



ANNUAL REPORT 2018

Exploring the Invisible Universe



I write to introduce you to the new Yale Wright Laboratory, which is also affectionally known as “Wright Lab”.

Wright Lab, which officially opened in 2017, has transformed the former home of the famous Yale Emperor tandem nuclear accelerator (MP-1), which was decommissioned in 2011 (*you can read more about this legacy on p.7*), into an active science community with facilities, infrastructure and technical expertise to develop, build and use research instrumentation for fundamental science in physics and beyond.

Wright Lab is advancing the frontiers of fundamental physics through a broad research program addressing big questions in nuclear, particle, and astrophysics that includes precision studies of neutrinos, searches for dark matter, investigations of the building blocks and interactions of matter, and observations of the early Universe. 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. Wright Lab is part of the Yale Physics Department and provides facilities, infrastructure and expertise for a large percentage of the research groups in the Physics Department. Wright Lab houses several Yale University core facilities that serve researchers across Yale’s Science Hill and beyond (*see p. 6 for more information*). Wright Lab’s cross-cutting, interdisciplinary approach allows research groups to seamlessly progress from R&D to construction to acquiring data to analyzing data for science results. In 2018, Wright Lab scientists won 10 awards (*see p. 11*), and this number continues to expand through 2019 as I write this note.

We have a commitment to education at Wright Lab, and students at Wright Lab are central to the research in all stages. We have included a spotlight on our student projects on page 9.

When we say Wright Lab, we might be referring to the building, or we may be referring to the community. Wright Lab supports a diverse and interactive community of scientists, staff and students, and is a hub where researchers from the globe come to achieve great science. In addition, we have a strong program of outreach, including partnering with the Yale Pathways to Science and the Yale Peabody Museum to provide enriching experience for local youth. Wright Lab also has a legacy of connecting art and science, including our artist-in-residence program, inaugurated by Professor Emily Coates (*see p. 10*).

