

STEWARDSHIP SCIENCE

2022-2023

THE SSGF/LRGF MAGAZINE

TAKING AIM

MIT's Raspberry Simpson uses two fellowship residencies and Livermore's powerful lasers to study matter's fundamental properties

Los Alamos: A fellow catches neutrons in the act

Sandia: An alumnus sees the light — at the petawatt scale

Plus: Taking explosives for extreme spins, bumping into asteroids and stressing materials with bars; fellows on location; a career talk with the former NNSA defense programs deputy; and this year's essay contest winner

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THE FIRST AND THE FUTURE

THIS ISSUE MARKS the final year for the first recipients of the Laboratory Residency Graduate Fellowship, one of the newer Department of Energy National Nuclear Security Administration stewardship science and technology workforce-development programs, with a fifth cohort joining this fall.

As such, it's only fitting that our cover story features one of those pioneering students, MIT's Raspberry Simpson. We highlight others from Raspberry's class in our Fellows-On-Location roundup, alongside outgoing recipients of the Stewardship Science Graduate Fellowship, well into its second decade as an incubator for some of the country's most talented young scientists and engineers.

It's not all goodbyes. Past fellows become members of a thriving alumni community. And with each departure comes an arrival. Please introduce yourself to members of the new fellowship classes, inside the back cover.

– *The Editors, Stewardship Science: The SSGF/LRGF Magazine*

FEATURES

Stewardship Science: The SSGF/LRGF Magazine showcases researchers and graduate students at U.S. Department of Energy National Nuclear Security Administration (DOE NNSA) national laboratories. *Stewardship Science* is published annually by the Krell Institute for the NNSA Office of Defense Program's Stewardship Science Graduate Fellowship (SSGF) and its Laboratory Residency Graduate Fellowship (LRGF), both of which Krell manages for NNSA under cooperative agreement DE-NA0003960. Krell is a nonprofit organization serving the science, technology and education communities.

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Attn: SSGF/LRGF | (515) 956-3696

EDITOR

Bill Cannon

ASSOCIATE EDITOR

Thomas R. O'Donnell

SENIOR SCIENCE WRITER

Sarah Webb

GRAPHIC DESIGN

julsdesign, inc.

FRONT LINES CONTRIBUTORS

Monte Basgall
Thomas R. O'Donnell
Sarah Webb

SSGF STEERING COMMITTEE

Alan Wan
University of California, Office of the President

Ramon J. Leeper
Los Alamos National Laboratory

Tracy Vogler
Sandia National Laboratories

Kim Budil
Lawrence Livermore National Laboratory

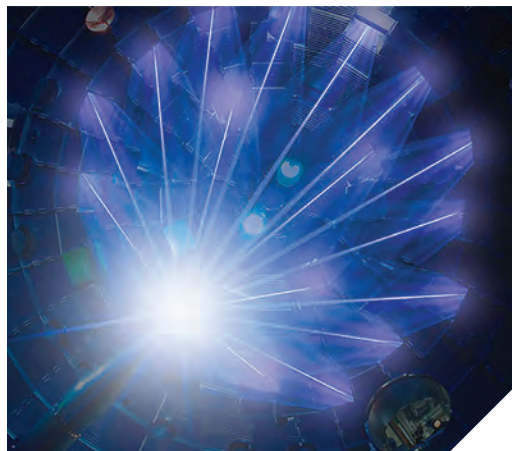
LRGF STEERING COMMITTEE

Bob Renovsky
Los Alamos National Laboratory

Nathan Meezan
Lawrence Livermore National Laboratory

Stephen Sterbenz
Nevada National Security Site

Mike Cuneo
Sandia National Laboratories



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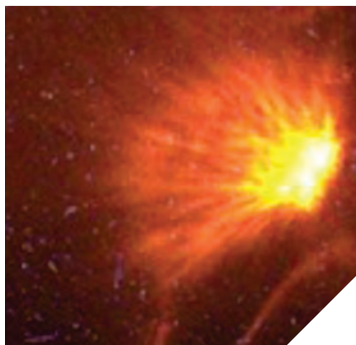
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THIN SKINS, WINDOWS OF OPPORTUNITY AND MORE

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ON THE COVER

DOE NNSA LRGF recipient Raspberry Simpson checks her setup at Lawrence Livermore National Laboratory's Jupiter Laser Facility. Simpson has studied laser-driven proton acceleration, tuning power, pulse length and other parameters to tweak the atomic particles' properties. The Massachusetts Institute of Technology Ph.D. student carried out two LLNL residencies during her primary graduate research with the lab's Tammy Ma. Simpson is a 2022 Lawrence Postdoctoral Fellow at LLNL. *Jason Laurea/LLNL.*



DIZZYING SPEED ►

The main machine at Los Alamos National Laboratory's Centrifuge Test Facility (CTF) is racecar fast, spinning at up to 220 times per minute to move the end of its 4.1-meter arm at up to 212 miles per hour in linear speed.

Imaging objects in the centrifuge's payload requires something equally speedy: flash X-ray radiography. The CTF, opened in 2016 as one the few such machines able to test weapon and electronic systems bearing significant high explosives, added the powerful imaging technology in October 2020.

Alex Cusick, a Los Alamos test engineer who supervises the facility, says the imaging system offers "us an additional set of data for quantitative analysis," comparable to previously gathered information, but also "the qualitative side, where we can actually see what a test object looks like in this environment, which is helpful – more helpful than you might think."

The CTF's main job is subjecting devices to extreme forces like those they would encounter when riding a rocket from Earth to space and back. The centrifuge may expose test articles to forces exceeding 220 times Earth's gravity, or 220 Gs.

The CTF often tests complete nuclear weapon systems like those found in the nation's stockpile, including full high-explosive charges but with surrogate substances replacing some of the most hazardous nuclear materials, Cusick says. "The ability to test full high-explosive assemblies is what sets us apart from other centrifuge facilities in the nuclear complex." Researchers supervise the experiments from a nearby bunker as a precaution.



The Centrifuge Test Facility's flash X-ray system.
Los Alamos National Laboratory.

"All materials will deform to some extent in these extreme environments," Cusick says, but explosives can distort even more. "It's not quite like Silly Putty, but under these G forces it acts pretty soft."

Engineers gather data via a range of diagnostic instruments placed at strategic locations in the test article, including strain gauges, accelerometers and sensors that detect displacement as materials distort under high G forces. The experiments provide input to computer models of electronics and other weapons hardware.

"It's an iterative process," Cusick says. Simulations may predict how devices will perform under high Gs, but "we actually measure them. We feed that data back into the models to validate them and improve their accuracy." Researchers run the simulations again and engineers test the new predictions at the CTF.

Many test devices, however, have curved surfaces and other features that make it difficult to gauge displacement. Most instruments capture a material's behavior in a single location but not elsewhere. Flash X-ray imaging provides complementary data "for us to have a better understanding of how the object is deforming."

X-ray data are "adding to what we already have and offering an additional quantitative method of analysis, but it's also giving us something very valuable on the qualitative side of things."

Acquiring radiographs takes precise engineering. The 5,000-pound imager, shaped like a propane heat tank, is mounted above the centrifuge enclosure but mechanically isolated from it to reduce vibrations. It rolls over a slot in the enclosure ceiling so obstructions don't interfere with the X-rays. Engineers use lasers to align the X-ray generator with the part of the test article they want to image and with phosphor plates anchored below the centrifuge arm. Then they lock the X-ray device in place.

The pulse must be fast – and this one is just 70 billionths of a second – to image the fast-moving object as it passes under the ceiling slot. The centrifuge arm triggers a magnetic sensor each time it passes. Engineers add a delay that depends on the arm's speed and the time the X-ray machine's electronics need to activate. "We just need to figure out what all those times are, fine tune the delays and get everything to coincide," Cusick says.

With flash radiography in place, the Los Alamos team has since given the CTF another capability, attaching what they call a boom box to the centrifuge arm. The containment vessel will let researchers study small explosive charges as they detonate under extreme gravity.

"To our knowledge, we have the only facility in the nuclear complex that has these two capabilities," Cusick says. "Testing detonators and small quantities of explosives in the actual environment they are designed to function in – that's what we're interested in there."
– Thomas R. O'Donnell



Can a spacecraft impact alter an asteroid's course? NASA's Double Asteroid Redirection Test aims to find out. NASA and Steve Gribben/Johns Hopkins APL.

HIGH-IMPACT ANALYSIS ►

NASA's Double Asteroid Redirection Test (DART), scheduled to crash into a binary asteroid system millions of kilometers from Earth in September 2022, is meant to change the smaller asteroid's orbit. It's an unprecedented asteroid-deflection mission, testing a kinetic-impactor strategy that could help protect Earth from a collision threat.

Lawrence Livermore National Laboratory researchers are helping the team analyze the impact to see if it altered the asteroid's path. The rocky objects can be seen from Earth with an optical telescope as flickering pixels. But with sophisticated simulations, Livermore researchers can model mission data and fill in collision details.

DART's target, Dimorphos, is a small moonlet asteroid approximately 160 meters across that orbits an asteroid five times bigger called Didymos. Researchers hope to slow Dimorphos' orbit by a millimeter a second, changing the pixels' flicker frequency as it passes in front of Didymos. "That change in orbital period will give us a measure for the first time of how effective the kinetic impact deflection technique can be when it's used on a real asteroid," says Megan Bruck Syal, a Livermore physicist who has worked on the project for several years.

The mission team knows Dimorphos' approximate size but understands little about its mass, shape, strength, porosity and internal structure, features that will affect the results. Earth-based measurements can't detect important details about the asteroid surface and composition, so the simulations allow researchers to work backward. They'll use direct observations from the collision to model the asteroid properties and conditions that could have produced them.

Asteroid geology is incredibly variable, says DART team member Katie Kumamoto, a Livermore postdoctoral researcher who studies

rock deformation. Some asteroids are dense metal bodies, but others are a combination of dust or boulders loosely bound by gravity. Thus the structure of Dimorphos could lead to dramatic differences in the DART impact crater's size and the resulting velocity change. "DART really is about the way that the asteroid itself is responding to being hit really, really hard," Kumamoto says.

The team is using Spheral, a hydrodynamics code developed by Livermore's Mike Owen. It's meshless, so it doesn't divide the area being modeled into small cells. Originally trained as an astrophysicist, Owen started Spheral as a side project to improve models of rapidly changing gas-like disturbances in cosmology and galaxy formation. The methods are complex and tend to be more computationally demanding than meshed approaches, but they also allow researchers to model a range of phenomena that involve changes in topology and objects with irregular shapes, even solids. That's what makes it useful for understanding rock deformation and asteroid collisions, Owen says. Hera, a planned European space mission scheduled for launch in 2024, will visit Dimorphos and take a closer look at the impact crater.

DART is a critical first step for planetary defense, Bruck Syal says. "But it's still just one data point. And there's a number of questions about how this experiment could generalize to other scenarios," including larger-than-DART impacts – akin to what diverting an Earth-bound rock may require – and asteroids with diverse material properties.

