an art medium.

The Graduate Student Assembly (GSA) is an elected body of students in the Graduate School of Arts and Sciences to identify the needs & concerns of graduate students, consider possible solutions, & present these to the Dean & other administrators.

The Graduate Student Advisory Committee (GSAC) serves as a point of communication between the department's graduate students and administration. The committee advises the Chair, the DGS, and other faculty on matters related to graduate students and the graduate program, including (but not limited to) helping plan annually scheduled departmental events.

Student Organizations

Yale Graduate Women in Physics+ (WiP+) is focused on fostering a supportive environment for underrepresented genders in the Physics, Applied Physics, and Astronomy departments. We coordinate mentoring and social events for graduate students, post-docs, research scientists, and faculty.

Yale Physics Department Happy Hour Committee coordinates the departmental happy hour that happens once a month. The happy hour is a chance for physics graduate students, faculty, and staff to socialize and build relationships in a relaxed environment.

Yale Physics Professional Development Organization (YPPDO) is a graduate student-led organization that provides professional development resources to physical science PhD students and postdocs. In particular, the YPPDO focuses on exposing PhD students and postdocs to non-academic career opportunities and providing them with opportunities to develop the skills required to make the transition to these fields. Please see yppdo.yale.edu for more information.

The Yale Society of Physics Students is a nationally registered chapter of the Society of Physics Students. We host weekly study sessions (with food!), dinners with professors in the physics department, fun study breaks, movie nights, outreach efforts, and other events. We also hold two prestigious senior lecture series every year, first held in 2018: the Howard L. Schultz Senior Prize Lecture in the spring, and the Beatrice Tinsley Senior Prize Lecture every fall.

Yale Undergraduate Aerospace Association promotes and advances aerospace engineering through collaboration, innovation, and outreach. YUAA cultivates leaders who meet challenges with discipline and creativity.

Yale Women in Physics is an undergradate organization that seeks to promote gender equality in STEM, especially in the physical sciences. We host national conferences, as well as lunches, panels, talks and social events for the physics community at Yale.

Discover more at physics.yale.edu/academics/student-organizations and in our **Outreach section** (*see page 58*).

Celebrating our community

At Wright Lab, we enjoy occasional celebrations and other social events that bring our community together.

Wright Lab Opening - May 16, 2017

Wright Lab 5-year Anniversary - May 16, 2022

Winter Celebration - December 12, 2018

Winter Celebration - December 13, 2021

Wear Red Day - February 7, 2020

Ice Cream Social - August 25, 2022

Discover more about these and other Wright Lab events at **wlab.yale.edu/calendar** and **wlab.yale.edu/news**

In memoriam

We celebrate the contributions and legacy of community members from both Wright Lab and WNSL who have passed away within the last five years, including:

Richard "Dick" Majka, Ph.D. '74 passed away on February 20, 2020.

Dick came to Yale as a graduate student, and, apart from a brief stay at LBNL as a Research Scientist, remained at Yale, working first with Jack Sandweiss, then with Helen Caines and John Harris in the Relativistic Heavy Ion Group on designing and testing new detectors for STAR, ALICE and the future EIC.

Dick was also a long-time collaborator on Alpha Magnetic Spectrometer (AMS) experiment on the International Space Station and was involved in other projects, including a search for strange quark matter in lunar soil.

Outside of physics, Dick was a fan of the theater, often traveling into New York; a supporter of local musicians; and an avid hiker, serving on the Board of Directors for the Sleeping Giant State Park.

Harris and Caines said, "the field has lost one of our key hardware experts. More personally, we will miss his presence and often humorous contributions to our wide ranging lunch conversations."

Nathan Cooper, Ph.D. '15 passed away on October 3, 2019 at the age of 35.

Nathan's thesis, titled "Structure of A = 76 Nuclei and Fast-Timing Studies of the Rare-Earth Region" (advisor Volker Werner) was the last Ph.D. thesis to come out of the tandem accelerator at Wright Nuclear Structure Laboratory.

Mary Anne Schulz passed away September 29, 2022. She was born January 15, 1938 in New Haven, and lived her entire life in this city she loved. Mary Anne worked at Wright Nuclear Structure Lab (WNSL) for 46 years, where she fortuitously met her husband Steve. Mary Anne loved her job at WNSL and cared deeply for the people she worked with.

Peter Parker, professor Emeritus of physics and former director of WNSL, reflected, "Mary Anne and the Lab are nearly synonymous in my mind. She was there when I arrived in 1966. She was [D. Allan] Bromley's right hand person; she knew everything about every non-physics aspect of the lab... She and I communicated as equals, acting as sounding boards for each other in regards to lab politics and personnel. She offered wise insights into personalities, and, despite her quiet demeanor, did not suffer fools lightly."

The following is an excerpt from a book published at the time she reached 45 years at Yale.

"Mary Anne has been a denizen of the Wright Nuclear Structure Laboratory (WNSL) . . . for nearly all of her 45 years at Yale. Mary Anne was hired by the founder of WNSL, D. Allan Bromley, who went on to become science advisor for President George H.W. Bush. As Executive Assistant to the lab's director, overseeing the daily operations of Yale's accelerator facility for subatomic physics, Mary Anne has known several generations of the world's leading nuclear scientists and many of the nation's top political and policy leaders. She has impressed every one of them, as well as her colleagues, with her incredible sense of responsibility, organizational skill, friendly attitude (she likes everybody), sheer efficiency, and uncanny ability to ensure nothing ever falls through the cracks, from birthdays to deadlines."

Discover more about their lives and careers in the *In Memoriam* articles posted at **wlab.yale.edu/news**

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 Peabody Museum Summer Camps

partner with Wright Lab to provide class lectures, hands-on experiences and demos, and lab tours to Peabody summer camp participants, who have ranged from grade 4 to 8.

Tours of Wright Lab

Wright Lab frequently provides tours of the lab for a variety of visitors and Yale groups, including for: Yale Alumni Association reunion weekends, Yale Founders Day, distinguished visitors to the University, Yale College classes, the Yale Science and Engineering Association, CTSEED, FlexSchool, the Yale Office of Development, and the Yale Society of Physics Students. If you are interested in a tour, contact the program manager.

Yale Pathways to Science & Yale Pathways to Science Summer Scholars

events bring 6th-12th grade students from the greater New Haven community to Wright Lab for week-long summer courses, open houses providing hands-on experiences and demos, and lab tours. Pathways also involves interested Wright Lab members in additional outreach activities outside of the lab.

Hosting outreach conferences

In January 2020, Yale Physics & Wright Lab hosted the 2020 **APS Conference for Undergraduate Women in Physics** (CUWiP).

In April 2022, Wright Lab, in partnership with the Girls Advancing in STEM (GAINS) network, coordinated the **2022 GAINS conference**, hosted at Yale and held remotely. Wright Lab is again co-coordinating the 2023 GAINS conference, to be held in person at Yale.

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

Communicating science and public engagement

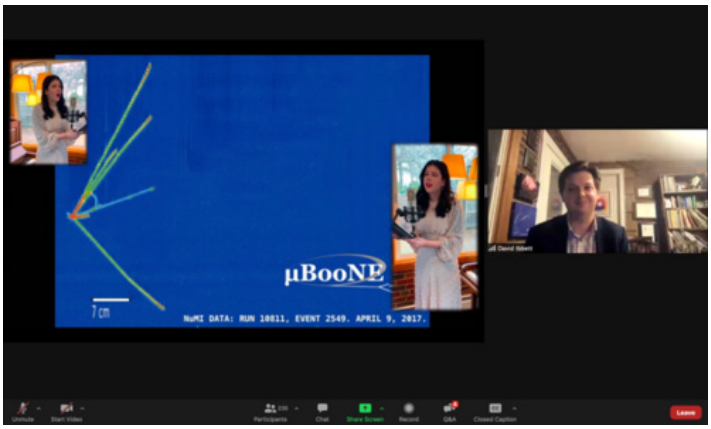
Wright Lab members also communicate science to the public through the media and special events, including:

Science Happy Hour at BAR: Wright Lab and Yale Physics hosted a Science Happy Hour at BAR in New Haven on Tuesday, April 23, 2019. The event was advertised as "a casual evening about contemporary science" and included a panel of five professors - four of whom were from Wright Lab (Keith Baker, John Harris, Agnes Mocsy, and Sarah Demers; joined by Carl Zimmer from the department of Molecular Biophysics and Biochemistry as well as a and a columnist and writer for *The New York Times*) - with ample time for audience questions and engagement.

Segments on ESPN: Wright Lab faculty were featured twice on ESPN. Steve Lamoreaux explained **the physics of football** for *Sunday NFL Countdown* that aired on November 21, 2021. John Harris explained **stellar evolution** in a segment for ESPN that aired on April 9, 2022 at the beginning of the broadcast of a National Hockey League game between the Pittsburgh Penguins and the Washington Capitals.

Wired: Wright Lab's Emily Kuhn (Ph.D. '22) is a former level 10 gymnast. She explained the physics of gymnastics in a 2020 video for WIRED called **"The Physics Behind Gymnastics, Explained (Vaults, Tumbles and Flips)"**. The description for the video on YouTube says that Kuhn "explains all the math behind the amazing flips and turns we see during the Olympic gymnastics competitions," including "why 'The Biles' tumbling routine is so difficult as well as the types of forces acting on these gymnasts every time they use the uneven bars."