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

Karsten Heeger
Director

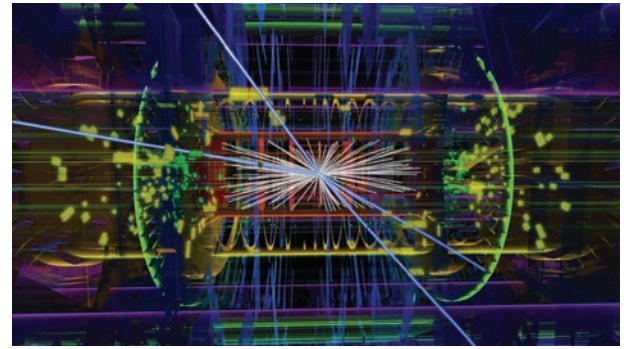


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Discover Research



Discover Instrumentation

Discover Facilities



Discover Education

Discover Community



Discover the Arts

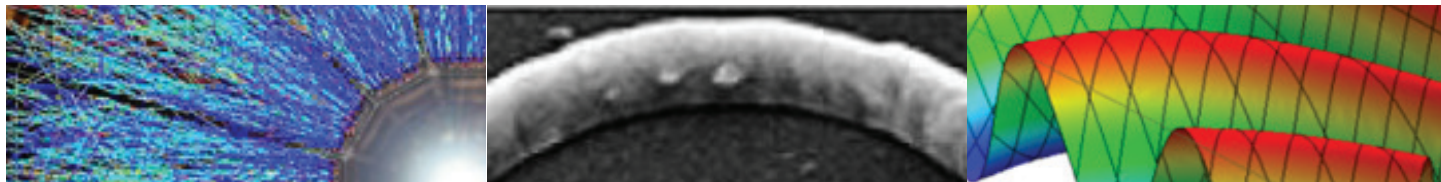
Discover Innovation

Discover



Wright
Laboratory

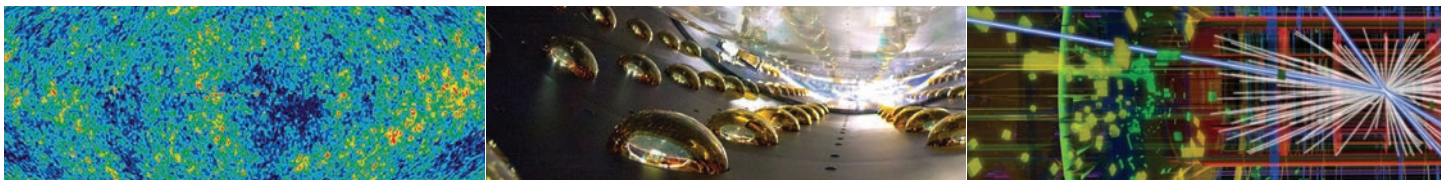
Discover Research



Wright Lab enables **cutting-edge, hands-on discovery** in a wide range of fundamental research areas from the smallest particle to the evolution of the Universe and facilitates frequent cross-disciplinary efforts between fields. While much of the research done at Wright Lab is experimental, Wright Lab also is home to theorists who engage with the experiment and instrumentation development done at Wright Lab.

Wright Lab fosters **cross-disciplinary research collaborations across Yale University and worldwide**.
Wright Lab:

- works with the **Yale Center for Research Computing (YCRC)** on novel solutions to the research computing challenges in nuclear, particle and astrophysics,
- collaborates with the **Yale Center for Astronomy and Astrophysics (YCAA)** on understanding dark matter in the Universe
- develops Quantum sensors and quantum information science techniques with the **Yale Quantum Institute (YQI)**, which are used for axion searches at Wright Lab
- offers data science projects in fundamental physics to collaborate with researchers in the **Yale Department of Statistics and Data Science**
- has explicit partnerships with **Brookhaven National Laboratory, CERN** and **Fermilab**.



Discover Instrumentation

Wright Lab researchers and their collaborators have utilized the unique facilities and infrastructure at Wright Lab to develop instrumentation for at least **27 national and international experiments** to explore the invisible universe, including:

- **Relativistic Heavy Ions** (Helen Caines, John Harris): ALICE, STAR, the future eRHIC.
- **Neutrinos & Fundamental Symmetries** (Bonnie Fleming, Karsten Heeger, Reina Maruyama, David Moore): ArgoNeUT, LArIAT, CUORE, Daya Bay, EXO-200, IceCube, MicroBooNE, Project 8, PROSPECT, SBND, and the future CUPID, DUNE and nEXO
- **Elementary Particles** (O. Keith Baker, Sarah Demers, Paul Tipton): ATLAS, Mu2e
- **Astrophysics and Cosmology** (Charles Baltay, Steve Lamoreaux, Reina Maruyama, Laura Newburgh): ACT, CHIME, COSINE-100, DM-Ice, DESI, HAYSTAC, QUEST, HIRAX and Simons Observatory
- **Quantum Physics & Devices**: SIMPLE (David Moore), the work of Dr. Jack Harris' research group
- Various in-house experiments in **Beam Physics** (Jay Hirshfield)



Discover more about Wright Lab research and instrumentation at <https://wlab.yale.edu/research>

Research in the News

DECEMBER 17, 2018



Reidar Hahn, Fermilab

[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 the US Department of Energy's Fermi National Accelerator Laboratory (Fermilab).

NOVEMBER 9, 2018



PROSPECT Collaboration

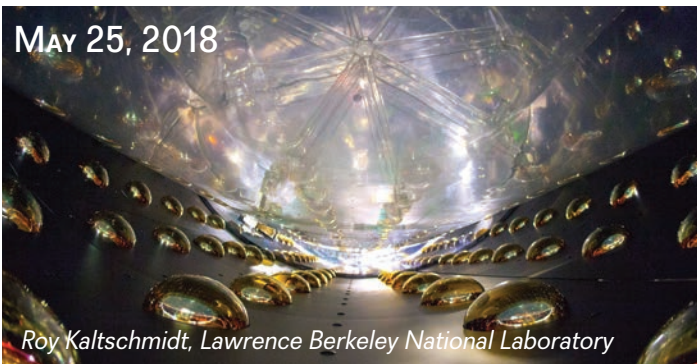
[PROSPECT results inspire neutrino detectors for diplomacy](#)

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 Professor 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*.

MAY 25, 2018



Roy Kaltschmidt, Lawrence Berkeley National Laboratory

[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 <https://wlab.yale.edu/research>.