"I think we're going to learn a lot from DART," says Bruck Syal, who has discussed post-DART planetary defense priorities with NASA and the National Academy of Sciences. "But I also think that it is going to generate a lot more questions, and we'll recognize that there's a lot more mission-based work to do for planetary defense preparedness." – Sarah Webb

NOT SO TENDER BARS ▶

Bo Song was in graduate school when he was asked to work with split Hopkinson pressure bars. He didn't know what they were.

Now, more than 20 years later, Song's team tests these metal rods and their high-tech sensors in a cramped but growing Experimental Impact Mechanics Laboratory on Sandia National Laboratories' Albuquerque, New Mexico, campus. The bars are crucial for evaluating and modeling potential breaking points of U.S. stockpile materials.

British engineer Bertram Hopkinson first proposed in 1914 using a metal bar to measure applied stress. By 1949 British physicist Herbert Kolsky suggested longitudinally linking two such bars, one after the other, to measure combined pulses of both stress and strain.

Song's lab uses these Kolsky bars, 30 feet long by 1 inch in diameter and made of steel and aluminum, to stretch or squeeze test samples mounted horizontally between them as the bars are pneumatically driven to bullet train speeds, Song says. "The steel bar is usually used for hard materials like metals and ceramics, whereas the aluminum bar is used for soft materials like polymers and foams." There are also 3-inch-diameter steel versions used to mechanically shock components or – in a non-defense application – test materials like rocks and concretes.

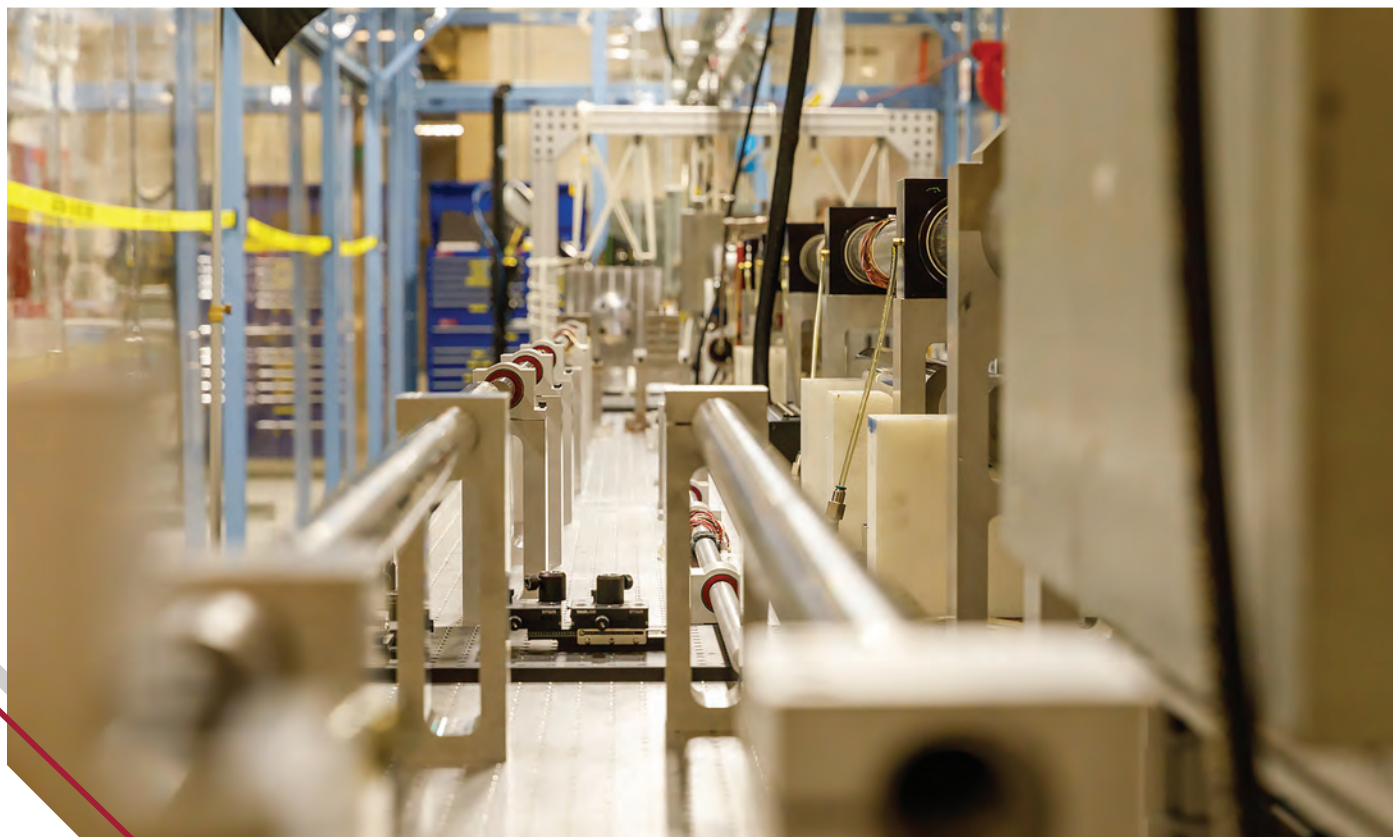
Pressure bars in the Experimental Impact Mechanics Lab. Kolsky bars and new instrumentation will increase the lab's testing capabilities and output. *Bret Latta/Sandia National Laboratories.*

His lab has pioneered a technique for measuring tensions applied to materials in free fall. This method employs single 12-foot-by-1-inch Hopkinson bars made of steel. Dubbed "drop-Hopkinson bars," they're attached to a 300-pound carriage that is allowed to plunge about 15 feet before striking an impact plate. A bungee cable, Song adds, can "further accelerate the drop when needed."

The Song lab's various bars are just one part of an elaborate testing regime that includes a network of wired sensors such as strain gauges and laser devices. Sometimes the material sample on a split Hopkinson bar is encased in an off-the-shelf chamber to test material properties at temperatures from minus-150 degrees Celsius to 300 C – up to 1,200 C on other, customized setups with a furnace or an induction heater. Fractions of a millisecond after impact, visible-light and infrared high-speed cameras capture samples' temperatures, strains and displacements.

With such equipment, "we can evaluate materials' response that nuclear warheads might be subjected to, both in normal operational environments and abnormal accidental environments," Song says. "In most cases we assist with material selection and modeling." To ensure that real components with radioactive materials will not be damaged, the lab uses alternative components of the same geometry and mass but lacking any hazardous materials.

Since Song started his Sandia lab in 2013, his team and budget has quintupled and the lab has doubled to 70-by-12 feet. The extra space boosts the number of tests and enables his team to stress materials in new ways. – *Monte Basgall*



ON FUSION AND STEWARDSHIP SCIENCE'S FUTURE



Charles Verdon served as the National Nuclear Security Administration's (NNSA's) deputy administrator for defense programs from September 2018 until April 2022. During the first half of 2021, he also was the acting undersecretary for nuclear security and NNSA administrator. Previously, he managed weapons programs and the National Ignition Facility (NIF) at Lawrence Livermore National Laboratory. He spoke with Stewardship Science's Sarah Webb. His comments were edited for space.

What have been the key steps in your education and career paths?

In high school I became interested in energy and energy production – conventional coal-fired plants, natural gas. I started to read more about nuclear reactors and became more and more interested in that topic. And that's what I pursued in college.

I took advantage of opportunities when they presented themselves. For example, when I was finishing my master's degree in nuclear engineering, I focused on reactors and fuel reprocessing. But then I took a course in inertial confinement fusion from a recent Los Alamos National Laboratory transplant. That was so interesting that I just decided to change to that area.

In summer 2021, NIF reached a near-ignition milestone. What was your reaction to this news?

I was immensely happy when I got the email, and I'm very proud of all the people who have continued to work on that effort for so many years. With NIF there were a lot of serious

questions about whether we could do this. And the teams worked to show that there were still ways to tame Mother Nature. It really speaks well of their dedication, and it was a spectacular result.

How important is it for SSGF and LRGF recipients and other early-career scientists to have access to facilities and teams like those at NIF?

Stockpile stewardship has always been a team sport. A facility like NIF and a goal like ignition takes a large cadre of many disciplines all working together to achieve a common goal where every little piece matters. Working on these scientific challenges is different from being an individual contributor.

2022 marks 30 years since the nuclear testing moratorium. What would you highlight as the key achievements in stockpile stewardship during that time?

Almost everything about the stewardship program has been a triumph. There were a lot of questions when the program formed. Could the underpinning science allow us to maintain confidence in the stockpile without

always shifting, so making sure that we can respond to changes requires us to develop the science and technology even as we apply it.

What are today's workforce needs?

The amount of work we have on our plate is more than even just 10 years ago, and it's still growing.

So we have to grow our workforce. It runs the gamut from scientists, engineers, technicians and security. The basic science and technology can be taught in school, but you have to learn about nuclear weapons on the job. Retaining people is key, and we must continue to offer our workforce growth opportunities and challenges so that they want to stay.

What advice do you have for someone entering that workforce?

Have a vision for what you want to do but look at the full breadth of what it takes to be successful. Let's say you're a physicist, and you can do a lot of things on a computer. You may find you idealized the problem a little too much and that manufacturing a solution may be more difficult than you first thought. You have to understand what nature says

Almost everything about the stewardship program has been a triumph.

testing? Could we develop a workforce that leadership would have confidence in? In those two key areas, we've seen the biggest triumphs. All the tools and capabilities – the computers, NIF, the experimental facilities – have been essential.

What are today's key challenges and how is NNSA addressing them?

The challenge is to apply what we learn to upgrading our production infrastructure while modernizing the stockpile in the absence of testing in a way that allows us to maintain confidence in the stockpile's safety, security and effectiveness. It's hard work. We also can't lose sight of what's over the horizon. The geopolitical environment is

and what technology makes possible to implement your ideas.

What else is important for the next generation of stewardship scientists to know?

It's an exciting field, with pros and cons in the public environment of nuclear weapons. But we need them for the defense of the nation and our allies. It's an important mission for the country. There's a pressing need for top-notch physicists and program managers and beyond. Take advantage of opportunities to visit or work at sites where you can learn about things that aren't available through a technical school or college and find a new area that you'd like to pursue.



The author, in her final year of the DOE NNSA SSGF at the California Institute of Technology, won the 2022 Essay Slam with this entry.

Planetary Black Boxes

By Olivia Pardo

To most people, the world of science may appear to be a black box that occasionally chirps loud enough to be heard in popular culture. The search for life on other planets, for example, seems to have transformed into a collective quest in which scientists and non-scientists alike perch on the edges of their seats, awaiting irrefutable evidence. Perhaps this research has gained popularity because it's tangible to those who aren't performing it. Yet there are other equally exciting black boxes, with scientists who devote their careers to poking holes into them and opening them up.

I was unfamiliar with scientific research when I started at the University of Chicago, but in a first-semester introductory geophysical sciences class I realized: There is an entire world below us. We've sent humans to the moon, 238,900 miles from here, but we've reached fewer than eight miles beneath our feet. For all the hours I spent looking up, inspired by rockets launching into space, I could have also looked down and been just as intrigued at the deep, unreachable regions of our own planet.