A musical collaboration: Wright Lab's professor of physics Bonnie Fleming has collaborated in the composition of a new piece of music called "MicroBooNE" by David Ibbett, the first composer-in-residence at Fermilab, through a series of discussions with the composer about the science of the Micro Booster Neutrino Experiment (MicroBooNE), which is the inspiration for the piece. "MicroBooNE" premiered on December 8 at an online evening of talks and performances hosted by Fermilab's Arts and Lecture Series.

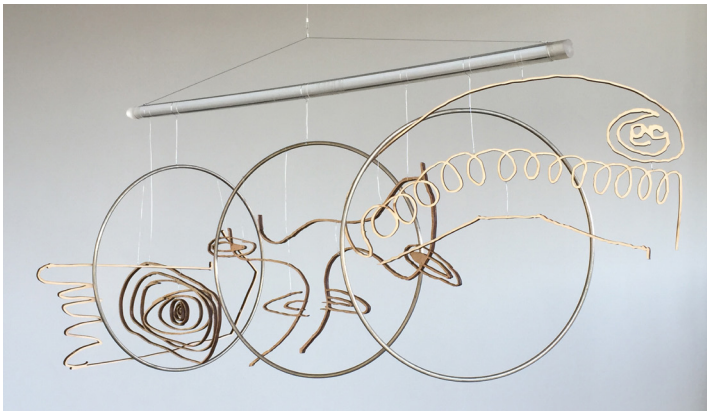


Connecting science and the arts and humanities

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:

Artistic collaborations at Yale: Wright Lab collaborates and partners with the Yale Peabody Museum, the Center for Collaborative Arts and Media (CCAM), the Yale Institute for the Preservation of Cultural Heritage (IPCH), the Center for Engineering, Innovation and Design (CEID), the Yale University Art Gallery, Whitney Humanities Center, the Franke Program in Sciences and Humanities, Yale Drama School, and the Yale Quantum Institute's (YQI) artist-in-residency program.

Visualize Science Contest: In 2019 and 2022, Wright Lab invited artists and scientists from the Yale community for a half-day-long event where teams of artists and scientists worked together, in competition with other teams, to create visualizations of various fundamental physics concepts being worked on by Wright Lab researchers using mixed media provided by Wright Lab. In 2019, the concept was the neutrino, and in 2022, the contest was part of Yale's Quantum Week and focused on quantum entanglement.



Art installations and exhibits: Artistic works and exhibits have been inspired by Wright Lab, including 15 pieces of the accelerator formerly housed at Wright Lab that are installed at the lab as art.

Ideation Accelerator mobile - V. L. Montgomery
Accelerator light show - D. Cho & G. Broshy
Portal sculpture - V. L. Montgomery, K. Heeger
Accelerator exhibits - Montgomery, Heeger, Ashenfelter
"Photographs of the Wright Laboratory" - M. Atherton

Physics Meets the Arts course at Yale: In spring 2019 semester a course teaching physics through various forms of arts was developed and taught by Yale Presidential Visiting Fellow, Agnes Mocsy, who was in residency at Wright Lab. The course culminated in a student exhibition of their final science-art projects at the Yale University Art Gallery, the first physics exhibit produced at YUAG, also in collaboration with Wright Lab.

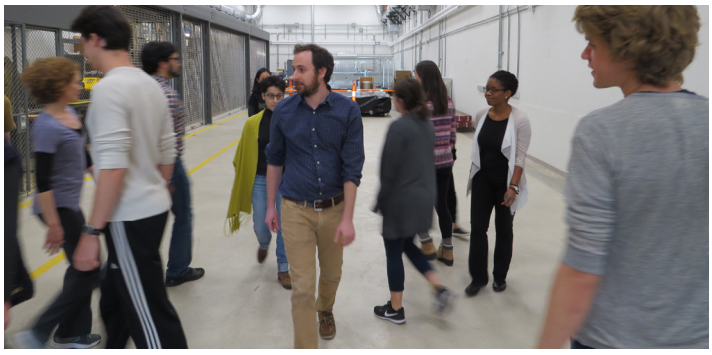
Connecting science and the arts and humanities

Wright Lab Artist-in-Residence program

Emily Coates (2018-2020)

Emily Coates is a dancer, writer, and choreographer who trained at the School of American Ballet and has performed internationally with New York City Ballet, Mikhail Baryshnikov's White Oak Dance Project, Twyla Tharp, and Yvonne Rainer. Her choreographic projects have been commissioned and presented by Guggenheim Works & Process, Performa, Wadsworth Atheneum, Hopkins Center for the Arts, Yale Art Gallery, University of Chicago, and Danspace Project, among others. Currently, she is director of dance at Yale University, where she created the dance studies program.

"Invisible Universe": is a feature-length experimental documentary and dance film directed by Coates that chronicles spontaneous collaborations between leading dance artists and scientists encountering each other for the first time within Wright Lab. "Invisible Universe" considers the poetic confrontation between the methods of the dance-maker and the metrics of the scientist. (WL screening - Nov. 2022.)

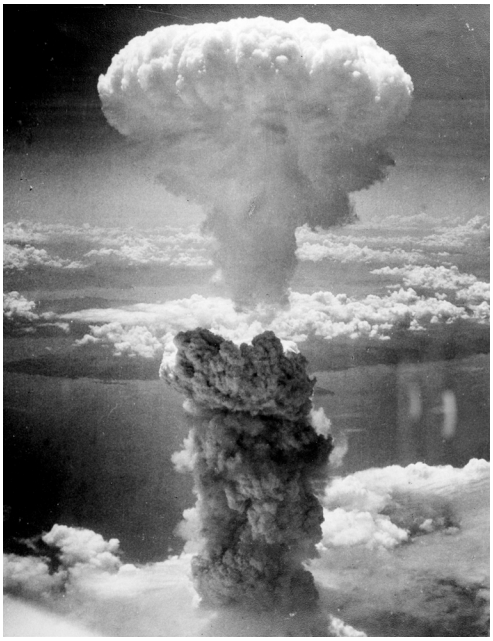


"The Choreographic Imagination: Movement Paradigms in Dance and Physics": included two movement workshops, in 2018 & 2019, that explored the concept of choreographic imagination from the perspective of both dance & physics. With the concept of movement as the point of connection, the goal was to create an active exchange of ideas between scientific & artistic disciplines, and a forum in which to consider physics knowledge & expertise from an alternative perspective.

"Physics and Dance" book: With Wright Lab professor of physics Sarah Demers, Coates co-authored "Physics and Dance" (Yale University Press, 2019), supported by the Alfred P. Sloan Foundation. The book is a fascinating exploration of our reality through the eyes of a physicist and a dancer—and an engaging introduction to both disciplines. Wright Lab hosted the official book launch in February 2019.

Connecting science and the arts and humanities

The Impact of the Atom Film and Lecture Series (2020)



In 2020, Shelly Lesher, Yale presidential visiting fellow and visiting associate professor in physics in residence at Wright Lab, offered a new course for undergraduates entitled "The Impact of the Atom". The seminar explored issues on how the atom has impacted the world using a multidisciplinary approach, including the impact of the atom on history, infrastructure, budget, arts and culture, peace and activism, healthcare, energy and climate change, policy, national security, international relations, science, and the future. A film and lecture series, open to the public, was held in conjunction with the course.

January 26:	"Godzilla"
February 9:	"Dr. Strangelove"
February 19:	The Craft of Writing with Richard Rhodes
February 20:	Richard Rhodes (Yale '59) - "Arsenals of Folly: The Parasitism of Nuclear Policy"
February 23:	"Atomic Café"
February 27:	Leslie Dewan - "Save the world with nuclear power"
April 8:	Ambassador Linton Brooks (students only)

"Yale's Wright Laboratory, A Photo Essay" for *Maquette*

Wright Laboratory was the subject of a photographic exhibition by photographer Monique Atherton, "Photographs of the Wright Laboratory," which was on view at the Yale Center for Collaborative Arts and Media (CCAM) from October 28 through November 22, 2019.

The exhibition included photographs from "Yale's Wright Laboratory: A Photo Essay," composed by Atherton for the new *Maquette* journal from CCAM, which was also released on the same day at an opening reception for both the journal and the exhibition.

The photographs portray Atherton's interpretation of how the machines in the lab behave, and how their functionality is hidden to the human eye. The exhibition captures the essence of the lab, with some photographs shot through a prism to incorporate spectral rainbows into the picture. With a prism between the camera and subject, distortion was brought to the picture through reflections of angles that were not directly in front of Atherton and her camera. Printed with ultra-violet cured ink on Dibond, which are composites of two pre-painted sheets of .012 inch aluminum with a solid polyethylene core, the photographic production process mimics the clean lines of the halls in the Wright lab that lead into the various nodes of activity.

Discover more arts and humanities at **wlab.yale.edu/media/arts**

Stay Connected

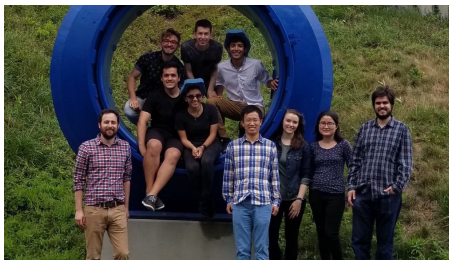
In January 2022, Wright Lab increased its presence on social media with the creation of Instagram, Twitter, and Facebook profile pages. The Wright Lab social media pages highlight news, research, community accomplishments, and events. The Wright Lab YouTube channel features seminar videos, workshops, and interviews. The Wright Lab Flickr page showcases photos of community events.