MARCH 26, 2018



Photo courtesy of CUORE Collaboration

[First result from CUORE constrains limits for finding neutrinoless double-beta decay](#)

The publication includes the result of Wright Lab graduate student 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 ^{130}Te ". Additional Wright Lab co-authors are Christopher Davis, Karsten Heeger, Kyungeun Lim, Reina Maruyama, and Tom Wise.

Discover Facilities

Wright Laboratory supports research in fundamental physics by providing **shared, on-site, first-rate facilities, tools, infrastructure and supporting personnel for instrumentation development on all scales, experimental investigations, and training.** Wright Lab is an integral part of the **Yale Physics Department** and the core facilities for **Instrumentation at Yale** (see also <https://instrumentation.yale.edu>).

YALE UNIVERSITY CORE FACILITIES AT WRIGHT LAB

Advanced Prototyping Center

Laser cutter, water jet cutter, 3D-printers for use by students and researchers, with supervision.

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 available. Classes available. Professional advice for design and fabrication of projects. Includes mills, lathes, welding shop, fume hood.



PHYSICS RESEARCH FACILITIES AT WRIGHT LAB



- a **CAD and Remote Operations Room**
- permanent and pop-up **clean rooms**
- a **cryogenic laboratory**
- **detector development laboratory**
- a **high-bay area** known as "The Vault" 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

The Wright Lab community also has **access to high performance computing** at Yale's Center for Research Computing and **access to world-class research facilities.**

- Brookhaven National Laboratory, United States
- CERN, Switzerland
- Daya Bay, China
- Fermilab, United States
- Istituto Nazionale di Fisica Nucleare, Italy
- Oak Ridge National Laboratory, United States
- Yangyang Laboratory, South Korea



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

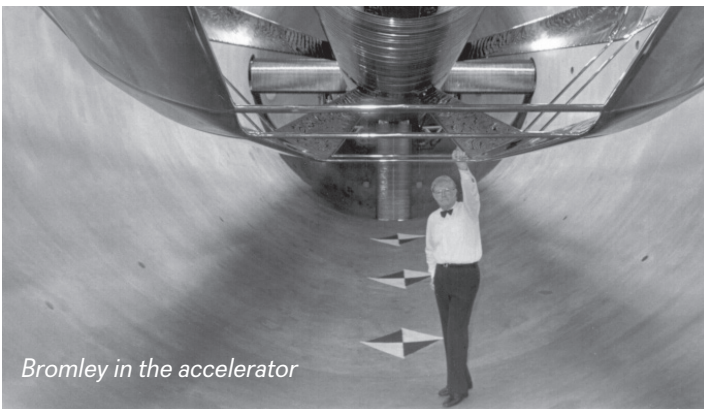
Discover more about Wright Lab facilities at <https://wlab.yale.edu/facilities>

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 University Department of Physics. WNSL, with its “**Emperor**” **tandem nuclear accelerator (MP-1)** played a **historic role in the development of the field of nuclear science**, and especially heavy ion nuclear physics. The Yale MP-1 accelerator was upgraded from 1985-88, under the direction of **D. Allan Bromley**, to become the **Extended Stretched TransUranium (ESTU) tandem accelerator**. The conversion made the ESTU **the most powerful stand-alone tandem accelerator in the world** until the end of its operation in 2011. The research at today's new facilities for the study of exotic unstable nuclei is an outgrowth of earlier studies with these advanced tandem accelerators, and relativistic heavy ion accelerators have a parentage in machines like Yale's tandem.



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**.

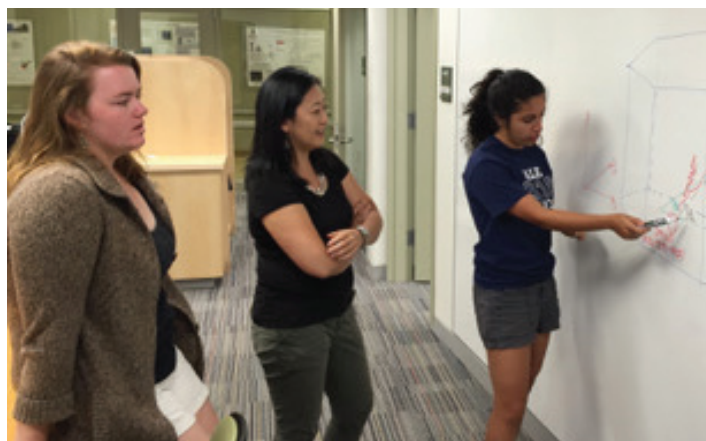


PROSPECT Assembly in 2018

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** that includes precision studies of neutrinos, searches for dark matter, investigations of the building blocks and interactions of matter, and observations of the early Universe. 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**.