At the end of the term I asked the professor: How do I even begin to *do* science?

At the end of the term I asked the professor: How do I even begin to *do* science? How can I be the one finding the answers to all these questions? A year later, I joined his research group in the laboratory for mineral physics, studying materials under the intense heat and pressure of the Earth's interior. I was, officially, in the black box of scientific research.

After graduating I continued deeper into materials under extreme conditions and joined Jennifer Jackson's group at Caltech for my Ph.D. In the lab, we use diamond anvil cells to create contained environments that simulate deep planetary interiors. The cells use two diamonds to squeeze a chosen material to pressures at the Earth's core, more than three million times greater than what we feel at the surface. The palm-sized cells seem unassuming from the outside, but they are incredibly powerful tools we can use to study the behavior of materials under planetary conditions. Coupled with specialized instruments that record a mineral's response to X-rays and other types of light, diamond anvil cells let us characterize the structural, electronic and vibrational behavior of a wide range of materials. I use these techniques to study minerals that comprise planetary environments on Earth, Mars and icy moons in the solar system.

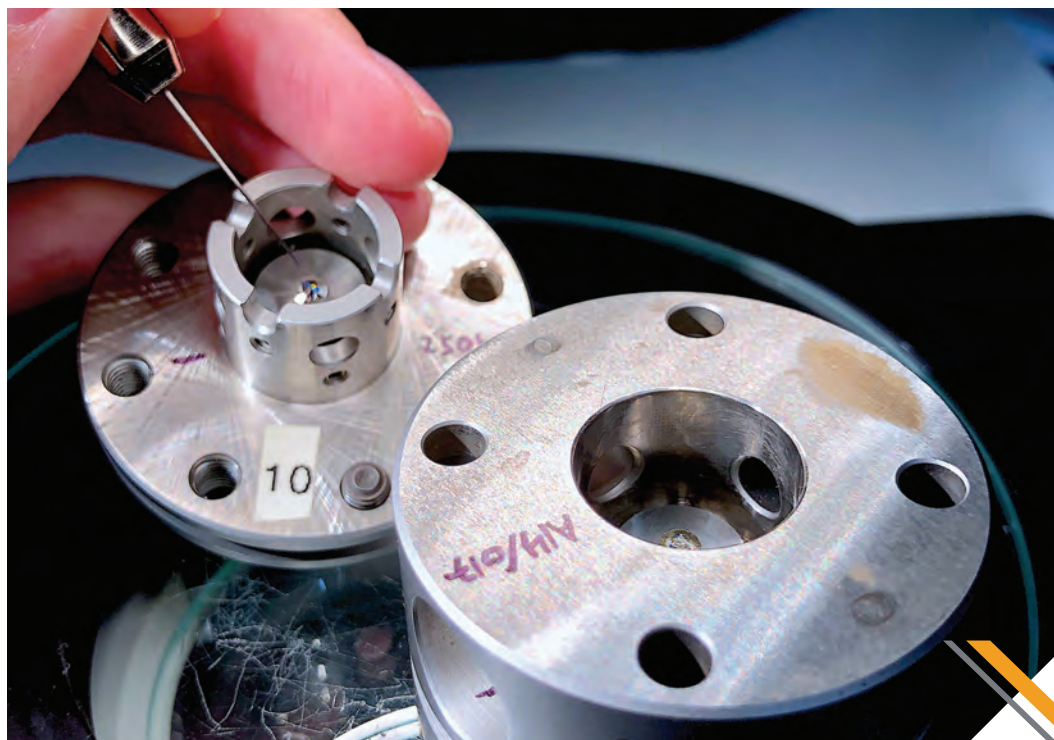
A planet or moon is a dynamic system. At high pressures and temperatures, rocks begin to flow and move. This leads to whole-planet cycling processes that link the surface to the deep interior, affecting things like the motion of tectonic plates and the amount of liquid

water on the surface. Describing these large-scale processes relies on characterizing the material that is cycled, which depends on understanding properties of the material itself at the scale of single atoms. My research connects a mineral's atomic-level behavior to its large-scale expression in a planet's interior. These material qualities are how we know the Earth's interior is comprised of several layers and why it has a liquid core.

I focus on szomolnokite, a mineral that contains iron, sulfur, oxygen and water. It's found on Earth and Mars and may be more abundant within the icy moons of Jupiter. Its water content makes szomolnokite an important factor in how much H₂O is found on the surface or underground. One of the key questions I'm interested in is: Does szomolnokite's structural behavior at high pressures let water move into an icy moon's interior? To answer this, I use instruments in combination with the diamond anvil cell to collect information about szomolnokite. Our results so far show that it's possible for this mineral and similar ones to retain their water at pressure and provide a way to store it deep underground.

My work on szomolnokite characterizes one anchor point of a multimineral system. Knowing the properties of different anchor points lets us more realistically model environments in Earth and other planetary bodies in our solar system.

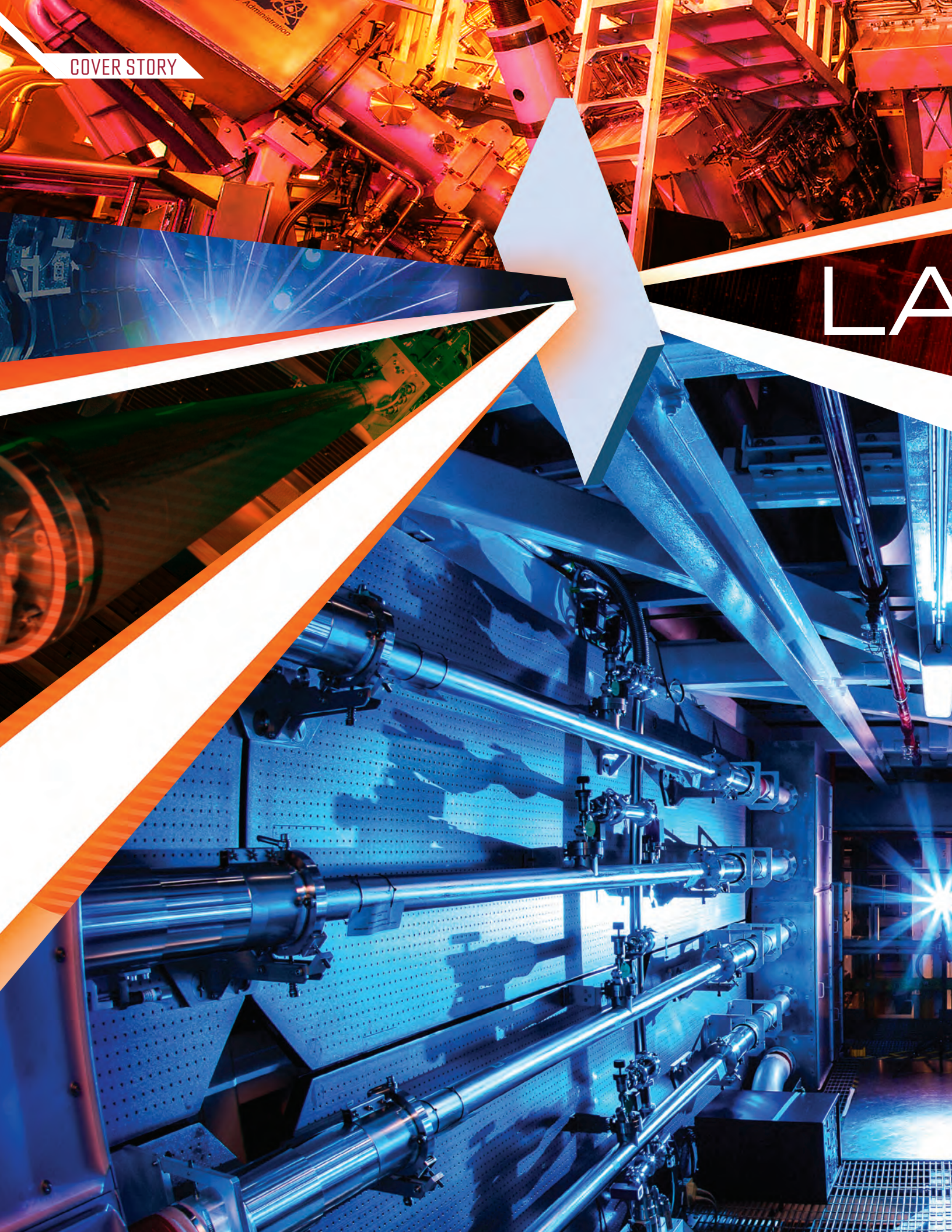
It's an exciting but difficult task to explore regions thousands of miles beneath laboratories on the surface. A variety of techniques allow glimpses inside these unreachable regions but all together construct comprehensive descriptions of a planet's inner workings. I hope that our research entices people new to science to ask their own questions and think of novel ways to understand our planetary black boxes.



An opened diamond anvil cell, with the piston at left and the cylinder at right. The pieces fit together to enclose a mineral sample and compress it to high pressures. Researchers use a needle to manipulate samples, which are placed on top of the diamond in the cell's center. The marks at lower left are scratches on the glass plate the cell is sitting on. *Olivia Pardo.*

COVER STORY

LA





LASER FOCUSED

A love of learning by doing leads to
the start of a brilliant physics career.

By Sarah Webb



Raspberry Simpson

When Raspberry Simpson arrived at Lawrence Livermore National Laboratory in early 2020 for a second research residency, she had supersized plans. Simpson, a Massachusetts Institute of Technology Ph.D. student working with plasma physicist Tammy Ma, hoped to field large-scale laser

experiments and do complementary computational work during her yearlong stay. For a month, Simpson's project went as expected, but in March the COVID-19 pandemic forced the entire lab to go remote.

As luck would have it, Ma's team was interested in a significant research problem that was suddenly even more relevant: building a fully remote and robust autonomous laser facility. Simpson, a Department of Energy National Nuclear Security Administration Laboratory Residency Graduate Fellowship (DOE NNSA LRGF) recipient, assisted, working on diagnostics and on developing machine-learning approaches that were fast enough to analyze data produced several times each second in real time.

"Raspberry played a really big role in defining the machine-learning aspects of the work for our team," Ma says. "She learned it on her own, during COVID actually, and she's quite adept now."

The team also did experiments, some of them virtually, with Colorado State University's ALEPH laser and the University of Rochester's OMEGA EP facility. Simpson recalls Zoom-based conversations with her collaborators: "Hey, can you point me at that screw please?" The confluence of remote work and the idea of building lasers that can run themselves made for an interesting test ground, she says.

Simpson's most recent Livermore project is just the latest in a series of research experiences that she has layered like bricks to build a foundation for her high energy density physics career. Simpson says she became a scientist because she loved to learn by doing. "I enjoyed being confused (about data) and being able to ask someone very earnestly, 'Oh, what do you think about this?'" Science is one of the few spaces where you can be openly confused."

Simpson grew up in New York City and remembers telling her mother that she wanted to be a cabbie because a taxi driver had once scoffed that "ladies can't do this." While in middle school, she participated in after-school astronomy programs at the American Museum of Natural History's Hayden Planetarium, which famed astrophysicist Neil deGrasse Tyson directed. That left an impression. "It was really important to see someone Black in those types of spaces because it just didn't even occur to me that that was a job people did."