Follow Wright Lab on Social Media:

Search YaleWrightLab
on Instagram, Twitter and Facebook

@YaleWrightLab

flickr.com/photos/yalewlab/collections



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subscribe.yale.edu

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.

Facilities and infrastructure

Wright Lab is a state-of-the art facility with infrastructure to support fundamental research and discoveries that enables an integrated approach to the design, development, construction, and testing of scientific instrumentation on all scales for experimental investigations and training. The on-campus location provides a unique setting to engage students and train future leaders.

With over 85,000 sqft of lab and office space, Wright Lab is home to several research groups in fundamental physics including nuclear, particle, and astrophysics, quantum physics, and precision measurement groups. Each group has dedicated core laboratory space and access to shared facilities. General laboratory space is outfitted with overhead cranes, ventilation, fume hoods, and other utilities. Shared facilities include those listed below.

Offices at Wright Lab are designed to be open and accessible, with windows and meeting spaces, fostering frequent interactions between researchers, collaborators and mentors. Furthermore, Wright Lab's flexible interaction spaces enable conferences and workshops for its collaborations, as well as regular seminars.

Wright Lab is an integral part of the Yale Physics Department and the core facilities for Instrumentation at Yale (see also **instrumentation.yale.edu**).

Physics Research Facilities at Wright Lab


F. Lopez

- a CAD and Remote Operations Room
- permanent and pop-up clean rooms
- a cryogenic laboratory
- detector development laboratory
- several high-bay areas for large scale instrument assembly and testing
- several laser rooms and optical laboratories
- an RF shielded room
- a wood and plastic shop
- a variety of investigator laboratories
- server rooms for Physics and Astronomy

Yale University Core Facilities at Wright Lab

Advanced Prototyping Center (APC)
Laser cutter, water jet cutter, 3D-printers for use by students and researchers, with supervision. Support for APC training, electronics prototyping, design work.

J.W. Gibbs Professional Shop
Staffed by professional machinists for precision machining, CNC, welding, work with plastics and exotic metals.

Research Support Shop and Teaching Shop
For use by students and researchers with professional supervision. Hands-on training and classes available. Professional advice for design and fabrication of projects. Includes mills, lathes, welding shop, fume hood.

Discover more about Wright Lab facilities at **wlab.yale.edu/facilities**

Computing

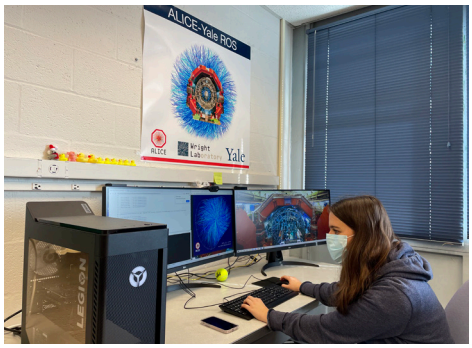
The goal of research computing at Wright Lab is to provide an open, secure, and reliable environment for its community of researchers and their global collaborators. Basic large-scale computation on several of Yale's compute clusters are available free of charge for researchers and students. Wright Lab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

Computing resources at Wright Lab

Server rooms for the physics and astronomy departments at Yale. The servers housed in these rooms provide a local sandbox environment for code development, experimental support and analysis, and collaboration with external institutions; enabling Wright Lab researchers to prototype computational approaches before attempting them in more powerful clustered compute environments. They provide research tools and environments for smaller, partner institutions that do not have access to those provided at the collaborating national laboratories, e.g., BNL, PNNL, FNAL, LLNL, or CERN.

Storage managed locally at Wright Lab, locally on the YCRC computing clusters, centrally at Yale through Storage@Yale and Box at Yale, and also through Google Team Drive and Microsoft Teams/Sharepoint.

High speed **Network** connections through Yale's campus network (10 Gigabit per second (Gbps) connected via 1 Gbps local networks) and Yale Science Net (100 Gbps connected via 10 Gbps fiber lines).



Computer Assisted Design (CAD) workstations for those working on instrumentation designs.

Remote operations room for control and monitoring of experiments.

Collaboration & documentation tools such as Google, Microsoft Office 365, Microsoft Teams, Slack, Zoom, DocDB, web-based wikis, and Indico.

Public cloud-based servers and platform services, hosted in Amazon Web Services, enable Wright Lab to offer collaboration and documentation tools such as DocDB, eLog, and Indico to its global research partners.

Support staff for research and technical computing needs through Yale's Information Technology Services (ITS) and Yale Center for Research Computing (YCRC) personnel.

Training workshops on a variety of computing needs, inlcuding high performance computing, parallel programming, cloud computing, github, python, and more. (*See p. 46 for more information*.)

Collaboration with Yale Center for Research Computing (YCRC)

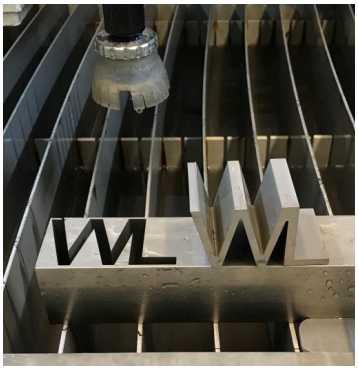
Wright Lab partners with YCRC on novel solutions to the research computing challenges in nuclear, particle and astrophysics. YCRC operates four primary high-performance computing (HPC) clusters located at Yale's West Campus. YCRC personnel are in residence at Wright Lab, and the Wright Lab community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

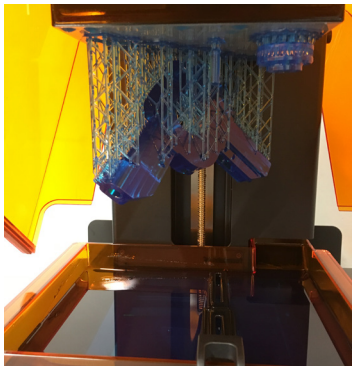
Portions of the Grace HPC cluster are dedicated to astrophysics research and available to Wright Lab researchers. Grace is ideal for high-throughput or highly parallel work and has 24,000 CPUs, 20+ GPU nodes, and 5 bigmem nodes (1.5 TB RAM); a large collection of installed software modules; and support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

Wright Lab Advanced Prototyping Center

At the Yale Wright Laboratory Advanced Prototyping Center (APC), which is located on the first floor of Wright Lab, our mission is to provide an advanced fabrication facility and design support for custom instrumentation within the Yale community. We also aim to help researchers develop design skills and educate them about modern prototyping techniques. The APC complements other research shops at Yale that provide traditional machining services and training.

APC Services





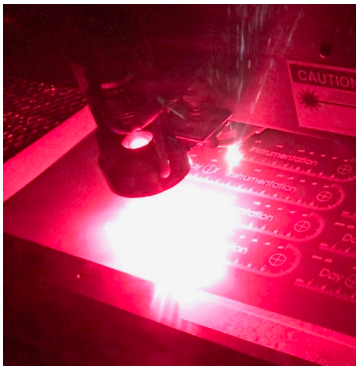
Abrasive Water Jet Cutting & Laser Cutting: We have a high pressure abrasive water jet cutter and a medium power laser cutter. These can be thought of as computer-controlled bands saws; they are largely used to cut through flat material stock. The laser cutter can also be used to etch various materials.

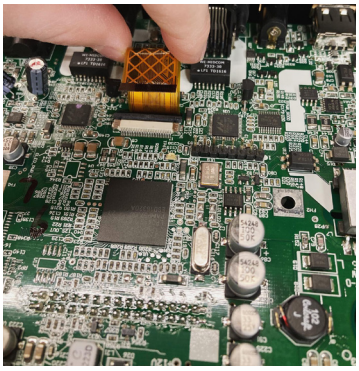
3D Printing: We have a small selection of 3D printers with a variety of materials to print with, including a resin based SLA printer.

Electronics prototyping: We have experience with a variety of electronics monitoring and control systems.

General design work: We have designed instruments and parts for groups across campus.

Training: We put on a variety of workshops throughout the year that anyone can sign up for.





APC People

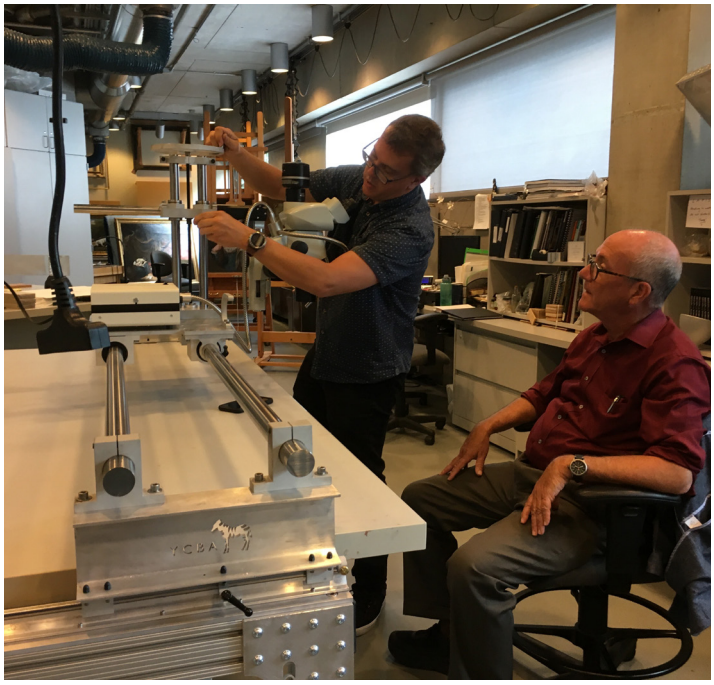
James Nikkel
Director
Research Scientist