Discover Education

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. As our mission statement states, we strive **"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.**"



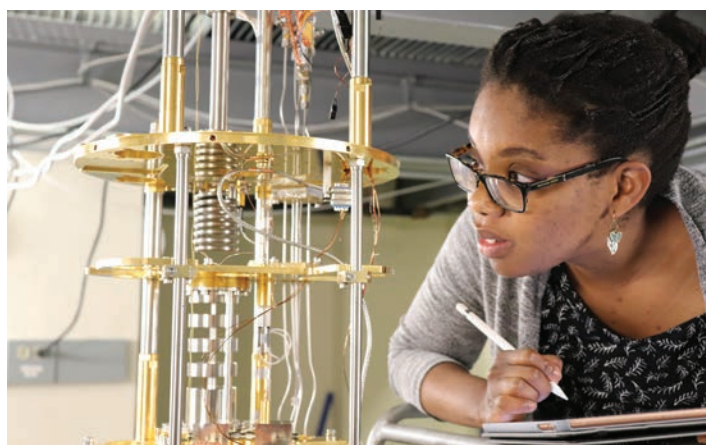
As Wright Lab is an entity that is closely related to, yet separate from an academic department, we have a holistic, interdisciplinary approach to education and training; serving **undergraduate and graduate students, postdoctoral associates** across Yale's "Science Hill" and beyond, and **the greater 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 empowers 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 in the **Student Voices video**, available on our website at <https://wlab.yale.edu/videos>



Student Projects

GRADUATE STUDENT THESES 2018



Jeremy Cushman '18 (Karsten Heeger, *advisor*)
A search for neutrinoless double-beta decay in tellurium-130 with CUORE
Currently a Software Engineer at Optimus Ride



Elena Gramellini '18 (Bonnie Fleming, *advisor*)
Measurement of the negative pion and positive kaon total hadronic cross sections on argon at the LArLAT experiment
Currently a Lederman Fellow in experimental physics at Fermilab



Ariana Hackenburg '18 (Bonnie Fleming, *advisor*)
Measurement of a Neutrino-Induced Charged Current Single Neutral Pion Cross Section at MicroBooNE
Currently a Data Scientist at Wayfair



Anthony Lollo '18 (Jack Harris, *advisor*)
Phase slips in isolated mesoscopic superconducting rings
Currently a Data Science Manager at the Yale School of Public Health



Jared Vasquez '18 (Paul Tipton, *advisor*)
Illuminating the Higgs boson: Measurement of the properties of the Higgs boson in the diphoton channel
Currently a Senior Data Scientist at GE Digital

UNDERGRADUATE THESES 2018

Joseph Balsells '18 (George Fleming, *advisor*) - *Invariant Correlations on a Sphere*

Nathaniel Barbour '18 (Charles Baltay and David Rabinowitz, *advisors*) - *Underlying Cause of the Incorrect PSF Photometry Measurements*

Arina Bykadorova '18 (Karsten Heeger, *advisor*) - *The PROSPECT Calibration System*

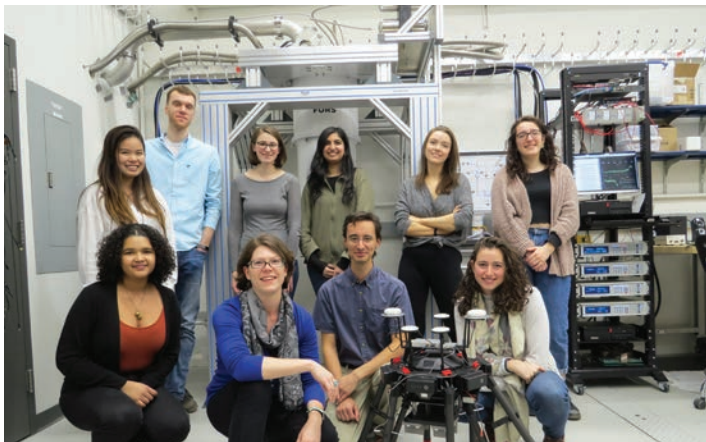
Suryabrata Dutta '18 (Reina Maruyama, *advisor*) - *Thermal Modeling and Parameter Estimation*