Simpson started high school at one of the city's specialized campuses, Brooklyn Latin, which emphasized classics, literature and language, an experience that Simpson credits with improving her communication

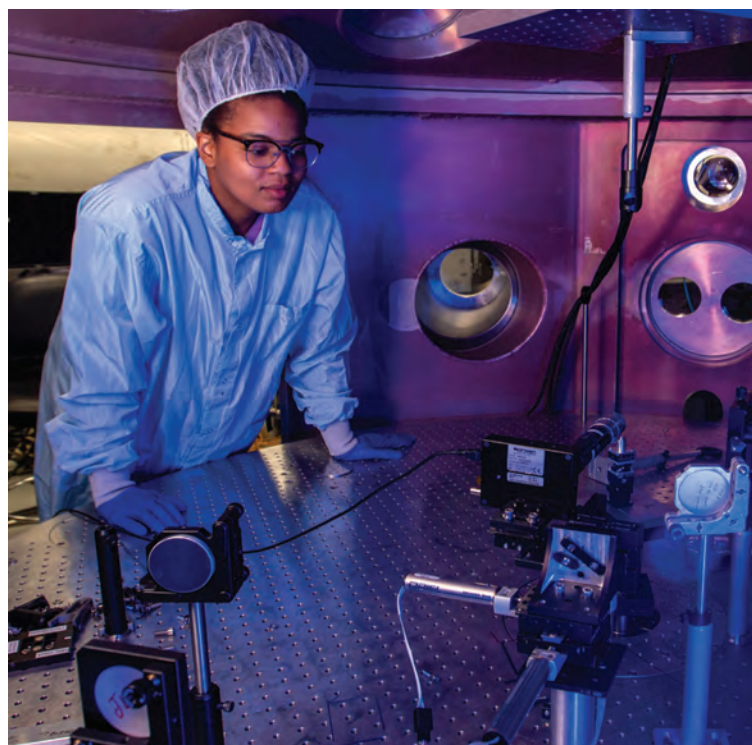
skills. After her sophomore year, she moved to Bard College at Simon's Rock, an early-college program in western Massachusetts focused on liberal arts.

To remain in residence during summer 2009, Simpson worked on research with Eric Kramer, a professor who was using computational tools to model how proteins and hormones move through plants. Suddenly these questions didn't come with answers, and she relished the open dialogue with data. "This is what I have. This is what I found. Let's try to figure out what best represents what I'm seeing."

The next summer she was accepted into a National Science Foundation Research Experiences for Undergraduates (REU) program to study particle physics at Hampton University, an historically Black institution in Virginia. That program had partnered with the Massachusetts Institute of Technology's summer research program, and Simpson was one of four Hampton REU students who went to Cambridge.

Simpson describes the experience as "Wakanda-like," citing the fictional African country from Marvel comics. "The program is designed to support all of you, not just your science, and just give you a sense of pride in your work." Simpson worked on gaseous electron multipliers, a light-based detector, for the OLYMPUS particle physics collaboration. She enjoyed the hands-on work and viscerally remembers the first time she broke something, damaging the detector's foils and making her fear that no one would let her work in a lab again. No one was hurt, and a colleague reassured Simpson that accidents happen.

Simpson returned to MIT in 2011, this time to work with Lindley Winslow, then a physics postdoc. Winslow wanted to use quantum dots – semiconducting nanoscale atom clusters – to boost



The DOE NNSA LRGF ‘looked tailor-made for how I’ve wanted to structure my life and research.’

neutrino detection with liquid scintillators. “I was super interested in the project, and Lindley gave me a lot of independent guidance.”

Winslow says Simpson’s natural talent and ability to organize her work left an impression. “I barely had to supervise her. She just got everything and made forward progress every single day, right from the beginning.”

That summer also marked a transition from having fun in the lab to thinking seriously about a science career. “It was ‘Oh, I’m good at this, and I can do this.’” Simpson transferred to Columbia University but took a leave of absence during her first year. Winslow invited her to return to MIT to continue their quantum dot work, which culminated in a 2012 *Journal of Instrumentation* paper.

Winslow referred Simpson to Los Alamos National Laboratory physicist Brenda Dingus, who needed a student researcher to work on calibrating multiplier tubes for the High-Altitude Water Cherenkov Observatory, an astrophysics experiment that was surveying the skies for high-energy photons from gamma rays. At 18, it was Simpson’s first time finding her own apartment.

Until then, she hadn’t known about the Department of Energy national laboratories, but Simpson loved the research immersion. “They’re so

big,” she says, “but that meant that I could always ask someone for help. They really prioritize students.” After six months, Simpson returned to Columbia with a clear goal: to work at a national lab. She completed her undergraduate physics degree in 2014.

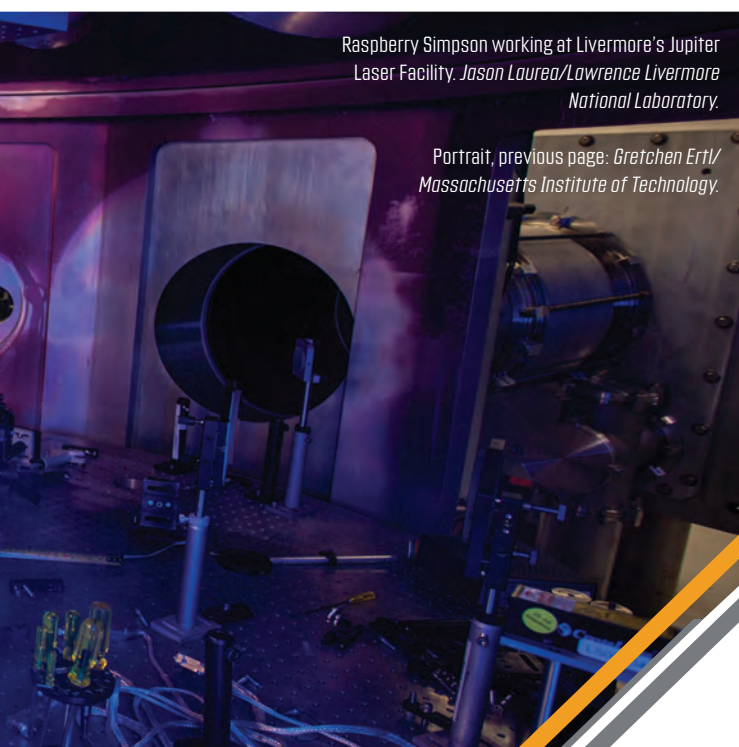
On a trip back to Los Alamos, she met physicist Frank Merrill while visiting former colleagues. He soon hired Simpson as a postbaccalaureate student to assist with his team’s project to field neutron-imaging systems for the National Ignition Facility (NIF) at Livermore.

At the time, NIF researchers were troubleshooting ignition problems in inertial confinement fusion (ICF) experiments, in which lasers heat and compress a small target containing a mix of hydrogen isotopes, aiming to initiate nuclear fusion, the process fueling the sun. Merrill’s team had helped develop neutron diagnostics for a single line of sight, but it became clear that having a second line of sight could help the team provide three-dimensional imaging and add to their understanding of the burning fuel. The researchers also needed a relatively low-cost solution. When Simpson arrived, the team had tested a promising strategy but needed to fully understand the science behind “their \$10,000 solution to a \$16 million problem,” as Merrill puts it, and convince the ICF community that their strategy was valuable and useful.

“Raspberry came with all the skills we were looking for,” Merrill says, such as expertise in the Python computer language and in GEANT, a Monte Carlo simulation code. She ran simulations that supported the Los Alamos team’s efforts, harnessing her knowledge and thinking critically, with a disciplined approach “so that you know that the answer you’re getting is the right answer,” Merrill says. Simpson became a team leader, collaborating with everyone and gathering ideas. “She was able to bring all of these together and make them bigger than an individual perspective. And that was truly unique.”

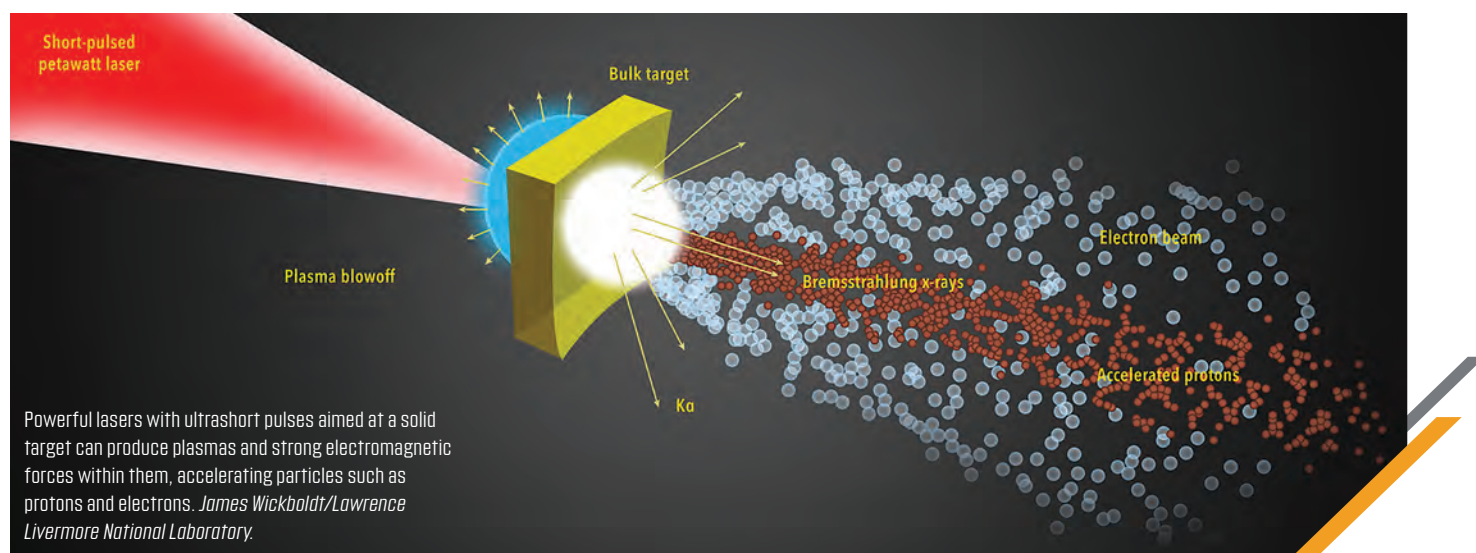
After working with Merrill for nearly three years, Simpson realized that she loved learning through research, and she knew that a Ph.D. was the next step. She chose MIT’s nuclear engineering department.

At Los Alamos, Simpson had become interested in laser-driven particle acceleration. A traditional particle-driver like the SLAC National Accelerator Laboratory is akin to “the thing that Iron Man built in his basement and takes up a lot of space,” Simpson says in another Marvel reference. Such facilities can require kilometers of distance to propel particles through large electromagnetic forces and produce high energies. But powerful lasers with short pulses also can create strong electromagnetic forces in plasmas, generating accelerated particles in spaces a fraction of the size.