Arina Telles
Deputy Director
Yale Physics
graduate student

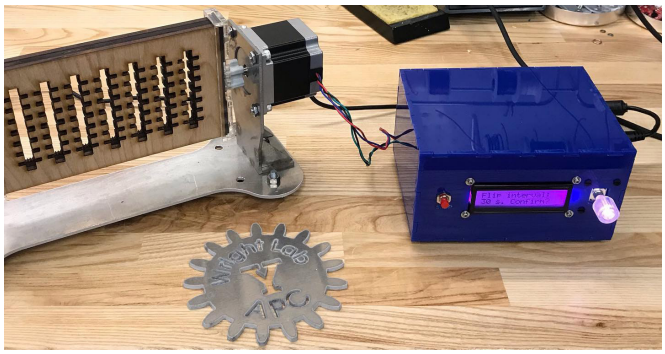
James Wilhelmi
Engineering Support
Research Support
Specialist at WL

Discover more about the Wright Lab APC at **advancedprototyping.yale.edu**

Sample APC Projects



Microscope Bridge for Yale Center for British Art: Following a tour of Wright Lab, the Chief Conservator of the Yale Center for British Art (YCBA) approached us with a request to design and fabricate a microscope bridge to replace their aging and vibration-prone system. After a few consultations and researching commercial versions, we came up with a robust solution that fit within their limited budget. Using standard aluminium extrusions, custom water-jet cut brackets, and a variety of linear slides, we produced a rigid platform for mounting their microscope that can be rolled around to cover different tables. In this case, the YCBA did not have the internal technical staff and facilities to fully realize this project, and suitable commercial products would have been cost-prohibitive and not as versatile. The APC was able to provide design, fabrication, and installation support for this vital piece of conservation equipment.



Fly Flipper: One of the APC's regular users is a graduate student in Damon Clark's lab. Clark is an Associate Professor of Molecular, Cellular and Developmental Biology and of Physics and of Neuroscience who spends much of his time studying fruit flies. In early December 2020, we received a request for a device to periodically flip over one of the fly mazes that we had previously laser cut out for them. Using a few left-over components from another project and a standard microcontroller, we quickly designed and built a device meeting their requirements. While this sort of project is not particularly taxing for a student to put together, there are situations that are time critical or simply an unwelcome distraction from the broader research program. The APC has shown itself to be a valuable resource for those situations.

Conference for Undergraduate Women in Physics: In January of 2020, Yale hosted the annual Conference for Undergraduate Women in Physics (CUWiP) for the New England region. A major part of the conference's vision is to expose underrepresented undergraduates to research that they might not encounter in their home institutions. To this end, the local organizers wanted to give attendees some hands-on experience with detectors and measurement in the form of a 3-hour workshop. This was too much for the organizers to do themselves, and through contacts in Wright Lab, the APC got involved in designing and conducting the workshop. By using Arduinos, LEDs, and light sensors, we put together a workshop that communicated particle detector concepts, as well as teaching some electronics and 'Internet of Things' basics.

Wright Lab Organization

Wright Lab is a Yale University facility and research community that is part of the Yale Physics Department that supports a diverse and active community of scientists, staff, and students. In November 2022, there were 126 people in the Wright Lab community. Wright Lab also serves the broader University community by providing core facilities (*see p. 64*) and connecting researchers with in-house technical experts (*see p. 70*) to advise and assist with the design and execution of research instrumentation projects.

Karsten Heeger, Wright Lab Director

The Wright Lab Director is responsible for providing the overall scientific and administrative leadership and vision of Wright Laboratory. The Director is assisted in this task by the following positions:

Jeff Ashenfelter, Associate Director for Operations

The Associate Director for Operations is responsible for overseeing the Wright Lab facilities, including shops and office and laboratory space, and technical personnel at Wright Laboratory. This position includes ensuring safety requirements as established by Yale Environmental Health and Safety are met.

James Nikkel, Associate Director for Instrumentation and Education

The Associate Director for Instrumentation and Education is responsible for developing the instrumentation initiative at Wright Lab and overseeing the operation of the Advanced Prototyping Center. He also is the lead for developing and teaching workshops, courses, and training programs related to the activities and shared core facilities at Wright Lab.

Victoria Misenti, Program Manager

The Program Manager is responsible for partnering with the Director to conceive, develop, and execute the strategic vision and programming for the Wright Laboratory. Areas of responsibility include: administration, development / fundraising, outreach, visibility and communications, and financial oversight for individual initiatives.

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 applications, training future leaders in research and development, educating scholars, and enabling discovery.

Wright Lab supports a diverse community of scientists, staff, and students who advance our mission and fosters cross-disciplinary collaborations across Yale University and worldwide.

Administrative support

Wright Lab administrative staff support the operations, research, and education at Wright Lab. The staff provide assistance with travel arrangements, purchasing and accounting, and support all such business functions.

Hannah Carroll, Lead Administrator for Physics and Astronomy

Hannah 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.

Taylor Dunnigan, Senior Administrative Assistant

Taylor provides administrative support to faculty, research staff, visitors, and students. She enjoys coordinating Wright Lab events, seminars, and sharing community news on the Wright Lab social media pages.

Paula Farnsworth, Senior Administrative Assistant

Paula supports the Relativistic Heavy Ion, Maruyama, and Fleming groups here at Wright Lab. She has been at the lab for over 20 years and continues to enjoy the variety of tasks she does on a day-to-day basis. One of her favorite things to do at Wright Lab is helping to organize the holiday party – it's her favorite time of year and she likes to help spread holiday cheer!

Kimberly Tighe, Senior Administrative Assistant

Kimberly supports the Heeger, Moore, and Baker groups, providing additional support to Jeff Ashenfelter (Tipton ATLAS) and R&D technicians Frank Lopez & Tom Hurteau here at Wright Lab. She joined Yale Physics six years ago, as a temp preparing & documenting infrastructure for the reopening of WL. Kimberly's role significantly changed when she became a permanent member of the admin staff supporting research. Kimberly enjoys the diversity of cultures with the folks she supports and values the camaraderie she has with coworkers, staff, researchers, and faculty alike.

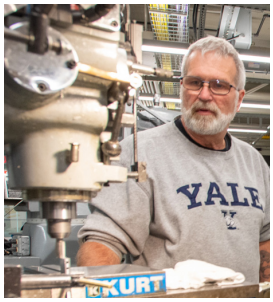
Wright Lab people by the numbers (2021-2022)

6 Administrative Staff	**21** Faculty	**64** Graduate Students
2 Computing Staff	**15** Research Scientists	**4** Postgraduates
15 Technical/Research Support Staff	**16** Postdocs & Fellows	**47** Undergraduates

Machine shops

Vincent Bernardo
Director
J.W. Gibbs Shop

Craig Miller
Manager
WL Research Shop



David Johnson
Manager
WL Teaching Shop

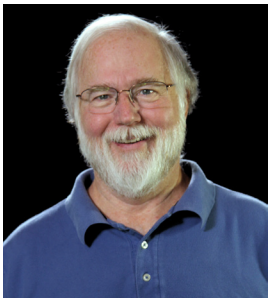
Rosario Bernardo
J.W. Gibbs Shop

Michael Nuzzo
J.W. Gibbs Shop

Dylan Vansteenbergen
J.W. Gibbs Shop

Wright Lab technical support

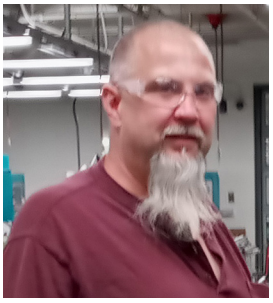
Several specialized staff support the technical work at Wright Lab. Their services are available as needed on an hourly basis or as a shared resource in the laboratory. The Wright Lab research support personnel covers a range of expertise from technicians and mechanical design to electrical engineering required to support a suite of projects.



Thomas Barker
Electrical Engineer

Will Emmett
Mechanical Engineer

James Wilhelmi
Mechanical Engineer

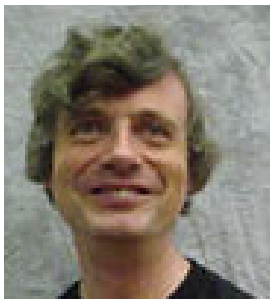


Tom Hurteau
Research Devel. Technician

Francisco Lopez
Research Devel. Technician

Computing support

Vincent Balbarin
Scientific Computing Support/YCRC

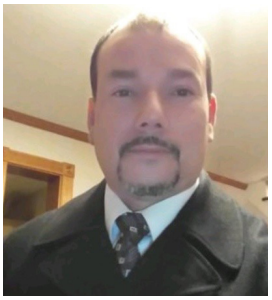


Andrew Currie
Client Support Specialist/ITS

Wright Lab staff alumni

The following staff have retired or accepted other positions within the last 5 years.

Alexander Behzad
Sci. Computing Support/YCRC



Edwin Baez
J.W. Gibbs Shop

Karen DeFelice
Yale Physics Operations Mgr.

William Fortune
J.W. Gibbs Shop

Nick Foster
ITS Computing Support

Candy Francis
Yale Physics Operations Mgr.