Ilana Kaufman '18 (David Moore, *advisor*) - *EXO-200*

Andrew Kilby '18 (Steve Lamoreaux, *advisor*) - *Optimizing Group-wise Parity-Based Error*

Discover more about Wright Lab students and alumni at <https://wlab.yale.edu/people>

Discover Community



Wright Lab **supports a diverse and active community of scientists, staff, and students.** In 2018, there were 150 people in the Wright Lab community: 17 faculty, 7 adjunct faculty, 17 research scientists, 23 postdocs, 3 postgraduate associates, 43 graduate students, 24 undergraduates, 6 administrative staff, and 13 technical/computing staff.

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.

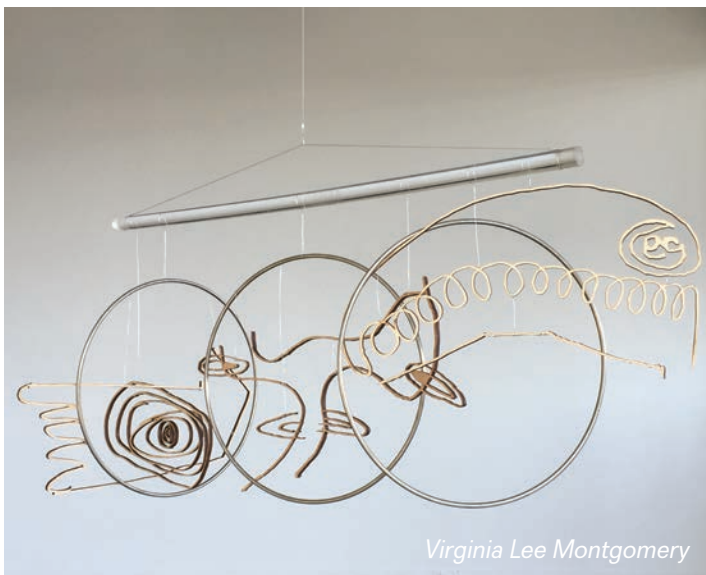
Wright Lab is a friendly, active science community; **researchers frequently interact with each other within and across research groups.** Wright Lab also uniquely **connects researchers with in-house technical experts** to advise and assist with the design and execution of research instrumentation projects.

Wright Lab has a steady stream of visitors passing through the building for collaborations, conferences and workshops, seminars, other events and outreach. Wright Lab is a **hub where researchers from across the globe come to achieve great science.** In turn, experts in related fields are able to share their results, wisdom and ideas with the Wright Lab community through giving seminar or workshop talks, as well as short- and long-term collaboration visits. In 2018 Wright Lab recorded 371 visitors.



Karen King Photography

Discover the Arts



Virginia Lee Montgomery

Wright Lab has a legacy of connecting art and science. Four pieces of art have been inspired by Wright Lab and 15 pieces of the accelerator formerly housed at Wright Lab are installed at the lab as art.

Wright Lab has also initiated an annual artist-in-residence program, welcoming **Emily Coates**, Associate Professor (adjunct) of Theater Studies and the Directing Program, and director of dance studies at Yale University for the 2018-19 academic year.

We plan to continue and expand upon this legacy by creating an ongoing, publicly accessible program series at Wright Lab to demonstrate and celebrate the intersectionality of fundamental physics and various forms of art.

Awards and Honors



Assistant Professor **Laura Newburgh** has been awarded a prestigious **NSF Faculty Early Career Award**. Her proposal, entitled *Towards Dark Energy – A High-precision Drone-based Calibrator for Next-Generation 21cm Cosmology Experiments* will fund her to develop and use radio telescopes to map out the expansion history of the Universe.