Raspberry Simpson working at Livermore’s Jupiter Laser Facility. Jason Laurea/Lawrence Livermore National Laboratory.

Portrait, previous page: Gretchen Ertl/Massachusetts Institute of Technology.



Simpson began related research at MIT but craved the opportunity to return to the national labs. She learned about the newly established DOE NNSA LRGF and knew she must apply. “It looked tailor-made for how I’ve wanted to structure my life and research.” Her initial Ph.D. research had focused on a NIF diagnostic, a Thomson parabola charged particle spectrometer, that helps to analyze particles based on the ratio of their charge to mass. Through that work Simpson met Ma, who agreed to supervise her national laboratory residencies.

On her first Livermore stay with Ma’s group, Simpson adapted her designs to work with the Titan two-beam instrument at the lab’s Jupiter Laser Facility, investigating how proton acceleration scaled with pulses just a few trillionths of a second long. “It reminded me of the first time I worked with Lindley (Winslow),” she notes, and it was a unique opportunity to conduct research at a premier high energy density physics facility. “These are marvels of engineering, but at the same time it’s hard to get hands-on experience as a student.”

After that episode, Simpson wanted to do her primary Ph.D. research with Ma at Livermore, and the fellowship support allowed her “to pivot to this work that I really enjoyed.” In addition, Winslow had returned to MIT as faculty and soon became her campus-based Ph.D. advisor.

Since then, Simpson has focused on laser-driven proton acceleration, learning how tuning the lasers – changing their power and pulse length, for example – alters the properties of those boosted particles. With her machine-learning work during the pandemic, she developed a computational approach that automatically analyzes one of the laser’s diagnostic outputs. She hopes to work on other diagnostics and eventually develop predictive models for tuning laser-driven acceleration.

Although much of her most recent Livermore residency was remote, Simpson also got an unexpected opportunity to do experiments on the Vulcan laser at the United Kingdom’s Rutherford Appleton Laboratory (RAL), led by Livermore postdoc Graeme Scott and RAL scientist Chris Armstrong.

At Livermore, Simpson had analyzed data from Scott’s laser-driven acceleration research on neutrons, and she was eager to get back into the lab. “It seemed like an extreme privilege to be able to do science in person during this pandemic,” Simpson says. “I definitely don’t take that for granted.”

Because the team had to be small, Simpson took on key responsibilities – setting up diagnostics, analyzing data and working with others to tease out the laser-driven particle physics.

Simpson isn’t afraid of challenges. She injects her ideas into research discussions and brings “a wealth of experience,” Ma says. “She’s met great people across the (NNSA) complex who she stays in touch with and are always there to help.”

In science, it’s easy to get trapped in scientific details, Winslow says, but Simpson knows how to zoom out and understand larger goals. She also has a healthy sense of perspective, acknowledging the comedy of science’s less glamorous minutiae, such as verifying a result for the umpteenth time or deciphering a mysterious data blip.

Besides frequently presenting her research at meetings, Simpson has invested in science outreach and service work, such as giving career talks, developing initiatives to cultivate welcoming learning environments at MIT, and serving on committees that support diversity, equity and inclusion within the American Physical Society’s Division of Plasma Physics.

Simpson, Winslow adds, has “this fearless pursuit of her science coupled with her ability to see the big picture. I think it’s a really powerful combination. And I’m just really excited to see where she goes next.”

Next, most immediately, happens to be more Livermore, for a Lawrence Postdoctoral Fellowship starting fall 2022. She is the fellowship’s first Black recipient. **SS**



LIGHT DUTY

A fellowship alumnus advances his career via powerful lasers at Sandia's Z facility.

By Thomas R. O'Donnell



Benjamin Galloway

Benjamin Galloway has mastered multitasking as a laser scientist and one of two operators for the Z-Petawatt laser at Sandia National Laboratories' New Mexico campus. Besides scheduling time on the beam, he's been on both ends of the facility on shot days, initializing the laser at the front end, ensuring it will deliver the desired energy, using the system to align it to targets, and analyzing post-shot data.

Galloway, who left Sandia early in 2022 for an industry position, delivered light for other scientists but also used the beam for his own research, which could help achieve nuclear fusion, the process powering the stars and a potentially plentiful clean energy source. He's also helped find new ways to produce and use high-energy X-rays for experiments on Sandia's Z pulsed-power machine. His projects have contributed data for stewardship science, research that helps maintain the safety and reliability of the nation's nuclear stockpile.

In his dual experimental role, Galloway often began shot days working alongside a second operator, Patrick Rambo, to start and align the laser. Galloway then ran to the target chamber next door (a high-tech pipe connecting the buildings carries the beams) and prepared the experimental apparatus.

"It's a lot for one person to do, to be honest," Galloway says. Rambo has been a huge help, but some tasks are small – removing targeting cross hairs from an alignment laser or switching to the Z-Petawatt (ZPW) beam. "They're among a few things that I wasn't going to ask Patrick, 'Hey, could you come in, gown up, move that one thing and leave again?'" The result: Galloway might have crossed between buildings as many as 16 times in a day.

The back-and-forth trips – up and down staircases and a ladder and across the beam-tube bridge – and experiment turnover could add up on busy days, Galloway says. He's not complaining; the job gave him experience and skills, including leadership, that have propelled his career.

It's been a leap from 2013, when Galloway, then at the University of Colorado Boulder, received a Department of Energy National Nuclear Security Administration Stewardship Science Graduate Fellowship (DOE NNSA SSGF), even though he was initially unsure what stewardship science encompassed. With Henry Kapteyn and Margaret Murnane, he researched high harmonic generation, in which a supremely

brief, intense infrared laser pulse fired into a gas emerges even shorter and produces X-rays at even higher-energy wavelengths.

His Lawrence Livermore National Laboratory practicum and the fellowship's program reviews led Galloway to embrace stewardship science's national security mission. At one of the meetings, he met Dawn Flicker, a Sandia scientist and manager. She passed Galloway's resume to John Porter, who was seeking a ZPW operator. Galloway's research and laser experience got him the job.

ZPW is one of two laser systems that can provide X-rays for flash radiographs – high-speed, high-sensitivity X-ray images – of Z machine experiments. Z produces tremendous, brief electrical pulses, creating potent magnetic fields for high energy density physics experiments. Scientists use it to investigate plasma behavior and how materials react under otherworldly pressures. They've also tested approaches to inertial confinement fusion, which employs Z's power to compress hydrogen isotope atoms so tightly they merge, releasing tremendous energy.

To track these incredibly fast experiments, researchers fire their powerful lasers into materials, such as metals. The photons hit atoms, knocking loose electrons that generate X-rays.

ZPW fires pulses, measured in trillionths or quadrillionths of a second, with up to a quadrillion watts of power. (A drugstore laser pointer has power measured in thousandths of a watt.) In that sub-eyeblick time ZPW delivers up to 1.2 kilojoules – similar to the wallop of a bullet fired from a .223-caliber rifle. "You wouldn't want to be on the receiving end of our photons," Galloway says.

Their operator roles meant he and Rambo worked with every experiment using ZPW, but Galloway concentrated on three. The first, Lasergate, aims to improve the performance of Magnetized Liner Inertial Fusion (MagLIF), which uses the Z machine's magnetic fields to crush a metal can (or liner) the size of a pencil eraser, compressing hydrogen isotopes such as deuterium inside. If all goes well, the nuclei fuse.

MagLIF's three steps happen in microseconds – millionths of a second. First, coils above and below the liner create a moderately strong magnetic field through its length that will help trap particles and the energy they carry.

Second, the Z-Beamlet laser, a ZPW sister, fires through a transparent plastic laser entrance window – just 2 or 3 millionths of a meter thick – in the liner's top, delivering up to 2.8 kilojoules of energy to preheat the hydrogen, pushing it closer to fusion-relevant conditions.

In that sub-eyeblick time ZPW delivers up to 1.2 kilojoules – similar to the wallop of a bullet fired from a .223-caliber rifle.

Finally, Z's magnetic fields converge, collapsing the liner.

The transparent window, however, reduces energy deposited in the fuel during preheating. "Lasers have trouble going through solid-density material, no matter how thin," Galloway says.

To address the issue, researchers fired ZPW to evaporate the window, conditioning it to better transmit the Z-Beamlet laser. But that process still loses energy as the material is vaporized and can lead to fuel contamination, radiating even more energy away during compression.

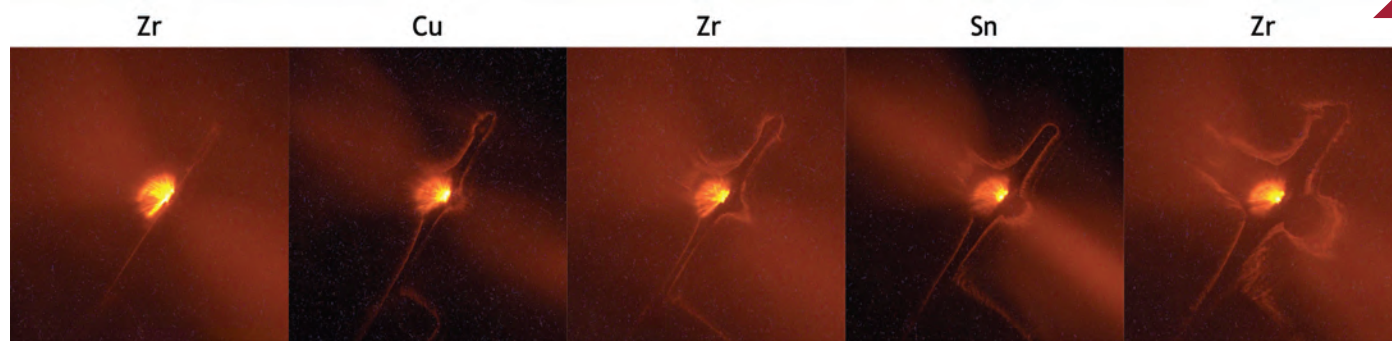
Finally, the window could cause the beam to disintegrate or to create instabilities and other effects inside the fuel, scattering photons. "Seeding those instabilities is another drawback to having a window at all," Galloway says. The result: Up to half of the Z-Beamlet laser's energy fails to couple with the fuel.

than 100 times less than the previous approach, which required 20 to 30 joules to eliminate the window. Therefore, scientists can use a smaller laser to cut the window rather than operating ZPW at a tiny fraction of its potential.

Next the team shot liners equipped with a range of window thicknesses and liner gas pressures and measured the time it took each window to open: 2 to 4 microseconds under MagLIF-relevant conditions.

"OK," Galloway says, "it takes microseconds for the window to blow open. Gas has to be escaping. How much?" The third test took eight measurements over 8 microseconds. The answer: only about 1 percent.

The final experiments integrated aspects of the MagLIF process. ZPW opened the window and Z-Beamlet fired as the team measured preheating. Compared to shots using only Z-Beamlet, Lasergate shots



Sandia theorist Stephen Slutz, who developed the MagLIF concept, proposed a solution: Instead of melting the window, ZPW would cut it, so it could be blown out of the way by the pressurized gas in the liner.