Tom Langford
Computational Rsch. Support/YCRC

Edwin Pike
J.W. Gibbs Shop

Lillian Vinston
Sr. Administrative Assistant

Recognizing long-service retirees

Wright Lab recognizes the long service of **Karen DeFelice**, who supported the Yale Physics Department for almost 45 years before retiring in 2020, and to **Lillian Vinston**, who retired in 2021 after 19 years of service to Yale.

Wright Lab Faculty and Research Areas

Keith Baker
D. Allan Bromley Professor of Physics

Elementary Particles
ATLAS, Axions, Hidden Sector Photons, Yale Microwave Cavity Experiment (YMCE)

Helen Caines
Professor of Physics

Relativistic Heavy Ions
STAR, ALICE, EIC

Sarah Demers
Professor of Physics, Director of Undergraduate Studies

Elementary Particles
ATLAS, Mu2e

David DeMille
Professor of Physics

Neutrinos & Fundamental Symmetries, Quantum Physics
Nuclear Anapole Moment Experiment

Now at University of Chicago

Jack Harris
Professor of Physics

Quantum Physics

Bonnie Fleming
Professor of Physics

Neutrinos & Fundamental Symmetries
ArgoNeuT, LArIAT, MicroBooNE, SBND, DUNE

Now deputy director at Fermilab

Karsten Heeger
Professor and Chair of Physics, Director of Wright Laboratory

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

Steve Lamoreaux
Professor of Physics

Astrophysics & Cosmology, Quantum Physics
HAYSTAC

Reina Maruyama
Professor of Physics

Neutrinos & Fundamental Symmetries, Astrophysics & Cosmology
CUORE/CUPID, COSINE-100, DM-Ice, HAYSTAC, IceCube

David Moore
Associate Professor of Physics

Neutrinos & Fundamental Symmetries, Quantum Physics
EXO-200, NEXO, SIMPLE

Laura Newburgh
Assistant Professor of Physics

Astrophysics & Cosmology
ACT, CHIME, HIRAX, Simons Observatory

Paul Tipton
Professor of Physics

Elementary Particles
ATLAS

Emeritus, Visiting, and Adjunct Faculty

Charles Baltay
Eugene Higgins Professor of Physics, Professor of Astronomy

Astrophysics & Cosmology

Richard Casten
Professor Emeritus *of Physics*

Nuclear Structure

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

Relativistic Heavy Ions

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

Neutrinos & Fundamental Symmetries

Peter Parker
Professor Emeritus *of Physics*

Nuclear Astrophysics

Adjunct Faculty

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

Neutrinos & Fundamental Symmetries

Harvey Moseley
Research Affiliate, VP Hardware Engineering, Quantum Circuits

Astrophysics & Cosmology, Quantum Physics

Ornella Palamara
Professor (Adjunct) of Physics & Fermilab & LNGS

Neutrinos & Fundamental Symmetries

Jurgen Schukraft
Professor (Adjunct) of Physics & CERN

Relativistic Heavy Ions

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

Relativistic Heavy Ions
EIC

Visiting and Adjunct Faculty Alumni

Emily Coates
Yale University
Professor of Theater Studies and Drama

Wright Lab Artist-in-Residence

Antonio Ereditato
University of Bern
Visiting Professor of Physics

Neutrinos & Fundamental Symmetries

Jay Hirshfield
Professor (Adjunct) of Physics

Beam Physics

Shelly Lesher
University of Wisconsin-La Crosse
Yale Presidential Visiting Fellow, Visiting Professor of Physics

Nuclear Physics

Ágnes Mócsy
Pratt Institute
Yale Presidential Visiting Fellow, Visiting Professor of Physics

Relativistic Heavy Ions

Berndt Mueller
Duke University
Visiting Professor of Physics

Relativistic Heavy Ions

Research Scientists

Mesut Arslandok
Associate Research Scientist

Relativistic Heavy Ions
ALICE

Sidney Cahn
Research Scientist, Senior Lecturer

Astrophysics & Cosmology
HAYSTAC

Domenico Franco
Associate Research Scientist

Neutrinos & Fundamental Symmetries
SBND, DUNE

Laura Havener
Associate Research Scientist

Relativistic Heavy Ions
ALICE

Brian Koopman
Associate Research Scientist

Astrophysics & Cosmology
ACT, Simons Observatory (SO), CMB-S4

James Nikkel
Research Scientist

Neutrinos & Fundamental Symmetries

Project 8, PROSPECT, Advanced Prototyping Center

Yogesh Patil
Associate Research Scientist

Quantum Science & Sensing
Jack Harris Lab

Gianantonio Pezzullo
Associate Research Scientist

Elementary Particles
ATLAS, Mu2e

David Rabinowitz
Senior Research Scientist

Astrophysics & Cosmology
QUEST, DESI, Roman Space Telescope

Penny Slocum
Associate Research Scientist

Neutrinos & Fundamental Symmetries
Project 8

Nikolai Smirnov
Research Scientist

Relativistic Heavy Ions
STAR, ALICE

Research Scientist Alumni

Henry Band, Xiangyun Chang, Satish Dhawan, George Fleming, Yong Jiang, Thomas Langford, Richard Majka (*deceased, see p. 57*), Rhagav Kunnawalkam Elayavalli, Sergey Schelkunov.

Postdoctoral Researchers

Current Postdoctoral Researchers

Govinda Adhikari (Maruyama): Astrophysics & Cosmology; Neutrinos & Fundamental Symmetries - DM-ICE, COSINE, DUNE
Avinay Bhat (Moore): Neutrinos & Fundamental Symmetries - nEXO
Fernando Flor (Caines): Relativistic Heavy Ions - ALICE, STAR
Michael Jewell (Maruyama): Astrophysics & Cosmology, Quantum Science & Sensing - HAYSTAC
Isaac Mooney (Caines): Relativistic Heavy Ions - STAR
Michael Oliver (Caines): Relativistic Heavy Ions - ALICE
Thomas Penny (Moore): Neutrinos & Fundamental Symmetries, Quantum Science & Sensing -SIMPLE
Pranav Sanghavi (Newburgh): Astrophysics & Cosmology - CHIME
Pranava Teja Surukuchi (Heeger): Neutrinos & Fundamental Symmetries - P8, CUORE, CUPID, PROSPECT
Jorge Torres (Maruyama) Neutrinos & Fundamental Symmetries - CUORE/CUPID
Yuqi Zhu (Maruyama): Astrophysics & Cosmology, Quantum Science & Sensing - HAYSTAC

Postdoctoral Alumni - Where are they now?

Gadi Afek (Moore): Senior Physicist and System Group Leader for Quantum Art in Israel
Maximillian Beyer (DeMille): Assistant Professor in Physics, Vrije Universiteit Amsterdam (VU Amsterdam)
Fernando do Rego Monteiro (Moore): Sr. Applied Scientist - Sensors for Amazon in Seattle, Washington
Eliane Epple (RHIG): Postdoc, Los Alamos National Laboratory
Audrey Francisco (RHIG): Junior Research Scientist, CEA, France
Ruediger Haake (RHIG): Research and Development, Vector Informatik, Stuttgart, Germany
Glen Harris (Jack Harris): Postdoctoral Research Fellow, ARC Centre of Excellence for Engineered Quantum Systems, Australia
Jay Hyun Jo (Maruyama, Fleming): Assistant Physicist, Brookhaven National Laboratory
K. Johnson (Jack Harris): Software Engineering Manager, Quantum Metric
Kirill Lapidus (RHIG): Data Scientist for InfoWatch, Germany
Zepeng Li (Moore): Postdoctoral Researcher UC San Diego
Kyungeun Lim (Maruyama): Senior Data Scientist at Cloud Trucks, San Francisco, California
Xiao Luo (Fleming): Assistant Professor, University of California, Berkeley
Mehdi Namazi (Jack Harris): Co-founder and Chief Science Officer at Qunnect Inc., New York City
Saehanseul Oh (RHIG): Assistant Professor, Sejong University, Korea
Ben Saliwanchik (Newburgh): Staff Engineer, Brookhaven National Laboratory
Mike Sas (RHIG): Fellow at CERN
Danielle Speller (Maruyama): Assistant Professor, Johns Hopkins University, Maryland
Francesca Stocker (Heeger): Scientific Counselor, State Secretariat for Education, Research and Innovation SERI, Bern, Switzerland
Serhan Tufanli (Fleming): Fellow at CERN
Li Yi (RHIG): Assistant Professor, Shandong University, China
Ling Zhong (Lamoreaux)

Graduate Alumni

Emma Castiglia '22

Current organization: Meta
Current position: Research Data Scientist
Dissertation title: *Machine Learning for Tau Leptons and the Search for the Associated Production of a Higgs Boson with a Vector Boson, with the Higgs Boson Decaying to a Tau Pair at ATLAS*
Thesis advisor: Sarah Demers

Benjamin Foust '22

Current institution: Pacific Northwest National Laboratory
Current position: Postdoctoral Researcher
Dissertation title: *Precise Measurement of the U-235 Antineutrino Energy Spectrum*
Thesis advisor: Karsten Heeger

Ako Jamil '22

Current institution: Princeton University
Current position: Robert H. Dicke Fellow
Dissertation title: *Rare Event Searches in Liquid Xenon with EXO-200 and nEXO*
Thesis advisor: David Moore

Emily Kuhn '22

Current institution: NASA Jet Propulsion Laboratory (JPL)
Current position: NASA Postdoctoral Program (NPP) Fellow
Dissertation title: *Calibration Instrumentation for the Hydrogen Intensity and Real-time Analysis eXperiment (HIRAX)*
Thesis advisor: Laura Newburgh