Assistant Professor **David Moore** is one of five Yale faculty members who were awarded a 2018 **Sloan Research Fellowship** to advance their work. Moore's research focuses on experimental nuclear and particle physics, including tests of the fundamental nature of neutrinos, dark matter, and gravity at microscopic distances.

Professor **Bonnie Fleming** has been awarded the a 2018 **American Physical Society Division of Particles and Fields Mentoring Award** "for her dedication to mentoring the next generation of experimentalists, providing opportunities and support for each to excel in their own way, tirelessly supporting diversity, developing new outreach initiatives, and showing by example how to be a physicist, colleague, and collaborator."



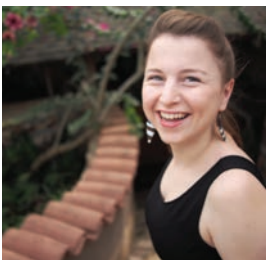
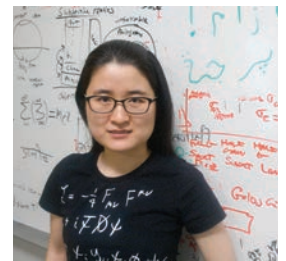
Postdoc **Kirill Lapidus** was awarded a **CERN fellowship**. He will continue his research in the field of heavy-ion collisions with ALICE (A Large Ion Collider Experiment).

Postdoc **Li Yi** was awarded a faculty position at Shandong University through **China National 1000 Talents Program for Young Scholars**.



Graduate student **Charles Brown '19** was awarded a **2018 Ford Foundation Dissertation Fellowship**.

Graduate student **Shilo Xia '20** was awarded a **2018 Graduate Instrumentation Research Award (GIRA)** honorable mention for her work "Developing high-bandwidth digital data transmission for next-generation $0\nu\beta\beta$ detections".

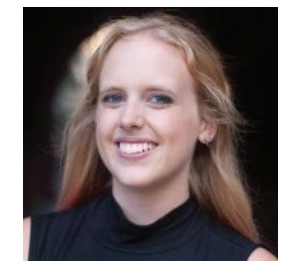


Undergraduate **Arina Bykadorova '18** was awarded the 2018 **DeForest Pioneers Prize**, awarded to a senior physics major at Yale University for distinguished creative achievement in physics. The Board of Directors of DeForest Pioneers, Inc. established the prize in 1960 in honor of the outstanding scientific achievements of Lee DeForest, Ph.D. 1896.

Graduate student **Emily Kuhn '22** was awarded both a 2018 **National Science Foundation Graduate Research Fellowship Program fellowship (NSF GRFP)** and a **2018 NASA Space Technology Research Fellowship (NSTRSF)**.



Graduate students **Danielle Norcini '19** and **Savannah Thais '20** are co-recipients of the 2018 **D. Allan Bromley Graduate Fellowship in Physics**.



Wright Lab Faculty



Keith Baker
Professor of Physics

Elementary Particles
ATLAS



Jack Harris
Professor of Physics

Quantum Physics



Charles Baltay
Eugene Higgins Professor of Physics and Professor of Astronomy

Astrophysics & Cosmology
DESI, QUEST



John Harris
D. Allan Bromley Professor of Physics

Relativistic Heavy Ions
ALICE, STAR, eRHIC



Helen Caines
Associate Professor of Physics

Relativistic Heavy Ions
STAR, ALICE, eRHIC



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

Neutrinos & Fundamental Symmetries
CUORE, Daya Bay, Project 8, PROSPECT, CUPID



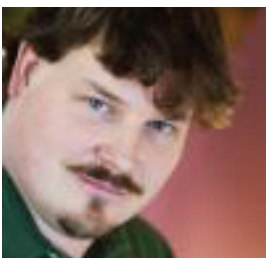
Sarah Demers
Horace D. Taft Associate Professor of Physics

Elementary Particles
ATLAS, Mu2e



Steve Lamoreaux
Professor of Physics

Astrophysics & Cosmology, Quantum Physics
HAYSTAC



David DeMille
Professor of Physics

Neutrinos & Fundamental Symmetries, Quantum Physics
Nuclear Anapole Moment Experiment