The Lasergate idea raised a host of concerns. How long until the window blows open? How does gas density inside the liner change? How much gas escapes? Galloway helped lead a research team that fired ZPW into liners to find answers.

Spoiler: "It's very successful," Galloway says. "It does its job." He's lead author on a November 2021 *Physics of Plasmas* paper reporting the results.

The researchers shaped the ZPW beam into three thin, line-like regions that cross into a six-pointed asterisk. The shaped beam cuts the transparent window along the etched lines and the lens fails, leaving triangular flaps that the gas pressure blows out like opening flower petals.

The team tested Lasergate in four studies. The first quantified the energy required to cut the window: a mere 100 to 200 millijoules – a light snap of a rubber band – for 2 billionths of a second. That's more

A series of side-on views of foil targets captured at various times after the ZPW laser focuses onto their surfaces. Heated material produces visible emission, leading to bright spots where the laser interacts with the foils and to indications of plasma ejected perpendicular to their surfaces. A red probe laser arrives 0 to 7 nanoseconds after ZPW and backlights the expanding foils, creating Schlieren images that highlight the evolution of edges and regions with large plasma density gradients. *Galloway et al., SAND2021-13786 R (2021).*

deposited 232 more joules of energy into the liner's implosion region. The shots attained 60 to 70 percent total energy-coupling efficiency, compared with 53 to 57 percent for non-Lasergate tests.

It's unclear whether the approach will reach the team's 2-kilojoule preheating target, Galloway says, because the experiment used helium rather than deuterium, but "it looks like there's an energy advantage to doing Lasergate."

Demonstrating preheating wasn't necessarily the goal, he adds; it was proof of concept. The team is developing deuterium experiments with full preheating laser energy. The researchers also plan to reconfigure the apparatus, removing the Z-Petawatt laser and using another.



Benjamin Galloway at the front end of the Z-Petawatt laser in the Z-Backlighter laser facility, which houses the Z-Beamlet and Z-Petawatt lasers. Galloway, SAND2021-1450 G (2021).

MagLIF preheating is an unusual task for both the Z-Beamlet and ZPW lasers; they mainly generate powerful X-rays. Galloway's second project fell into that realm: producing K-alpha, a higher-frequency, higher-energy flavor of X-rays than currently available at the facility, extending the range of experiments that can be imaged on Z.

"Low-energy X-rays don't go through much material. You're limited in the targets you can field" to those with relatively simple elements holding fewer protons in their nuclei.

The X-rays the Sandia scientists want to produce range from about 10 keV – thousands of electron volts, a measure of radiation energy – to greater than 20 keV, more than double the photon energy of standard medical X-rays. The team wants to demonstrate that ZPW can produce X-rays bright enough for Z machine radiography.

In September 2021, Galloway and his colleagues fired the ZPW laser into a range of metals, knocking out and accelerating electrons to generate X-rays. They tested a copper target as a benchmark, producing 8 keV K-alpha rays, then tried zirconium, producing 16 keV rays, and tin, at near 25 keV.

The team is quantifying how efficiently laser energy converted to X-rays. It's "at the upper limit of what is expected," Galloway says. "It's promising and may make nice radiographs in the Z environment."

With higher-energy X-rays, experimenters can examine materials with heavier nuclei or thicker samples. They can see how substances respond to and absorb energy from these potent beams. High-energy X-rays also can provide more information from dynamic diffraction experiments that track how materials' structures change under terrific pressures.

The same laser shots also accelerate protons from the target. The protons can hit another material and convert to neutrons. "Now you have a pulsed neutron source that you can use for developing neutron diagnostics" for fusion experiments.

Galloway also pursued a different way to use ZPW for X-ray production. In laser wakefield acceleration, a high-energy laser pulse creates an electric charge in a cloud of ionized gas. As the charge moves, electrons ride it like a surfer to near light speed, wiggling and producing X-rays.

Galloway first researched the idea in 2014 while on his DOE NNSA SSGF practicum at Lawrence Livermore National Laboratory. He'd helped conduct laser wakefield acceleration experiments on the lab's Titan laser and analyzed the results.

Galloway thought the technique might be useful for Z machine diagnostics and proposed it for a lab-directed research and development (LDRD) award. The project was funded on his second try.

ZPW could produce highly energetic X-rays via a twist on standard laser wakefield acceleration. The laser packs high energy but with a pulse long enough that it could overlap the charged bubble it produces. "The electrons are accelerated in this bubble, or several bubbles, and the laser field is also present," Galloway says. This self-modulated regime pushes electrons to energy levels that are lower than those a shorter-pulse laser might reach, but it produces more of them. The resulting X-rays also are lower in energy but higher intensity.

LDRD grants often help early-career scientists develop their skills. "I found it incredibly useful to go through the exercises of making a proposal, the risk analysis and budgeting and team assembly and coordination," Galloway says. Those "are all important to me for developing my career."

It's a career that's now turned to industry, with a position at aerospace, defense and technology giant Lockheed Martin in his native Colorado. He's a fiber laser engineer, joining a group that develops high-performance remote-sensing systems.

Among his projects, Galloway will work with laser systems for quantum optics applications and on improving the readiness of newer, high-power laser systems.

Leaving Sandia was difficult, he says. The lab provided brilliant, engaging colleagues and a first-rate facility. "It's such an incredible place to work," Galloway adds, but he and his wife wanted their toddler daughter to grow up near family.

The career change doesn't end Galloway's connection to the DOE NNSA SSGF and its sister, the Laboratory Residency Graduate Fellowship. "I keep coming back to the fellowship, looking for ways that I can be involved, because it's a way for me to give back and also attract new colleagues. It's one of the best pools of talent." **SS**



A HEAVY LIFT

By Andy Boyles

A FELLOW SEEKS CLUES TO
RAPID NEUTRON CAPTURE,
FROM A LOS ALAMOS PRACTICUM
TO MULTIPLE DOE NATIONAL LABS.

Previous page: Chad Ummel works on the GODDESS detector's ionization chamber. Harrison Sims/Rutgers University. Right: Ummel with GODDESS. Jolie Cizewski/Rutgers University.



Chad Ummel was a high school sophomore in Carlsbad, California, when his mother casually told a family friend that her son was enjoying physics class.

That friend happened to be Max Fenstermacher, a physicist at the Department of Energy's Lawrence Livermore National Laboratory. He soon gave the youth a private tour of DOE's DIII-D National Fusion Facility at General Atomics, a contractor in nearby San Diego. "That was kind of the big eye-opening moment for me," Ummel says, "that I wanted to be a physicist, and I wanted to work in a big experimental lab like that one."

Ummel, a Rutgers University physics Ph.D. candidate, is getting his wish, with help from his DOE National Nuclear Security Administration Stewardship Science Graduate Fellowship (DOE NNSA SSGF). His studies of how the universe created heavy elements, such as copper, nickel and cobalt, are part of a collaboration among Rutgers, and Oak Ridge, Lawrence Livermore and Argonne national laboratories, and the University of Tennessee, Knoxville. So much of his research

happens at the national labs that Ummel spends little time at Rutgers. He lives in Tennessee and works at Oak Ridge, doing his experiments there and at Argonne.

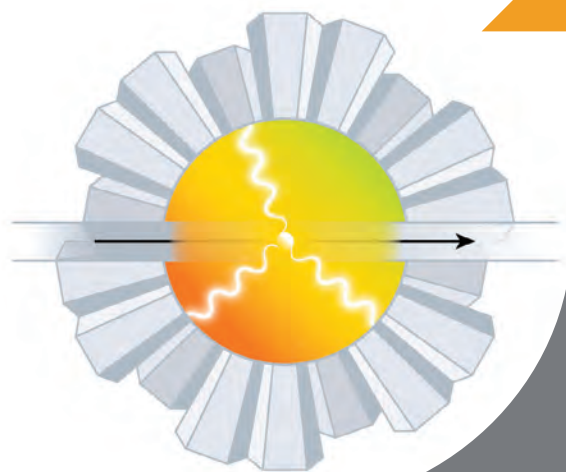
The origins of light elements are well understood. Hydrogen and helium appeared soon after the Big Bang. Nuclear fusion in stars like the sun produces many others, such as carbon, oxygen, chromium and iron. But stellar nuclear fusion stops at iron. It can't make heavy atoms – the trans-iron elements, which are forged through other routes.

"One thing we're very interested in is something called the rapid neutron-capture process, or r-process," Ummel says. It occurs in certain supernovae and yields about half of the universe's trans-iron elements. "There are a lot of open questions about this process." The multilab, multi-university collaboration has let Ummel conduct experiments that replicate small steps in the r-process, catching neutrons in the act of settling into their new homes in the nuclei of a xenon isotope.

"Chad's work is central to our research program," says his advisor, Jolie Cizewski, Rutgers distinguished professor of physics and astronomy. A lead investigator in the collaboration, she has spent decades studying how trans-iron nuclei form and hold themselves together.

Coincidentally, Ummel got his research initiation at General Atomics. As a University of California, Berkeley, undergraduate, he received an internship through Sandia National Laboratories that let him maintain specialized probes and participate in experiments at the DIII-D facility. "I'm incredibly grateful for that opportunity," Ummel says, "but I learned very quickly that plasma physics was not for me, and I wanted to do something different."

DANCE STUDIO



Scientists at Los Alamos National Laboratory's Detector for Advanced Neutron Capture Experiments (DANCE) Collaboration knew they faced a challenge, and they thought Chad Ummel could help them surmount it. They brought him onto their team for his DOE NNSA SSGF practicum.

Neutron capture is the moment when a neutron hits an atomic nucleus and joins it. The process is key to the creation of nearly all elements heavier than iron. It's also critical to controlling and operating nuclear reactors and to diagnostic testing of nuclear weapons.

Neutrons pass through the DANCE detector and interact with an isotope sample (center). Neutrons that enter the sample material's nucleus excite it to a high-energy state. The nucleus emits gamma rays as it relaxes to its lower-energy state. Instruments surrounding the sample measure the physics of the emitted rays. *Los Alamos National Laboratory.*

At the same time, he was working toward a minor in nuclear engineering, an interest that took Ummel on a course more to his liking. He soon began working for Bethany Goldblum, associate research engineer in Berkeley's Department of Nuclear Engineering and a nuclear physicist at Lawrence Berkeley National Laboratory.

Ummel was now in his element, so to speak. During the next two years, he designed and built collectors that captured debris from fusion experiments, designed a probe for Cal's High Flux Neutron Generator and participated in investigations at Berkeley Lab's 88-Inch Cyclotron.

He also spent six months at Sandia National Laboratories in 2015 as a Nuclear Forensics Undergraduate Scholar through the Department of Homeland Security. At Sandia, Ummel helped develop a software package called the Dynamic Analysis Environment, which incorporates data on the unique compositions of spent fuels from nuclear reactors. Using it, forensic researchers can interdict a contraband nuclear material, run a range of analyses and compare the material to known samples to narrow down the possible sources.

His work with Goldblum, Ummel says, "steered me to apply to graduate programs in the fundamental experimental nuclear science area. So that's what I do now."