Michael Oliver '22

Current institution: Yale Wright Laboratory
Current position: Postdoctoral Associate (Caines)
Dissertation title: *Measurement of Correlations Between Neutral Pions and Charged Hadrons in Heavy Ion Collisions with ALICE*
Thesis advisor: John Harris

David Stewart '22

Current institution: Wayne State University
Current position: Postdoctoral Associate
Dissertation title: *Jet to Event Activity Correlations in Small System Collisions at STAR*
Thesis advisor: Helen Caines

Graduate Alumni

William Thompson '22

Current institution: Harvard University
Current position: Fellow of the Department
Dissertation title: *Jet to Event Activity Correlations in Small System Collisions at STAR*
Thesis advisor: Reina Maruyama

Kelly Backes '21

Current organization: MITRE Corporation
Current position: Quantum Sensor and Security Specialist
Dissertation title: *A quantum-enhanced search for dark matter axions*
Thesis advisor: Steve Lamoreaux

Jeremy Gaison '21

Current institution: Pacific Northwest National Laboratory
Current position: Linus Pauling Postdoctoral Fellow
Dissertation title: *Measurement of the Reactor Antineutrino Spectrum of U-235 by PROSPECT and Daya Bay*
Thesis advisor: Karsten Heeger

Mariel Pettee '21

Current institution: Lawrence Berkeley National Lab
Current position: Chamberlain Postdoctoral Research Fellow
Dissertation title: *Interdisciplinary Machine Learning Methods for Particle Physics*
Thesis advisor: Sarah Demers

Luis Saldana '21

Current organization & institution: The Estée Lauder Companies Inc., Yale University
Current positions: Senior Data Scientist, Research Affiliate
Dissertation title: *Novel Signal Reconstruction Techniques in Cyclotron Radiation Emission Spectroscopy for Neutrino Mass Measurement*
Thesis advisor: Karsten Heeger

Christian Weber '21

Current institution: Brookhaven National Lab
Current position: Research Associate Physics
Dissertation title: *New Search for H→ZZ_d→4l using pp collision data at √s=13 TeV with the ATLAS detector*
Thesis advisor: Keith Baker

Graduate Alumni

Yuqi Zhu '21

Current institution: Yale Wright Laboratory
Current position: Postdoctoral Associate
Dissertation title: *Experiments with 87Rb: Towards Co-trapping 88Sr19F and 87Rb*
Thesis advisor: David DeMille

Supraja Balasubramanian '20

Current institution: Fermi National Laboratory
Current position: Research Associate
Dissertation title: *A Differential Cross-Section Measurement of Muon Neutrino-Induced Charged Current Neutral Pion Production in MicroBooNE*
Thesis advisor: Bonnie Fleming

Estella Barbosa de Souza '20

Current organization: Boston Consulting Group
Current position: Consultant
Dissertation title: *A Model-Independent Search for Dark Matter-Induced Annual Modulation Signal with the COSINE-100 Experiment*
Thesis advisor: Reina Maruyama

Christopher Davis '20

Current organization: CarMax
Current position: Senior Data Scientist
Dissertation title: *Search for Neutrinoless Double Beta Decay with Majoron Emission in CUORE*
Thesis advisor: Reina Maruyama

Raymond Ehlers '20

Current institution: Oak Ridge National Lab
Current position: Postdoctoral Associate
Dissertation title: *Jet-Hadron Correlations Measured in Pb–Pb Collisions at √(sNN)=5.02 TeV with ALICE*
Thesis advisor: Helen Caines

Brooke Russell '20

Current institution: Lawrence Berkeley National Laboratory
Current position: Chamberlain Postdoctoral Research Fellow
Dissertation title: *An Electron Neutrino Appearance Search in MicroBooNE with 5 x 10^{19} POT*
Thesis advisor: Bonnie Fleming

Graduate Alumni

Shilo Xia '20

Current institution: LBNL
Current position: Chamberlain Postdoctoral Research Fellow
Dissertation title: *Search for Neutrinoless Double Beta Decay and Detector Physics Measurements with the Final EXO-200 Dataset*
Thesis advisor: David C. Moore

Salvatore Aiola '19

Current organization: Prima Assicurazioni
Current position: Data Scientist
Dissertation title: *Jet and heavy-flavor measurements in pp and Pb–Pb collisions with ALICE*
Thesis advisor: John Harris

Charles D. Brown III '19

Current institution: Yale University
Current position: Assistant Professor of Physics
Dissertation title: *Optical, Mechanical and Thermal Properties of Superfluid Liquid Helium Drops Magnetically-Levitated in Vacuum*
Thesis advisor: Jack Harris

Danielle Norcini '19

Current institution: University of Chicago
Current position: Grainger and KICP Postdoctoral Fellow
Dissertation title: *A search for eV-scale sterile neutrinos and precision measurement of the U-235 antineutrino spectrum with the PROSPECT experiment*
Thesis advisor: Karsten Heeger

Savannah Thais '19

Current institution: Columbia University
Current position: Research Scientist
Dissertation title: *Utilizing Electrons in the Search for Associated Higgs Production with the ATLAS Detector: Higgs decaying to a tau pair and vector boson decaying leptonically*
Thesis advisor: Sarah Demers

James Mulligan '19

Current institution: Lawrence Berkeley National Laboratory
Current position: Postdoctoral Researcher
Dissertation title: *Inclusive jet measurements in Pb-Pb collisions with ALICE*
Thesis advisor: John Harris

Graduate Alumni

Elena Gramellini '18

Current institution: Fermilab
Current position: Lederman Fellow Experimental Physicist
Dissertation title: *Measurement of the negative pion and positive kaon total hadronic cross sections on argon at the LArIAT experiment*
Thesis advisor: Bonnie Fleming

Ariana Hackenburg '18

Current institution: Google
Current position: Senior Quantitative Researcher
Dissertation title: *A Model-Independent Search for Dark Matter-Induced Annual Modulation Signal with the COSINE-100 Experiment*
Thesis advisor: Bonnie Fleming

Jeremy Cushman '18

Current organization: Amazon
Current position: Software Development Engineer
Dissertation title: *A search for neutrinoless double-beta decay in tellurium-130 with CUORE*
Thesis advisor: Karsten Heeger

Benjamin Brubaker '17

Current organization: Quanta Magazine
Current position: Staff Writer
Dissertation title: *First Results from the HAYSTAC axion search*
Thesis advisor: Steve Lamoreaux

Stephen Horvat '17

Dissertation title: *Measurement of the collision energy dependence of jet-quenching signatures of de-confinement at STAR*
Thesis advisor: Helen Caines

Anna Kashkanova '17

Current institution: Max Planck institute for the science of light
Current position: Postdoctoral fellow
Dissertation title: *Optomechanics with Superfluid Helium*
Thesis advisor: Jack Harris

Graduate Alumni

Alexey Shkarin '17

Current institution: Max Planck Institute for the Science of Light
Current position: Postdoctoral Fellow
Dissertation title: *Quantum Optomechanics with Superfluid Helium*
Thesis advisor: Jack Harris

Saehanseul Oh '17

Current institution: Sejong University
Current position: Assistant Professor
Dissertation title: *Correlations in particle production in proton-lead and lead-lead collisions at the LHC*
Thesis advisor: John Harris

D. Allan Bromley Graduate Fellowship in Physics

The D. Allan Bromley Fellowship for graduate research in physics was established in 2005 to honor D. Allan Bromley, Sterling Professor of the Sciences at Yale University, and founding director of the Yale Wright Nuclear Structural Laboratory (which has been transformed into the current Wright Lab). The fellowship was created by Bromley's former students Joel Birnbaum, '65 Ph.D.; Joe Allen, '65 Ph.D.; and John Manoyan, '87 Ph.D.

The Fellowship is awarded annually to graduate students in Physics who have advanced to candidacy in the Ph.D. program, particularly those "who exhibit a broader interest than just physics, including, but not limited to, science and public policy, engineering, and applied science." Candidates are nominated by the Physics faculty and selected by the D. Allan Bromley Professor of Physics and the Director of Graduate Studies. The indenture says, "In this way, the recipients will reflect and celebrate Dr. Bromley's distinguished and honorable persona in the exceptional scope, standing, talent, and character of his distinguished personal, public, and academic life."

Wright Lab students who have received this award during the past five years include:
2019-20: Kelly Backes, *advisors Steve Lamoreuax, Reina Maruyama* & Emma Castiglia, *advisor Sarah Demers*
2017-18: Savanna Thais, *advisor Keith Baker* & Danielle Norcini, *advisor Karsten Heeger*
2016-17: Charles Brown, *advisor Jack Harris*, (shared with Tonima Ananna, *advisor Meg Urry*)

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.