Reina Maruyama
Associate Professor of Physics

Neutrinos & Fundamental Symmetries, Astrophysics & Cosmology
CUORE, CUPID, IceCube, CO-SINE-100, DM-Ice, HAYSTAC



Bonnie Fleming
Professor of Physics

Neutrinos & Fundamental Symmetries
ArgoNeuT, LArLAT, Micro-BooNE, SBND, DUNE



David Moore
Assistant 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 and Adjunct



Richard Casten
Professor Emeritus

Nuclear Structure



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

**Neutrinos & Fundamental
Symmetries**



Peter Parker
Professor Emeritus

Nuclear Astrophysics



Flavio Cavanna
Professor (Adjunct) of Physics

Fermilab and University of
L'Aquila



Emily Coates
*Associate Professor (Adjunct) of
Theater Studies and Drama, Wright
Lab Artist-in-Residence*



Ornella Palamara
Professor (Adjunct) of Physics

Fermilab and Laboratori Nazionali del Gran Sasso



Jay Hirshfield
Professor (Adjunct) of Physics

Beam Physics



Thomas Ullrich
Professor (Adjunct) of Physics

Brookhaven National Laboratory

Events at Wright Lab



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 and discussion groups include:

- Nuclear Particle Astrophysics research seminars
- Weak Interaction Discussion Group
- Yale Physics Professional Development Organization
- Instrumentation Lunch
- Dark Matter Discussion Group

In 2018, Wright Lab hosted the following **conferences and workshops**, as well as a **summer school**:

- **November 16:** 2018 [Yale Day of Instrumentation](#)
- **November 8-10:** CUORE Collaboration Meeting
- **October 11-12:** Project 8 Analysis Workshop
- **October 5-6:** [Symmetries and Order: Algebraic Methods in Many Body Systems](#)
- **September 11-12:** U.S. ATLAS Site Review
- **July 16-20:** PROSPECT Analysis Workshop
- **June 17-30:** [National Nuclear Physics Summer School 2018](#)
- **May 21-25:** HAYSTAC workshop
- **March 13-14:** 3rd COSINE-100 Collaboration Meeting
- **February 24:** La Silla-QUEST Southern Hemisphere Variability Survey Workshop
- **February 1-2:** Project 8 Software Workshop

Wright Lab hosts regular **training workshops and orientations** for the Advanced Prototyping Center (APC), shop facilities and computing facilities at Wright Lab.

- Introduction to the Wright Laboratory Shop Facilities
- Environmental Health & Safety (EHS) Shop Orientations
- 3D-Printing Workshop
- Laser Cutter Workshop
- Abrasive Water Jet Cutting Workshop
- Micro-Controller Workshop
- Introduction to Scientific Computing at Wright Lab
- Data Analysis with Python
- Scientific Parallel Processing
- Containers for Scientific Computing



2018 OUTREACH

Yale Alumni Weekend tours

Yale Society of Physics Students tour

a hands-on tour for the **FlexSchool**

two hands-on events with **Yale Pathways to Science**
in-school demonstrations by Wright Lab researchers

Discover more about Wright Lab events at <https://wlab.yale.edu/calendar>

160 People in the Wright Lab Community

17	Faculty	29	Undergraduates
7	Adjunct Faculty	3	Postgraduates
17	Research Scientists	6	Administrative staff
23	Postdocs	12	Technical support staff
43	Graduate Students	3	Computing support staff
371	Visitors	170	Graduate alumni since 1965

10 Awards and Honors**255** Publications **15,934** Citations**4** Yale University Machine Shops

20	Cranes	3	Permanent Clean Rooms
20	Mills	3	3D-Printers
19	Lathes	1	Water Jet Cutter
4	Welders	1	Laser Jet Cutter

310 Terabytes of Data

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

80 Events

54	Seminars	7	Workshops/Collaboration meetings
2	Conferences	1	Summer school
6	Outreach events	1	Undergraduate research symposium

1982 Flickr Photos

3	Videos	4	Works of art inspired by Wright Lab
15	Accelerator pieces installed as art	1	Artist-in-Residence

Wright Lab does research in **16** Countries on **6** Continents**1961** Start of Wright Nuclear Structure Laboratory**2017** Re-opening of transformed Yale Wright Laboratory**272** Front door address



wlab.yale.edu