The r-process stands in contrast to the slow neutron-capture process, or s-process, which cooks up, roughly, the other half of the naturally occurring trans-iron elements. At work in certain giant stars, the s-process doles out small numbers of neutrons over thousands of years, gradually transforming light elements into heavy ones. It's thought to be the major source of copper. The r-process isn't so

A central question in the formation of these big nuclei is why they don't fall apart.

leisurely; by bombarding light nuclei with neutrons, it beefs them up to bigger ones in seconds.

To rapidly hammer out such hefty elements, the r-process operates only where the temperature and neutron concentration are so high that the particles stick to nuclei faster than the nuclei can decay. So far, astrophysicists have found only two instances in which those conditions exist. The first is a type II supernova, also called a core-collapse supernova. The second, rare case: when a binary consisting of two neutron stars merges, forming a cauldron of heat and neutrons.

A central question in the formation of these big nuclei is why they don't fall apart. The nuclear force that binds protons and neutrons in the atom works only at tiny distances. As nuclei grow larger, the nuclear force can be equaled or overcome by the protons' repulsive Coulomb force, which extends farther. Even for chargeless neutrons, the nuclear force can hold only a limited number together with its short-range links. If a nucleus gets big enough, neutrons begin to fall away like drops from a leaky faucet.

Cizewski and Ummel focus on the nuclear shell model, which explains why so many larger nuclei stay in one piece despite these limitations.

"DANCE studies reactions for all of these disciplines – from nuclear astrophysics to nuclear technology to weapons physics," says Aaron Couture, physics research scientist at Los Alamos and DANCE's principal investigator. The instrument is one of many used at the Lujan Neutron Scattering Center, a neutron beam facility operated under the NNSA and located at the Los Alamos Neutron Science Center (LANSCE).

An important property of an element or its isotope is the cross-section, the readiness with which the nucleus captures a neutron, and a gamma ray indicates neutron capture. DANCE is a spherical array of 160 gamma-ray detectors. The research team places an isotope sample in the center and bombards it with neutrons. The gamma ray photons detected yield the number of neutrons captured and indicate the cross-section.

The research team's challenge follows from a facility upgrade at the Lujan center, scheduled for this year, which will greatly

increase the number of high-energy neutrons in the beam line. The boosted neutron flux will offer great advantages, but for the DANCE Collaboration it also will create a new gamma-ray background strong enough to obscure rays the team must detect. With Couture as his practicum advisor, Ummel updated and adapted an existing software package, enabling simulations that revealed how the new background would affect DANCE measurements and suggested ways to mitigate the effects.

"Chad's hard work and willingness to continually test and adjust small optimizations was an essential contribution to helping to understand how the new backgrounds will affect our future experimental program," Couture says. "Further, his work on updating the simulation code to a more modern simulation toolkit is paying real benefit" to DANCE users from both inside and outside the lab.

The model is analogous to the electron shell model that explains how atoms interact. The protons and neutrons in a nucleus inhabit orbitals, as electrons do. A few of these orbitals have the remarkable quality of shoring up the nucleus. When the number of protons or neutrons fills one of these orbitals, they achieve greater cohesion and the nucleus becomes more fixed.

These levels are called magic numbers – 2, 8, 20, 28, 50, 82 and 126 – and apply separately to protons and neutrons. Common nickel has a full shell of protons, with 28, but a less cohesive collection of neutrons, with 31. Oxygen-16, with 8 protons and 8 neutrons, and lead-208, with 82 protons and 126 neutrons, are among the most stable isotopes. They have full shells of both protons and neutrons and are known as doubly magic.

To probe the nuclear shell model, Ummel's experiment arranged a high-velocity impact between nuclei of a xenon isotope and deuterium nuclei, or deuterons – each a single proton coupled with a single neutron. On impact, the xenon splits the deuteron, capturing the neutron as the proton spins off. The proton's trajectory retains telltale information about the neutron it left behind. In most impacts, the xenon bounces off the deuterons. However, sometimes the neutron goes into a specific xenon excited state that emits gamma rays as it decays. Measuring these rays and the protons enables physicists to deduce the excited states' structure.

For the isotope beam, the team used xenon-134, which has 80 neutrons – just two short of the magic number 82. Upon impact with a deuteron, the xenon nucleus gains a neutron, its 81st. The shell model makes precise predictions about how this neutron should behave as it settles

into its new home. It can take brief turns populating higher orbitals before relaxing into the ground state. According to the shell model, such a neutron would then exhibit characteristic energy and spin structures as it moves from one orbital to another.

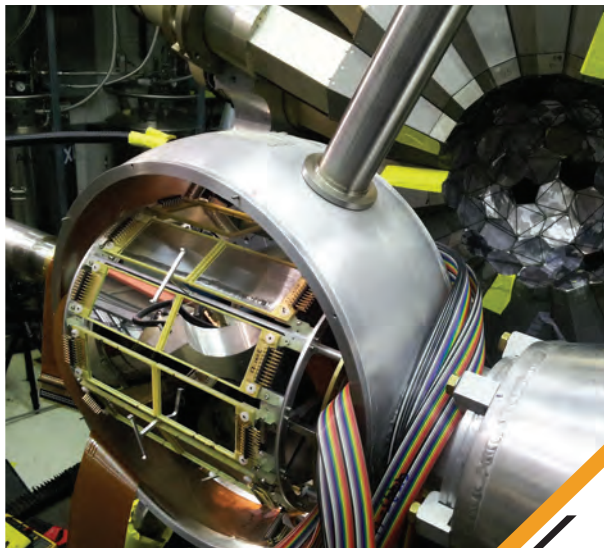
Central to the experiment: a device named GODDESS, which Cizewski developed in collaboration with Steven Pain, a research staff member in the Experimental Nuclear Astrophysics Group at Oak Ridge, and with Andrew Ratkiewicz, now a research staff member in Livermore's Physics Division. GODDESS is a unique combination of particle detectors that capture proton data at an unprecedented resolution and Argonne diagnostics that measure gamma rays emanating in all directions.

The team transported GODDESS from Oak Ridge to Argonne and aligned it with ATLAS (the Argonne Tandem Linac Accelerator System). The ATLAS team boosted a xenon-134 beam to about 1.3 billion electron volts, about 15 percent of the speed of light. The researchers trained the beam on a diaphanous plastic sheet in which deuterium replaced the hydrogen atoms. ("Think of Saran Wrap," Cizewski says.) That put deuterons in the beam's path. The team let the xenon-134 pummel the deuterons for two days, capturing clear data on 600,000 protons populating excited states. That was enough information to have sufficient statistics for an analysis that should provide significant results.

The gamma-ray data are in. "I've identified four new excited levels and their associated gamma cascades," Ummel says. "That's brand new and hasn't been published yet, and those are four previously unobserved levels. So it's kind of exciting."

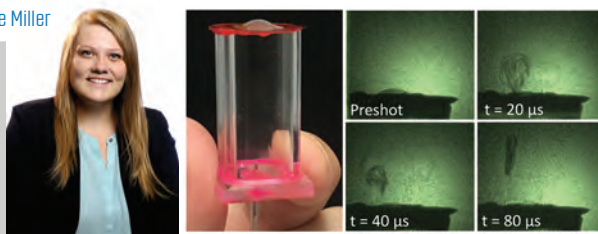
Next, Ummel will analyze the proton data. GODDESS captured information about how far the protons tilted off their axes when they spun off the nuclei – their angular distribution. Ummel will isolate protons that came from each of the four excited levels and analyze their behavior against the expectations of nuclear shell theory. A perfect match would indicate that the excitation level involved a single neutron, signaling that the nuclear shell model gives an excellent prediction. An imperfect match would show that the shell model is still correct but that the excitation was not a pure single-neutron state. "And that's the most likely outcome," Ummel says. "There is some mixing of core excitations of the remaining protons and neutrons in xenon-135." That would mean there's more to learn about how neutrons find their place in a growing nucleus.

He defended his dissertation in spring 2022. Now, his goals have gone beyond the laboratory. Ummel intends to apply his nuclear science experience to science and technology policy. "I want to use my scientific expertise to make a broader impact upon society," Ummel says, "and I think working in policy, specifically in nuclear security/arms control, would be a natural and exciting way for me to do that." 



The GODDESS detector. Steven Pain/Oak Ridge National Laboratory.

Stephanie Miller



A Laser Gate prototype. When pressurized with target material, the laser entrance hole window material domes upward. During laser preheating in a MagLIF experiment (green panel images), the window material weakens, cracks and flaps open. *Stephanie Miller.*

Outgoing fellows describe their research experiences. (Abbreviation key: SSGF/LRGF = DOE NNSA Stewardship Science Graduate Fellowship/ Laboratory Residency Graduate Fellowship.)

THIN SKINS

LRGF recipient **Eldred Lee** was at Bard College at Simon's Rock to study jazz performance when a general physics course steered him toward science. He started with physics and biomedical engineering at Bard and **Dartmouth College** as an undergraduate before moving into materials science in graduate school, also at Dartmouth.



Eldred Lee

For his Ph.D. he initially focused on coatings and other solar-absorbing materials. But by his second year Lee was craving a new challenge and wanted to work on a new project with his advisor, Jifeng Liu, and electrical engineer Eric Fossum, the inventor of CMOS image sensors. Their goal: to use high-Z semiconducting materials –

substances with heavy atomic nuclei – as thin films to boost X-ray image sensors' efficiency. Such devices could sharpen pictures of material phase changes and other high-energy phenomena in projects such as the Matter-Radiation Interactions in Extremes (MaRIE) at Los Alamos National Laboratory.

Lee addressed this problem during two residencies at Los Alamos. During the first three-month stint in 2019, he learned the Monte Carlo modeling code MCNP for simulating radiation transfer. In his second residency, completed virtually in 2020 due to the pandemic, Lee used simulations to evaluate an ultra-thin layer (less than 1 micron) of high-Z semiconductor over silicon active-pixel image sensors. In these sensors, high-energy photons lose energy in the high-voltage layer. The silicon layer then absorbs the photons more efficiently. Lee built and tested prototypes of these chips.

The LRGF experience gave Lee a critical foundation that he uses in his position with the semiconductor, flat-panel and solar voltaic company Applied Materials. Much of his work is with Samsung, where he takes advantage of his fluency in Korean.

WINDOW OF OPPORTUNITY

When **Stephanie Miller** started her **University of Michigan** undergraduate degree, she envisioned becoming a nuclear reactor engineer. As she dug into scientific problems, however, a plasma physics course sparked her interest. For her Ph.D. research, also at Michigan with Ryan McBride, Miller has collaborated with Sandia National Laboratories to investigate a preheating step critical for pulsed-power fusion experiments on Sandia's Z machine.

The LRGF recipient first worked on the Laser Gate project, which considered energy loss during preheating. A target window admits a laser to a capsule while confining the gas fusion fuel inside it. The window, however, also reduces laser energy available to preheat the fuel and achieve fusion. Researchers also want to control this process carefully so that window material doesn't produce implosion instabilities. Miller devised a way to heat the window with a small wire, sufficiently weakening it so it would crack and fly open from the pressurized fuel. Miller tested this approach on her first Sandia residency in 2019 and began to scale it toward testing on the Z machine.