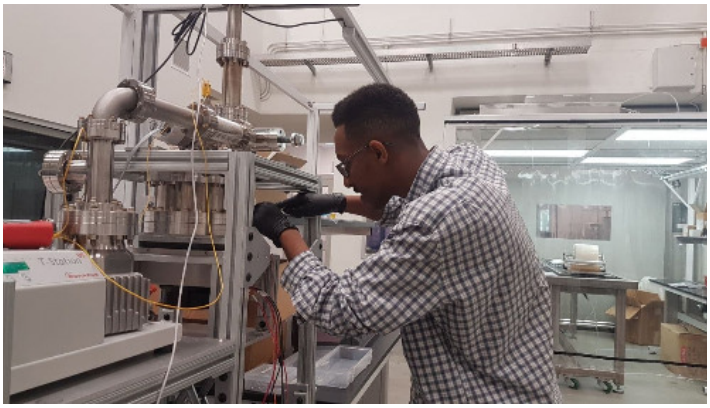
Undergraduate researchers (2017-2022)

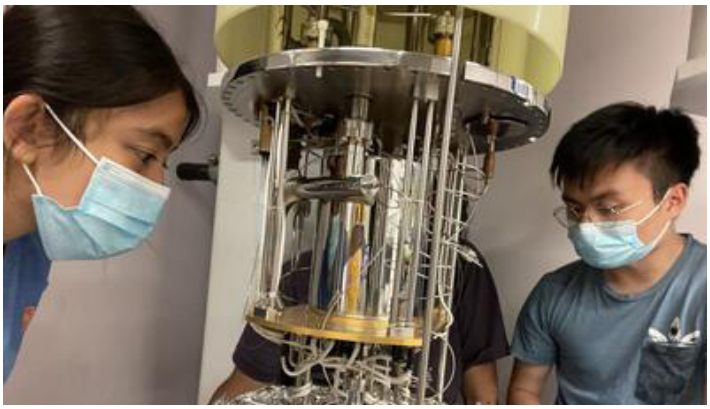
Yale Undergraduates at Wright Lab

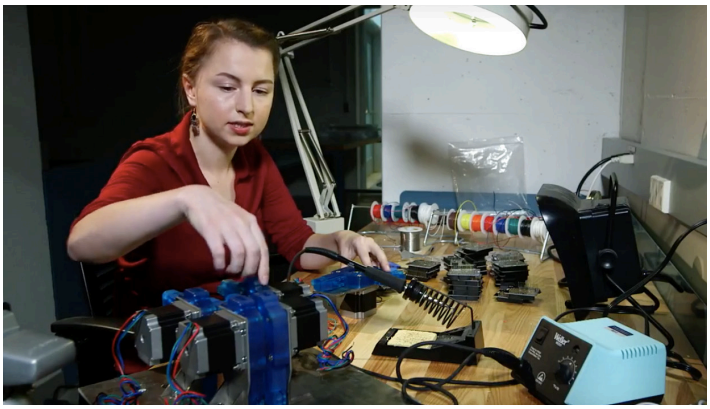
Matthew Dobre '26, HAYSTAC (R. Maruyama)
Quinn Ennis '26, HAYSTAC (R. Maruyama)
Jason Guo '25 (L. Newburgh)
Wayne Ariston '25, nEXO (D. Moore)
Aaron Chizhik '25, MicroBooNE, Project 8 (B. Fleming, K. Heeger)
Spencer Greenfield '25, analysis of data from drone test flights over radio telescopes (L. Newburgh)
Forrest Hutchison '25, DESI (C. Baltay)
Ana Maria Melián '25, drone beam mapping of radio telescopes (L. Newburgh)
Emily Peng '25, SIMPLE (D. Moore)
Quazi Rumman Rahman '25 (C. Baltay)
Coryell Smith '25 (D. Moore)
Rose Branson '24 (S. Demers)
Audrey Cesene '24 (L. Newburgh)
Zixin (Jessie) Chen '24, nEXO (D. Moore)
JianHui Chen '24 (RHIG)
Elsa Durcan '24, RAY (R. Maruyama)
Sophia Getz '24, RAY (R. Maruyama)
Annie Giman '24, RAY (R. Maruyama)
Argyris Manes '24 ATLAS (K. Baker)
Luke Mozarsky '24, SIMPLE (D. Moore)
Juan Recoaro '24, SIMPLE (D. Moore)
Audrey Whitmer '24 (L. Newburgh)
Barkotel Zemenu '24, nEXO (D. Moore)
Marvin Durogene '23 (K. Baker)
Caitlin Gainey '23 (R. Maruyama)
John Gunderson '23 (R. Maruyama)
Tausif Hossain '23 (S. Demers)
Neal Ma '23 (R. Maruyama)
Alexa Murray '23 (L. Newburgh)
Kohsuke Sato '23 (C. Baltay)
Trey Skidmore '23 (D. Moore)
Shayaan Subzwari '23, Project 8 (K. Heeger)
Giovanna Truong '23, Levitation (J. Harris)
Sarah Dickson '22, SIMPLE (D. Moore)
Ryan Flynn '22 (D. Moore)
Luke Grossman '22 (C. Baltay)
Maile Harris '22, drone calibration (L. Newburgh)
Hanbai Lyu '22 (D. Moore)
Charlie Mayhew '22 (D. Moore)
Eitan Minsky-Fenick '22, sensor calibration (D. DeMille)
Daniel Qenani '22 (O. K. Baker)
Matthew Schneider '22 (C. Baltay)
Ema Smith '22 (L. Newburgh)
Will Sun '22 (Jack Harris)
Sebastian Tsai '22 (L. Newburgh)
Huaijin (Jean) Wang '22 (R. Maruyama)
Grace Zdeblick '22
Yiming Zhang '22 (Jack Harris)
Andrew Zheng '22 (R. Maruyama)
Laura Zhou '22, RAY (R. Maruyama)
India Bhalla-Ladd '21, PROSPECT, ATLAS (K. Heeger; S. Demers)
Shoumik Chowdhury '21, SIMPLE (D. Moore)
Rachel Cohen '21, "Situating Science Podcast" (S. Demers)
Vincius Da Silva '21, ATLAS (K. Baker)
Krish Desai '21, Digital Noise Source Development (L. Newburgh)
Gabe Hoshino '21, "Measurements with a Desktop Muon Detector" (R. Maruyama)
Robert Howard '21, SNID/WFIRST (C. Baltay)
Charlotte Kavaler '21, nEXO (D. Moore)
Claire Laffan '21, Mu2E, ATLAS, (S. Demers)
Alexander Lathem '21, "Calibration of Type Ia Supernova Photometry", nEXO (C. Baltay; D. Moore)
Lucy McEwan '21, "Erbium 168 Transition Probabilities from Lifetime Measurements" (S. Lesher)
Mike Ogego '21, Quantum Machine Learning (K. Baker)
Annie Polish '21, drone beam mapping of radio telescopes (L. Newburgh)
Josh Purtell '21, Using Machine Learning Techniques to Identify Heavy Jets (H. Caines)
Sajan Ramanathan '21, CHIME (L. Newburgh)
Ben Rosand '21, STAR/ALICE; "Automated Patient Mortality Prediction from Clinical Notes" (H. Caines; P. Tipton)
Vinicius Da Silva '21, "Preliminary Results on H->Za->4l Monte Carlo Interpretation" (K. Baker)
Gabriel (Gabe) Hoshino '21, "Measurements with a Desktop Muon Detector" (R. Maruyama)
Sukhman Singh '21, SIMPLE; HAYSTAC (D. Moore; S. Lamoreaux)
Lukas Baker '20, PROSPECT (K. Heeger)
Sam Borden '20 (D. Moore)
Sofia Checa '20, STAR/ALICE (H. Caines)
Samuel Day-Weiss '20, nEXO; Simons Observatory (D. Moore; L. Newburgh)
Daniel Heimsoth '20 (R. Maruyama)
Michael Holmes '20 (D. Moore)
George Iskander '20 (K. Baker)
Nathaniel Kerman '20 (R. Maruyama; L. Newburgh)
Katherine Melbourne '20, CUORE (R. Maruyama)
Ryan Montesi '20, Type Ia Supernovae (C. Baltay)
Stuart Nicholls '20, Studying the Quark Gluon Plasma using Machine Learning (H. Caines)

Undergraduate researchers (2017-2022)

Elizabeth Ruddy '20, COSINE-100 (R. Maruyama)
Mojique Tyler '20 (K. Baker; C. Baltay)
Natalie Wright '20 (B. Fleming)
Cady van Assendelft '19, SIMPLE; HAYSTAC (D. Moore; S. Lamoreaux and R. Maruyama)
Byron Daniel '19, CUORE (R. Maruyama)
John Patrick (JP) Dervan '19, ATLAS (S. Demers)
Alec Emser '19, SIMPLE (D. Moore)
Adam Fine '19, SIMPLE (D. Moore)
Heather Harrington '19, Mu2e (S. Demers)
Michael Mossman '19, SIMPLE (D. Moore)
Maxime Pradier '19, CHIME (L. Newburgh)
Jack Roth '19, PROSPECT; laser cooling (K. Heeger; D. DeMille)
Joshua Swerdlow '19, Project 8 (K. Heeger)
Tuna Uysal '19, optical modes of helium (Jack Harris)
Walter Wilson '19, Deep learning applied to data analysis (O. K. Baker)
Nathaniel Barbour '18 (C. Baltay)
Victoria Beizer '18 (L. Newburgh)
Arina Bykadorova '18, PROSPECT (K. Heeger)
Suryabrata Dutta '18, CUORE (R. Maruyama)
Dominic Eggerman '18 (R. Maruyama; L. Newburgh)
Ilana Kaufman '18, EXO-200 (D. Moore)
Andrew Kilby '18 (S. Lamoreaux)
Nicole Pereira '18 (B. Fleming)
Lauren Chambers '17, DM-Ice (R. Maruyama)
Anthony Gagliardi '17, Deep learning applied to data analysis (O. K. Baker)
Robert Hurn '17 (C. Baltay)
Jonah Majumder '17 (D. DeMille)
Kristo Ment '17 (C. Baltay)
Bárbara Santiago '17 (D. DeMille)
Nate Stemen '17, PROSPECT (K. Heeger)
Ivy Wanta '17, CUORE (R. Maruyama)