During the pandemic, Miller pivoted to another project: studying shockwaves in pulsed-power fuels and the walls that contain them. The work required both simulations and benchmark experiments at the University of Rochester's OMEGA laser facility, in collaboration with SSGF alumnus Matt Gomez and Jeff Fein, both of Sandia.

Miller planned to finish her Ph.D. in summer 2022 and spend the following year in Washington as an NNSA Graduate Fellow.

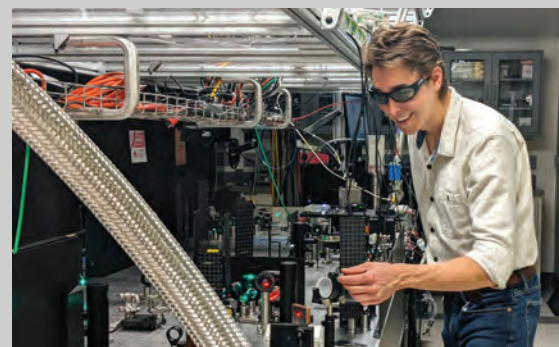
PIANISSIMO X-RAYS

For SSGF recipient **Drew Morrill**, manipulating light is like playing his violin. In his research, he generates novel lightscapes in which imperceptible colors mix like a chord's tones to produce exotic effects.

Morrill's physics research with Margaret Murnane at the **University of Colorado Boulder** aims to produce laser-like soft X-ray light bursts from a lab-scale instrument far smaller than the facilities that generate them now. Such a light source could peer into materials at ultrasmall and ultrafast scales.

Soft X-rays are less energetic than their medical cousins, enabling novel imaging techniques and high-precision spectroscopy with extreme time resolution. Murnane's lab wants to generate them via high harmonic generation (HHG), in which laser light pulses into a gas, pulling electrons from their atoms. Some electrons recombine with their parent atoms and emit high-energy photons – soft X-rays.

The catch: Coaxing the atoms to produce these photons requires a laser operating in the mid-infrared – a longer-wavelength light than most generate. That's Morrill's research problem: building a laser that meets the exacting demands of soft X-ray HHG – or more specifically, squeezing significant energy into a tiny burst of light at a mid-infrared wavelength of 3.1 millionths of a meter.



Drew Morrill with the OPCA device at JILA on the campus of the University of Colorado Boulder. *Kenna Castleberry/JILA.*

To address the problem, Morrill and his colleagues are assembling the world's most advanced laser technology into a system known as an optical parametric chirped pulse amplifier (OPCPA).

Morrill's 2021 Lawrence Livermore National Laboratory practicum further enhanced his laser technique repertoire. With Leily Kiani and Michael Messerly, he probed the limits of short-pulse, high-energy lasers based on fiber-optic technology.

Now fiber lasers have found their way into Morrill's OPCPA in Boulder. The first, faint light of his system is born from a fiber based on erbium-doped glass. As the light builds in intensity, still confined in hairlike glass filaments, it escapes the realm of linear optics and colors morph and branch into the necessary wavelength for HHG.

"Just like in playing the violin," Morrill says, "the more techniques you know, the more creative you can be, and the more fun you can have."

WATER ON THE ROCKS

Olivia Pardo is fascinated by the scales her research spans: analyzing atomic-level changes in minerals under high pressures and temperatures to understand conditions deep inside Earth, Mars and icy moons circling

other bodies. "You're trying to describe a planet in a device that's the size of your hand," she says.

The device is a diamond anvil cell (DAC), which squeezes mineral samples between two diamonds at extreme pressures. With Jennifer Jackson at **Caltech**, Pardo uses high-tech instruments to capture crystal structure changes that can influence planetary bodies' observable

features. With the objective of improving models of complex planetary processes, Pardo studies szomolnokite, an iron sulfate that incorporates multiple water molecules.

Szomolnokite is involved in volatile transport. On Earth, for example, rock slabs carry chemicals such as water deep underground over eons. High pressures and temperatures in the mantle alter szomolnokite's crystal structure, or phase. Over millennia, the material returns to the surface. Pardo wanted to know if phase changes cause szomolnokite to release water near the surface or deep inside the planet.

DAC experiments found szomolnokite's structure changed at pressures of about 5 GPa (billion pascals) and 16 GPa. (Earth's atmospheric pressure is about 100,000 pascals.) Results suggested the mineral's crystals retained water molecules across both transitions and as the samples relaxed to low pressure. That was surprising, Pardo says, because szomolnokite, which is easily altered at a planet's surface, kept its structure under pressure. Now she's considering how high pressure and low temperatures – like those inside icy moons – affect it.

Pardo's Livermore practicum used dynamic DACs, which apply varying pressure over time, to explore similar questions regarding silicon. Previous research indicated high pressures alter silicon's phases and that those changes fade at room pressure. Pardo's experiments examined how varying compression and decompression rates affected silicon's phase and its stability.

Most of the data await analysis. Meanwhile, she's working to place szomolnokite's properties in the context of a planetary environment. "I'm not quite itching to leave Caltech yet because I want to finish what I've started," Pardo says, but she expects to graduate in 2023.

MIXING IT UP

William Riedel worked for Apple after finishing his **Stanford University** electrical engineering master's degree but wasn't satisfied with researching display hardware, he says. "I wanted to work on a big problem – something I thought was really important." Riedel chose fusion energy, returning to



William Riedel

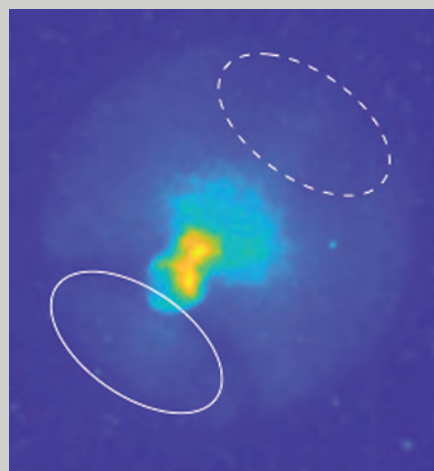
Stanford and working with Mark Cappelli to study plasma physics experiments that could advance inertial

confinement fusion (ICF). As conducted at Livermore, ICF uses powerful lasers to flood a cylindrical shell the size of a pencil eraser, generating X-rays that crush a BB-sized pellet of hydrogen isotopes. If all goes well, the nuclei fuse, releasing tremendous energy.

In Livermore residencies with Nathan Meezan, LRGF recipient Riedel modeled inverted corona fusion experiments to help unravel ICF's kinetic physics. Instead of using X-rays from the shell to compress a capsule, spherical inverted corona targets have hydrogen isotopes embedded in their shells and in the gas filling them. Lasers enter through one or two windows and bounce off the interior, ejecting plasma that converges at the center with enough pressure to fuse nuclei in a dense hotspot.

Typical ICF simulations ignore kinetic physics, but that assumption isn't always correct. Inverted corona experiments can provide data to improve these models, including information on shell material mixing with the gas, which could inhibit fusion. Researchers usually focus on how mix affects the hotspot, but more research is needed into mix at the interface between the gas and shell wall.

Riedel used one-dimensional simulations to explore mix in inverted corona experiments and found that ejected shell ions can penetrate deeply into the gas before colliding. But with higher initial pressures – denser gas – fewer shell particles reach the hotspot. Riedel's simulations predicted how gas pressure influences mix. Experimental data from the OMEGA facility agreed well with those predictions, suggesting that the one-dimensional approach can explain the observed behavior.



X-ray emission image of an inverted corona experiment at 1.1 nanoseconds. The circles indicate the laser-entry hole positions; the bright yellow spot is the gas fill tube location. William Riedel.



Olivia Pardo with an empty diamond anvil cell near her Caltech lab's gas loading system. Olivia Pardo.

His residencies gave Riedel access to powerful computing resources but, more importantly, to top experts and interesting projects. Having Meezan, a “sort of co-advisor” who’s “in my corner and has a vested interest in my development also has been a huge benefit.”

UNTANGLING SHOCK WAVES

As a Purdue University undergraduate, **Michael Wadas** studied fluid dynamics

because the field offered the right balance. He worked around wind tunnels and water tanks and could see practical applications. Plus, he says, “the math behind it, the theory, was just really, really elegant.” As a **University of Michigan** Ph.D. student in the SSGF program, Wadas has studied the hydrodynamics – the wave behavior from pressure or

shocks – that occur where two unlike fluids meet. Such disturbances are important for understanding a range of flow physics, including those that can occur in inertial confinement fusion experiments.

Wadas primarily focuses on theory and computation, but when Livermore’s Marius Millot provided a chance to work on shock compression experiments during a 2019 practicum, Wadas had “an awesome time” developing a method to strengthen shock waves in dynamic compression experiments. Such trials load helium, hydrogen and other elements into a DAC, a problem that required Wadas’ expertise in how shocked materials act at interfaces. The practicum led to a publication in *Physics of Plasmas*, and Wadas has continued to collaborate with the team. In another project, they’ve examined compressed helium in an important regime for characterizing its equation of state, leading to improved models of astrophysical body interiors.

Wadas enjoys connecting the dots in relatively dissimilar fields, applying his knowledge of fundamental fluid mechanics to the more exotic behavior of high energy density systems. For example, he has used classical fluid dynamics theory to explore the vortex rings that occur in stellar explosions and fusion implosions. After graduating in early 2023, he plans to pursue an academic postdoc or a position at a national security lab.



Michael Wadas

MEET THE NEW DOE NNSA GRADUATE FELLOWS



Kelsey Anderson
University of Notre Dame
Actinide Chemistry

Sofia Gomez
University of Texas at El Paso
Mechanical Engineering

Lansing Horan IV
Massachusetts Institute of Technology
Nuclear Engineering/Plasma Physics

Christopher Jasien
Colorado School of Mines
Metallurgy and Materials

Derek Kuldinow
Stanford University
Multidisciplinary Computational Sciences

Elyse Schriber
University of Connecticut
Materials



Maren Hatch
University of New Mexico
Electrical Engineering
Sandia National Laboratories

Justin Kunimune
Massachusetts Institute of Technology
Fusion
Lawrence Livermore National Laboratory

Jazmin Ley
University of Nebraska-Lincoln
Mechanical Engineering and
Applied Mechanics
Los Alamos National Laboratory

Taylor Sloop-Cabral
Georgia Institute of Technology
Materials Science and Engineering
Los Alamos National Laboratory

For the complete listings of current fellows and alumni, please visit the fellowship websites.

<https://www.krellinst.org/ssgf/> | <https://www.krellinst.org/lrgf/>

For more information, contact program coordinator Kris Moran, kmoran@krellinst.org, (515) 956-3696.



PICTURING PLASMA

A side view of a laser-heated foil wafer, with plasma ejected perpendicular to its surface. The image was captured from a series of experiments on Sandia National Laboratories' Z-Petawatt laser. Read more about the project in "Light Duty," which begins on page 15.



The Krell Institute
1609 Golden Aspen Drive, Suite 101
Ames, IA 50010
(515) 956-3696
www.krellinst.org/ssgf