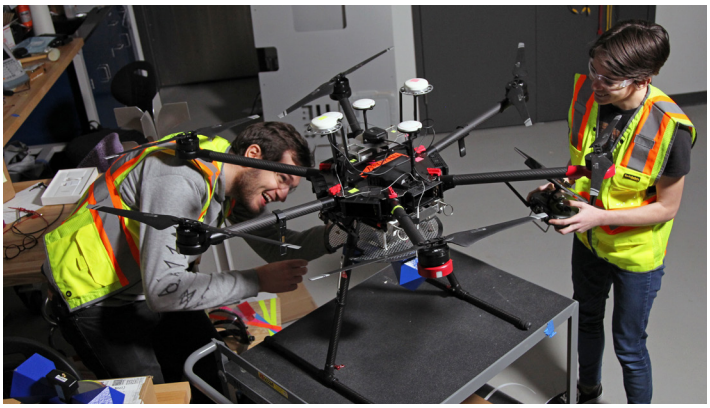






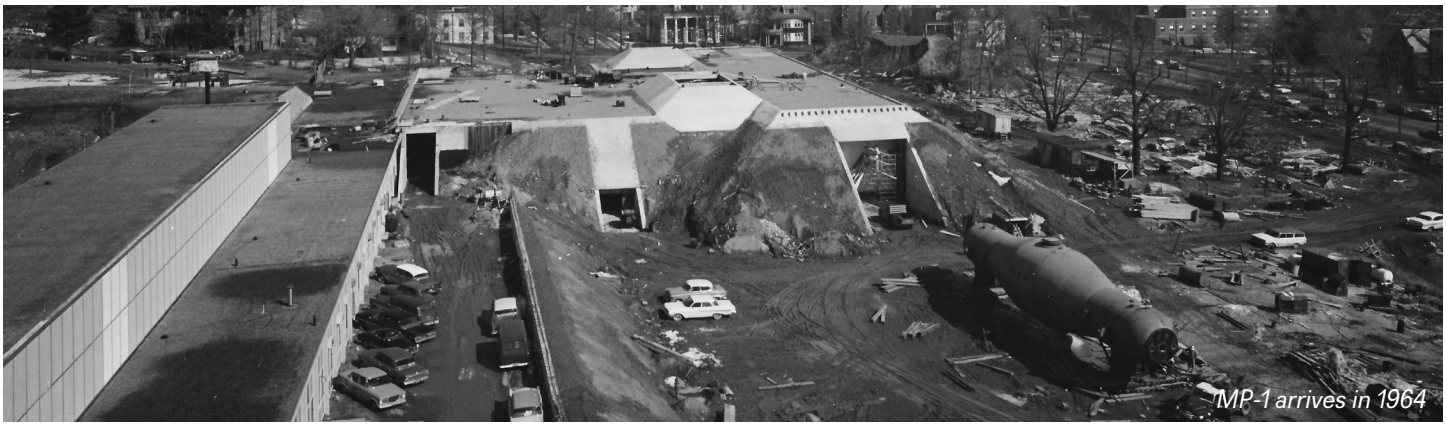
Visiting Students in Research at Wright Lab

Tiziano Buzzigoli (2022), nEXO (D. Moore)
Antonio Ferraloro (2022), DUNE (A. Ereditato, B. Fleming)
Terren Wise (2022) (J. Harris)
Zihui (Mary) Zhang (2022) (RHIG)
Sergio Nunez Silva (2020), PROSPECT (K. Heeger)
Jared Fox (2019), Superfluid-filled Caviites (Jack Harris)
Ananya Karanam (2019) (L. Newburgh)
Ava Polzin (2019) (L. Newburgh)
George Halal (2018), Machine Learning for Heavy Flavor Jet Tagging (RHIG)
Victor Valera Baca (2017), PROSPECT (K. Heeger)

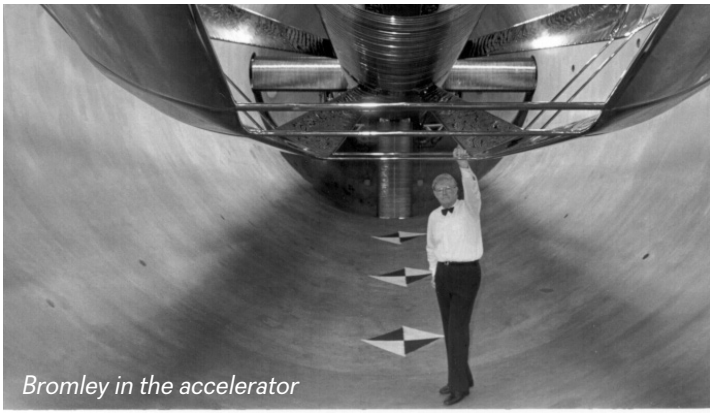


Discover more at **wlab.yale.edu/undergraduate-projects**

A Legacy of Exploring the Invisible Universe


MP-1 arrives in 1964

Wright Lab has been **advancing scientific investigation since 1966**, when the Wright Nuclear Structure Laboratory (WNSL) opened as a facility of the Yale Physics Department. WNSL, with its **"Emperor" tandem nuclear accelerator (MP-1**), under the direction of **D. Allan Bromley**, played **a historic role in the development of the field of nuclear science,** and especially heavy ion nuclear physics. MP-1 was upgraded from 1985-88 to become the **Extended Stretched TransUranium (ESTU) tandem accelerator**, making 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 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.


Bromley in the accelerator


WNSL Control Room in 1988

WNSL was also associated with the **design of new instrumentation for fundamental science**. Its physics program needed, encouraged, and directly advanced the development of new types of instrumentation for gamma ray detection and nuclear reaction studies. WNSL was one of the laboratories on the forefront of the development of computer instrumentation for data acquisition and control of accelerator experiments, **pioneering the use of computers to enable a new class of physics investigation**.


PROSPECT Assembly in 2018

In 2013, the ESTU was decommissioned to make way for the new Yale Wright Laboratory, which opened in 2017. The transformed Wright Lab continues to **advance the frontiers of fundamental physics** through a broad research program **addressing big questions in nuclear, particle, and astrophysics**.

The laboratory's unique combination of on-site state-of-the-art research facilities, technical infrastructure, and interaction spaces supports **innovative instrumentation development, hands-on research, and training the next generation of scientists.**

Why Wright Lab?

In November 2021, the Wright Lab community met in several focus groups as part of a Wright Lab strategic planning process. The quotes below come from their feedback.

Community & Environment

"Wright Lab connects people."

"Wright Lab is **a very diverse and inclusive place** with a more **balanced gender ratio** than other institutions."

"When I visited as a prospective student, **grad students at Wright Lab seemed really happy**."

"People want to be here and that shows."

"**Proximity to the machine shops**, **on-call suppor**t from technical staff, c**omputing resources**, helpful **administrative support**"

"**Wright Lab, the department, and the University as a whole, are all integrated**. The opportunities provided by **Yale's academic and extracurricular diversity** add value to life here."

Mentoring & Professional Development

"The professors here listen and care."

"There are **so many helpful people** around in the shops and around the lab who provide **expert, professional advice** and suggestions on our projects."

"Being able to participate in **outreach with local schools** provided a great mentoring experience for me."

"The people who have come through my group in the past are the ones who are now **building up the faculty positions around the country and the world in my field**."

Research

"There is so much research going on here!"

"Wright Lab has **a great community of similarly focused researchers**, and especially at the beginning of your graduate career, that is very helpful."

Wright Laboratory

FY2022

190 People in the Wright Lab Community

- 11 Faculty
- 4 Adjunct Faculty
- 15 Research Scientists
- 16 Postdocs
- 64 Graduate Students
- 243 **Graduate alumni since 1965**
- 47 Undergraduates
- 4 Postgraduates
- 6 Administrative staff
- 15 Technical support staff
- 2 Computing support staff
- 203 **"Alumni" (all roles) of WL 2017-2022**
  includes faculty, staff, and students

22 Awards and Honors

353 Publications

1,174 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

332 Terabytes of Data

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

141 Events

- 33 Seminars
- 8 Dissertation Defenses
- 4 Outreach events
- 8 Workshops/Collaboration meetings
- 2 WL-led summer research programs
- 1 Undergraduate research symposium

5976 Flickr Photos

- 57 **Videos**
- 15 **Accelerator pieces installed as art**
- 7 **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

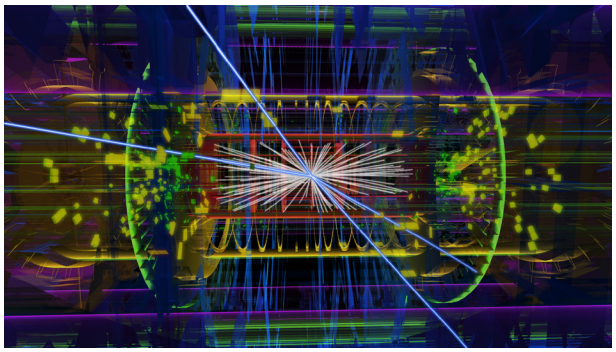
272 Front door address

Wright Laboratory

Exploring the Invisible Universe

Discover more at wlab.yale.edu

Discover Research



Discover Instrumentation

Discover Facilities

Discover Education

Discover Community

Discover the Arts

Discover Innovation

Discover Wright Laboratory


wlab.yale.edu